START YOUR EM(OTION EN)GINE

START YOUR EM(OTION EN)GINE: TOWARDS COMPUTATIONAL MODELS OF EMOTION FOR IMPROVING THE BELIEVABILITY OF VIDEO GAME NON-PLAYER CHARACTERS

BY
GENEVA M. SMITH, M.A.Sc. (Software Engineering)

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AUTHOR:	Geneva M. Smith M.A.Sc. (Software Engineering), McMaster University, Hamilton, ON, Canada
SUPERVISOR:	Dr. Jacques Carette
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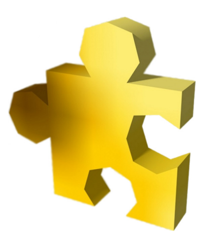

Jiggy
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Lay Abstract

Video games can deeply engage players using characters that appear to have emotionally-driven behaviours. One way that developers encode and carry knowledge between projects is by creating development tools, allowing them to focus on how they use that knowledge and create new knowledge.

This work draws from software engineering to propose three methods for creating development tools for game characters "with emotion": a process for analyzing academic emotion literature so that the tool's functions are plausible with respect to real-life emotion; a process for translating academic emotion literature into mathematical notation; and a process for creating tests to evaluate these kinds of development tools using narrative characters. The development of an example tool for creating game characters "with emotion", EMgine, demonstrates these methods and serves as an example of good development practices.

Abstract

Believable Non-Player Characters (NPCs) help motivate player engagement with narrative-driven games. An important aspect of believable characters is their contextually-relevant reactions to changing situations, which emotion often drives in humans. Therefore, giving NPCs "emotion" should enhance their believability. For adoption in industry, it is important to create processes for developing tools to build NPCs "with emotion" that fit with current development practices.

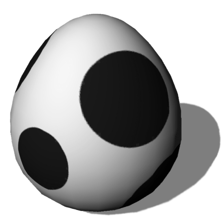
Psychological validity—the grounding in affective science—is a necessary quality for plausible emotion-driven NPC behaviours. Computational Models of Emotion (CMEs) are one solution because they use at least one affective theory/model in their design. However, CME development tends to be insufficiently documented such that its processes seem unsystematic and poorly defined. This makes it difficult to reuse a CME's components, extend or scale them, or compare it to other CMEs.

This work draws from software engineering to propose three methods for acknowledging and limiting subjectivity in CME development to improve their reusability, maintainability, and verifiability:

- A systematic, document analysis-based methodology for choosing a CME's underlying affective theories/models using its high-level design goals and design scope, which critically influence a CME's functional requirements;
- An approach for transforming natural language descriptions of affective theories into a type-based formal model using an intermediate, second natural language description refining the original descriptions and showing where and what assumptions informed the formalization; and
- A literary character analysis-based methodology for developing acceptance test cases with known believable characters from professionally-crafted stories that do not rely on specific CME designs.

Development of EMgine, a game development CME for generating NPC emotions, shows these methods in practice.

For Oma
Finally! A non-medical doctor in the family!



Black Yoshi Egg
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Over the highest mountains and through the deepest dungeons, this thesis has been a journey. It would not have been possible—or much fun—if I had to do it alone. I have many thanks to bestow on my ragtag party of knights, mages, archers, machinists, and foebreakers.

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Moogle
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Notation, Definitions, and Abbreviations

Notation

$\mathbb{B}$	The set of Boolean values *True* and *False*
$\neg x$	NOT x
$x \wedge y$	x AND y
$x \vee y$	x OR y
$\forall x$	Universal quantifier
$\exists x$	Existential quantifier
$\mathbb{N}$	The natural numbers, zero inclusive
$\mathbb{Z}$	The integers
$\mathbb{R}$	The reals
$[x, y]$	A closed interval bounded by x and y, inclusive
(x, y)	An open interval bounded by x and y, exclusive
$\lvert x \rvert$	Absolute value of x
$\lceil x \rceil$	Ceiling function
$\sum_{i=x}^{y} s_i$	Summation of s_i from $i = x$ to y inclusive
$x \cdot y$	Multiply x and y
$P(B \mid A)$	Conditional probability of B given A
$\{x_0, x_1, ..., x_n\}$	A set of n elements
$\{X\}$	A set of elements of type X
$X \subset Y$	X is a proper/strict subset of Y
$X \subseteq Y$	X is a subset of Y

$A \times B$	The Cartesian product of A and B
$(x_0, x_1, ..., x_n)$	A sequence of n elements
$x : X$	A variable x of type X
$x : X \to y : Y$	A function mapping $x : X$ to $y : Y$
$x \oplus y$	Shorthand for `apply`(x, y), where `apply` is a function that changes x by y
$X^?$	An Option/Maybe type that returns a value of type X or Nothing/None
$\langle e_1, ..., e_n \rangle$	An enumeration with n labels
$\{l_1 = v_1, ..., l_n = v_n\}$	A record with n fields each with a label l and value v such that no two sets of l and v must have the same type
$\{r \text{ with } x = y\}$	Update a record r that has the label x with the value y
$x \mathrel{\hat{=}} y$	x "is defined by" y

Definitions

Affective Computing Computing that relates to, arises from, or deliberately influences emotion and other affective phenomena (Picard, 2009). It combines engineering and computer science with disciplines like psychology, cognitive science, neuroscience, sociology, linguistics, education, medicine, psychophysiology, value-centred design, and ethics.

Affective Science An interdisciplinary field of study devoted to all aspects of affect and emotion (Scherer, 2009a). It draws from biology, psychology, economics, political science, law, psychiatry, neuroscience, education, sociology, ethology, literature, linguistics, history, and anthropology.

Antecedent A real or imagined event or stimulus that an organism perceives as important to its physical, social, or personal well-being (Ellsworth, 2009). It often elicits, signals, or sets occasion for a particular behaviour or response.

Arousal A short-term state of excitement or energy expenditure (Fowles, 2009).

Autonomous Agent Artificial entities that interact with their environment with a relatively high level of independence to make and execute their own decisions driven by their relation to and perception of their internal state and the external environment (Cañamero, 2009).

Circumplex A circular depiction of the similarities between variables shown by their distance from each other on the circle (Barrett and Russell, 2009).

Coping Cognitive and behavioural strategies to manage the demands of a taxing or stressful situation (Folkman and Moskowitz, 2009).

Valence The anticipated satisfaction of goal attainment or event outcome (Brosch and Moors, 2009).

Abbreviations

AI	Artificial Intelligence
CME	Computational Model of Emotion
DDD	Document Driven Design
FPS	First Person Shooter
HCI	Human-Computer Interaction
IDE	Integrated Development Environment
MG	Module Guide
MIS	Module Interface Specification
NPC	Non-Player Character
OS	Operating System
PX	Player Experience
SRS	Software Requirements Specification
UX	User Experience
V-A	Valence-Arousal (as affective dimensions)

Declaration of Academic Achievement

I, Geneva M. Smith, declare this thesis to be my own work. I am the sole author of this document.

I published parts of this work as journal articles in the *IEEE Transactions on Affective Computing* and *Eludamos: Journal for Computer Game Culture* and a presentation for the IDEA workshop at AAMAS 2023. Reviewers are considering parts of this work for publication as a journal article in *Entertainment Computing*. Chapter 1.1 has details about these publications.

I reprinted published content in this thesis with permission. To the best of my knowledge, the content of this document does not infringe on anyone's copyright.

Dr. Jacques Carette provided valuable support and guidance at all research stages where I was the sole contributor. While I was the primary contributor, Dr. Carette made significant contributions to: model development in Chapters 9, 11.4, and 12; module decomposition in Chapter 10.1.2; and reviews of EMgine's source code.

Part I

Ready Player One

Would you like to play a game?

Joshua, *Wargames*

Welcome!

This part presents relevant background information necessary to understand EMgine, its purpose, and its location in the broader research field. "Introduction" (Chapter 1) introduces the work, briefly motivates it, and describes the research questions it wants to answer. "Engaging Players with Believable Characters" (Chapter 2) describes the motivation in further depth, linking player engagement with video games to believable game characters, and "Meet Emotion (Briefly)" (Chapter 3) reviews essential information about affect and emotion necessary for this work. "On Designing Emotion Engines" (Chapter 4) describes how software engineering does and could influence the development of computational systems "with emotion", and supporting development methodologies proposed as an outcome of the work on EMgine. Finally, "Affective Theories in Computational Models" (Chapter 5) surveys existing software systems that model emotion and related phenomena for common design decision trends and theoretical roots in Affective Science.

When you are Ready Player One, Start Your EMgine!

Chapter 1

Introduction

Let's get this party started!

Claptrap, *Borderlands: The Pre-Sequel*

In both literature and film, richly layered characters make significant narrative contributions and increase the audience's enjoyment and emotional attachment to the story world's events and characters. However, video games might be a more influential medium because the direct interaction with game characters can make it feel "more real" to players (Rusch, 2009, p. 2; Rusch, 2008, p. 28). The increasing complexity of game narratives is a prominent and generally well-received evolution in video game technology and design (Kuo et al., 2017, p. 117). Many players fondly remember favourite game characters and tend to talk about how they—the player—feel about them as if they are real. This is due, in part, to the *believability* of those characters shown through their interactions with the world. One element of believability is their emotional behaviours (Figure 1.1), which help players empathize with these characters. This suggests that game developers can leverage character emotion to increase the impact they have on players.

Development approaches in industry emphasize the fast-paced and iterative nature of game

(a) An annoyed Fran subtley warns Vaan that he is asking an intrusive question in Square Enix's *Final Fantasy XII: The Zodiac Age* (Square Enix, 2017)

(b) Espeon and Deerling celebrate a reunion in Nintendo's *New Pokémon Snap* (Bandai Namco Studios, 2021)

Figure 1.1: Examples of Believable Game Characters

development (McKenzie et al., 2019). This environment requires reliable tools and processes which a systematic software engineering approach can help create. The proprietary nature of the video game industry means that *postmortem* reports are often the sole source of information on the development process (Politowski et al., 2020, p. 553). However, even this limited information reveals that some problems relate to inadequate or absent tools (Ullmann et al., 2022b, p. 13; Politowski et al., 2020, p. 556) despite tools being a common form of code reuse in game development (Murphy-Hill et al., 2014, p. 4). The *postmortems* also reveal that familiar technologies, prototyping, and testing-related factors contribute to successful projects (Ullmann et al., 2022a, p. 20–21). This suggests that methods for creating game development tools aimed at "emotional" NPC creation are ideal because it allows developers to build their own tools and evaluate other ones to see if they are a good fit for the intended task.

1.1 Research Questions and Contributions

Prior research on believable computer agents focused on developing specific tools such as GAMYGDALA (Popescu et al., 2014), Em/Oz (Reilly, 1996), and The Soul (Bidarra et al., 2010). Each tool has proven successful in their domains and beyond, but their development process is unclear. Consequently, it is difficult for others to build on them to create other tools to suit their needs. This is untenable in game development where time is a scarce resource and building new tools from scratch is expensive. Therefore, assuming that game developers aim to engage players with "emotional" NPCs (Chapter 2) and prefer to have tool creation *methods* over any single tool itself, a research question that follows is:

> **RQ0** *What software engineering-based methods and/or techniques can aid the creation of game development tools for believable characters with emotion?*

An exploration of what "emotion" means in Affective Science and psychology (Chapter 3), then Computational Models of Emotion (CMEs) and how developers apply software engineering practices to their development and testing (Chapter 4, which Osuna et al. (2020) critically influenced) led to the creation of EMgine, a domain-specific CME for generating NPC emotions. Initially, there was a naive assumption that EMgine's development would merely follow the software design stages—requirements analysis, design, implementation, verification, and validation. During development, questions concerning how to choose theories and/or models for CMEs (Section 1.1.1), how to build acceptance test cases to see if it produced expected emotions (Section 1.1.2), and how EMgine could be of practical use to the CME development community (Section 1.1.3) quickly proved this assumption false.

1.1.1 Choosing Theories and/or Models for CMEs

By definition, a CME takes at least one emotion theory and/or model to base its design and testing on that aligns with its requirements. Often, considering additional domain knowledge helps clarify user needs. This connection moves theory selection into *requirements analysis* because it influences model specifications, ultimately defining what to build. For EMgine, several theories that other CMEs use appeared promising. However, those CMEs have only a partially satisfactory answer to *why* they chose those theories. It effectively made the choice seem arbitrary and lacking justification. A shallow decision of theories for EMgine based on what "looked promising" led to significant modelling challenges that ultimately became untenable, raising the question:

RQ1 *How can user-oriented software requirements and domain knowledge inform the selection of emotion theories and/or models for CMEs built as game development tools?*

Work & Contributions A systematic survey of 67 CMEs that generate emotion and whose design rely on at least one emotion theory revealed that each one tended to serve a particular purpose, implying that it strongly supports certain kinds of CME requirements (Chapter 5). This prompted the design of a document analysis-based methodology for choosing emotion theories for CMEs using their high-level requirements and target domain (Chapter 4.2.1). EMgine served as a test to evaluate the methodology's viability (Chapters 6 and 7) and a series of sketches about choosing theories for other types of CMEs shows the methodology's potential (Chapter 8).

Publications The systematic survey of CMEs appears in the *IEEE Transactions on Affective Computing* as a survey article (What Lies Beneath—A Survey of Affective Theory Use in Computational Models of Emotion, Smith and Carette (2022)). A description of the methodology with illustrative examples is under review for publication as a research article in *Entertainment Computing*, currently available as a preprint (Start Your EMgine—A Methodology for Choosing Emotion Theories for Computational Models of Emotion, Smith and Carette (2023b)).

1.1.2 Building Acceptance Test Cases for CMEs

One of the challenges in CME design is translating natural language theories into formal models for implementation. Often, testing with information defined independently of how CMEs work is the only way to know if its models are "correct". However, simply using empirical observations of emotions is unproductive because *believable* is not necessarily *realistic*. Often, story characters have exaggerated behaviours that many would claim unrealistic if they saw them in real life. If a CME is for creating believable characters, the question becomes:

RQ2 *How can existing narratives inform the development of test cases for evaluating CMEs built as game development tools?*

Work & Contributions This led to the development of a character analysis-based methodology for developing acceptance test cases (Chapter 4.2.4), illustrated with examples (Chapters 11 and 12). EMgine uses these as part of its validation test plan (Section 1.1.3).

Publications A presentation at the Interdisciplinary Design of Emotion Sensitive Agents (IDEA) workshop at AAMAS 2023 described the methodology with an illustrative example demonstrating the specification of a test case template and extension for EMgine (Building Test Cases for Video Game-Focused Computational Models of Emotion[1], Smith and Carette (2023a)). Pre-EMgine work on test case development appears in a research article, which the workshop submission and thesis expands on, in *Eludamos: Journal for Computer Game Culture* (Design Foundations for Emotional Game Characters, Smith and Carette (2019)).

[1]Originally titled "Inspect Your EMgine—Building Acceptance Test Cases from Narratives for Entertainment-Focused Computational Models of Emotion", shortened to stay in the page limit.

1.1.3 EMgine as a Basis for Future Research and Development

Ultimately, EMgine demonstrates the value of a software engineering approach to the creation of game development tools. This includes embodying software qualities such as reusability and replicability to encourage others to use and expand on EMgine's design. Some qualities are especially desirable for researchers, allowing them to independently verify EMgine's, and other CMEs', abilities now and in the future (Benureau and Rougier, 2018). Moving towards this goal means asking:

RQ3 *What steps can be taken during the development of domain-specific CMEs to improve their reusability and replicability?*

Work & Contributions To this end, a significant effort went into documenting EMgine's development process. Descriptions of EMgine's underlying models trace the translation from: informal and natural language concepts based on two affective theories (Plutchik's psycho-evolutionary synthesis and Oatley & Johnson-Laird's Communicative Theory of Emotions), one affective model (Mehrabian's PAD Space), and other sources from Affective Science and existing CMEs; to a second natural language description refining the first with EMgine's assumptions about the concept, using specific types of data; and finally into a type-based formal model (Chapter 9).

EMgine's architecture design documents the rationale for choosing a component-based style and the organization of models into modules with known issues resulting from the decomposition (Chapter 10). There is also documentation about EMgine's implementation, including why it uses C# and the development environment configuration.

Publications Open-source versions of EMgine's documentation, implementation, and test documents are available on GitHub (https://github.com/GenevaS/EMgine). There are currently no peer-reviewed publications of this work.

1.2 A Word About the Cultural Dependence of the Language of Emotion

EMgine's design heavily relies on emotion terms from an English-speaking, North American lexicon. It is unwise to proceed without acknowledging the role of language and culture in our understanding of emotions. Some emotion theories refer to emotions that people mainly recognize in English, which can cause issues when using EMgine in other cultures and languages (Ortony, 2022, p. 8, 10). Even among English-speaking theorists, there is little consistency between definitions of "emotion" in the literature (Plutchik, 1980, p. 80). Some languages lack an equivalent term for "emotion" (Wierzbicka, 1999, p. 3). How is it possible to model something that appears to be fundamental to the human experience but does not exist in everyone's vocabulary?

Based on the lexical sedimentation hypothesis, researchers propose that everyday languages have captured useful information about emotions based on the importance of emotion in human social interactions and literature (Scherer, 2013, p. 8). Evidence strongly suggests that there are, albeit limited, dimensional representations and categorical clusters of emotion terms common across different languages and cultures (Fontaine, 2013, p. 37, 40, 43). They are not incompatible, as researchers have replicated the clusters in dimensional space and found that they remain systematically differentiated.

However, the specific *word* someone uses to describe their internal state does not exist reliably across languages—often with no direct equivalent (Ogarkova, 2013, p. 62). A word is only a representation of an emotion and "...surely we should not be so narrow as to insist that it has to be an English word!" (Ekman, 2007, p. 199). An emotion term might only be an abbreviation for common scenarios that are noteworthy to members of the cultural group (Wierzbicka, 1992, p. 548). This aligns with a suggestion that self-reports about emotional experiences reveal affective properties rather than emotion categories (Barrett, 2006, p. 37). In this sense, emotions are social constructions—the specific scenarios and conditions for them—based on a common need for cognitive management (Oatley, 1992, p. 119) that often relates to observable body "symptoms" of those states. Therefore, it is imperative that descriptions of EMgine's generated emotions use terms such as "feel", "good", and "bad" (Wierzbicka, 1999, p. 275) so that localizing it for different languages and cultures will be easier.

Chapter 2

Engaging Players with Believable Characters

I hope the motivation is effective.

EDI, *Mass Effect 3*

Like "good" books and "good" movies, specifying what makes a "good" game is not straightforward. Instead, game designers often aim to create a good player experience (McAllister and White, 2015, p. 11, 13). Player experience (PX) is a complex concept with many moving parts that developers aim to understand and design by adapting user experience (UX) concepts and methods (Bernhaupt, 2015, p. 2, 7; Scacchi and Cooper, 2015, p. 4). An important UX concept for games is *engagement*: a quality of the user experience describing a positive human-computer interaction (O'Brien and Toms, 2013, p. 1094)[1].

Player research suggests that an engaging *narrative* is essential to the gaming experience in non-linear sandbox and multiplayer games in a wide variety of genres such as action, fighting, role-playing, shooter, simulator, and survival (Carvalho and Furtado, 2020, p. 67–68)—suggesting that most video games have some form of narrative (Qin et al., 2009, p. 110). Even in games that do not traditionally have a strong or complete narrative, like First Person Shooters (FPSs), the inclusion of one made players more physiologically aroused, feel more involved in the game, and liked their experience more than one without a story (Schneider et al., 2004, p. 370; Kuo et al., 2017, p. 107).

Computer-controlled characters—the *Non-Player Characters* (NPCs)—often drive game narratives and populate the game world, filling important mechanical and narrative roles (Jørgensen, 2010, p. 315; Lee and Heeter, 2015, p. 47–48; Phan et al., 2016, p. 1231; Warpefelt and Verhagen, 2017, p. 40; Harth, 2017, p. 2; Emmerich et al., 2018, p. 142). As with narrative, players have stated that NPCs help them connect to the game world (Carvalho and Furtado, 2020, p. 67) and can help them identify with their own character (Rogers et al., 2018, p. 278). However, creating NPCs who react "correctly" is challenging because games with a lot of player agency have a lot of unpredictable situations (Reilly, 1996, p. 2; Loyall, 1997, p. 2; Gebhard et al., 2003, p. 48; Ochs et al., 2009, p. 281; Harth, 2017, p. 4; Bidarra et al., 2010, p. 337; Carbone et al., 2020, p. 465). The subjective nature of what *players* see as *believable* (Livingstone, 2006, p. 4; Lee and Heeter, 2015, p. 55; Warpefelt and Verhagen, 2017, p. 42) further exacerbates the problem. Inconsistent

[1] It differs from related concepts like flow and immersion, although people do use the terms interchangeably (Brockmyer et al., 2009, p. 624; Turner, 2014, p. 33; Glas and Pelachaud, 2015, p. 944; Cairns, 2016, p. 81; Doherty and Doherty, 2019, p. 99:4).

NPC behaviours "...remind the player that it is just a game" (Sweetser and Johnson, 2004, p. 321) or that the NPC is "broken" (Carvalho and Furtado, 2020, p. 70). Consistent—believable—NPCs on the other hand help reinforce the game narrative's believability (Yannakakis and Togelius, 2015, p. 328) and often results in a higher emotional investment from the player (Yannakakis and Paiva, 2015, p. 465; Lankes et al., 2015, p. 116; Emmerich et al., 2018, p. 150). This can "...evoke social effects similar to human co-players" (Emmerich et al., 2018, p. 143). In many cases, this is ideal because it promotes continued interactions with the game.

2.1 Games and Player Engagement

Engaging players is a fundamental goal of games, having a key role in player satisfaction—"the degree to which the player feels gratified with his or her experience while playing a video game" (Phan et al., 2016, p. 1220). Players have a disposition towards being, and expect to be, engaged when they play (Cairns, 2016, p. 84). This could be because playing games is a voluntary activity done for pleasure (Poels et al., 2007, p. 86–87; Yannakakis and Paiva, 2015, p. 459) in which they are an active participant (Mäyrä and Ermi, 2010, p. 94). The inherent disposition players have towards engagement shifts the game designer's focus from *why* players engage with a particular game to *how* they become engaged (Cairns, 2016, p. 85).

Schønau-Fog and Bjørner (2012, p. 406–407) propose six general causes of player engagement: intellectual, physical, sensory, social, narrative, and emotional. Emotional engagement emerges from the player's personal feelings aroused by an in-game event, character, asset attributes, or another player which causes them to want to continue playing. Many have argued that to deepen engagement, a game *must* affect the player's emotions, both positive and negative (Brown and Cairns, 2004, p. 1299; Freeman, 2004; Jennett et al., 2008, p. 657; Hudlicka, 2008, p. 5; Yannakakis and Paiva, 2015, p. 465; Bernhaupt, 2015, p. 3; Takatalo et al., 2015, p. 89; De Byl, 2015, p. 3; Lankes et al., 2015, p. 116; Zhang et al., 2017, p. 5). This suggests that emotional engagement could be the most potent type of engagement. Players themselves have said that a game must elicit an emotional response from them for it to deeply engage them (Sweetser and Johnson, 2004, p. 323) and are generally open to and actively seek emotional experiences when playing games (Yannakakis and Paiva, 2015, p. 460). Researchers have found games well-suited for emotion-related studies (Scherer, 2021, p. 290) further supporting their ability to elicit player emotions. As well as the control that emotion has over one's actions and decision-making (Turner, 2014, p. 38), this need for emotional engagement could be due to the personal value attached to an emotional experience which can be a powerful motivation to play (Ryan et al., 2006, p. 353; Takatalo et al., 2015, p. 98–99).

Emotion-invoking game content can create more engaging experiences that players perceive as more realistic, natural, and believable than their non-emotional counterparts (Baños et al., 2004, p. 739). It also does not depend on interaction medium (Aymerich-Franch, 2010, p. 653) or technology, following the observation that interacting with, forming attachments to, and empathizing with game elements elicit player emotions (Yannakakis and Paiva, 2015, p. 461). For example, a puzzle game can emotionally engage a player with its level of challenge whereas a role-playing game can emotionally engage a player with its narrative (Schønau-Fog and Bjørner, 2012, p. 407). This indicates that it is possible to engage a player emotionally in any kind of game because it depends less on what the game is and more on the inclusion of well-crafted game content.

2.2 Engaging Player Emotions with Narratives and Characters

Narratives play a significant role in human cognition and affect (Schneider et al., 2004, p. 362)—one does not have to look far to see the prevalence of stories in human culture. It follows that creating a game narrative can be an effective way to elicit player emotions, leading to their emotional engagement with the game (Qin et al., 2009, p. 128; Chilukuri and Indurkhya, 2011, p. 292; Adams, 2009, p. 183; Yannakakis and Paiva, 2015, p. 462; Takatalo et al., 2015, p. 89). Narratives for games are also not limited to "happy" stories, since players willingly extend their interactions with uncomfortable game narratives if there is something they want to do (Schønau-Fog, 2011, p. 228–229). The interactive nature of games has the potential to engage players more deeply in a narrative than other mediums because games can give players an active role in the unfolding story (O'Brien and Toms, 2008, p. 946; Qin et al., 2009, p. 111; Takatalo et al., 2015, p. 89; Kuo et al., 2017, p. 107–108, 110; Carvalho and Furtado, 2020, p. 70). This helps players establish who their character is (Sweetser and Johnson, 2004, p. 323; Schneider et al., 2004, p. 371; Calvillo-Gámez et al., 2015, p. 46) and make their role personal (Ng and Khong, 2014, p. 80; Takatalo et al., 2015, p. 98).

An NPC can have a significant impact on a player's emotional investment and engagement if the player believes that they have an impact on the NPC (Hall et al., 2005, p. 736), sometimes to the point where the player's attachment to them influences their in-game actions (Harth, 2017, p. 16; Bopp et al., 2019, p. 319). In general, players become attached to NPCs that they feel responsible for and do not see as a burden, share personal experiences with, or view as a friend in that they are loyal, caring, and accommodating (Bopp et al., 2019, p. 319). A player's ability to empathize with an NPC nurtures their attachment to them (Paiva et al., 2005, p. 244; Mäyrä and Ermi, 2010, p. 101–102; Adams, 2009, p. 157; Phan et al., 2016, p. 1231; Broekens, 2021, p. 356–357) as they build their relationship via interactions over time (Yannakakis and Paiva, 2015, p. 462; Harth, 2017, p. 13). A player might also become emotionally attached to NPCs that they must work with to complete tasks (De Byl, 2015, p. 13). This appears to be consistent with strategies to build prosocial behaviours (Roseman, 2001, p. 85–86). Industry recognizes the power of this connection between player and NPC and have been designing their games to encourage this "character experience" (Prasertvithyakarn, 2018). Prerequisites of this experience include their *functionality* in the game and their *believability* so that player can become comfortable with the NPCs.

2.3 What Makes a Believable Character?

A believable character, central in artistic mediums like literature and film, "...allows the audience to suspend their disbelief and...provides a convincing portrayal of the personality they expect or come to expect [from the character]" (Loyall, 1997, p. 1). Disney animators have described how they give this "illusion of life" to their characters to ensure that their actions are understood by the audience. This includes building a conceptual model of their internal processes and state—even when no such processes are taking place (Thomas and Johnston, 1995). Believability is not limited to "smart" or "normal" characters because it depends on the situational context and the character's personality (Reilly, 1996, p. 10–12; Loyall, 1997, p. 3–4; Lisetti and Hudlicka, 2015, p. 95). What "believable" means also depends on the application domain—the expectations in entertainment differ from those in soft skills training (Ortony, 2002). In short: for an NPC to be believable, it must behave reasonably within the context of its game world. Generally, NPCs are believable when they (Loyall, 1997, p. 15–26; Lankoski and Björk, 2007, p. 417; Warpefelt et al., 2013, p. 10):

- Appear to be self-motivated,
- Are aware of what is happening around them, and
- React in ways appropriate for their surrounding context while adhering to their personality.

A character's *emotion* is one element that makes them believable (Loyall, 1997, p. 19; Gard, 2000; Paiva et al., 2005, p. 237; Lankoski and Björk, 2007, p. 417; Warpefelt et al., 2013, p. 4; de Melo and Gratch, 2015, p. 116; Lisetti and Hudlicka, 2015, p. 95; Emmerich et al., 2018, p. 145). Characters with emotion address the core features of believability because they convey a character's goals and desires (*self-motivated*) by showing their *awareness* of, *responsiveness* to, and care (*personality*-driven) for their surroundings (Bates, 1994, p. 124; Reilly, 1996, p. 12; Broekens, 2021, p. 356). It follows that one way to improve an NPC's believability is to have them react emotionally to their surroundings.

Emotional behaviours are not necessary for all NPC types, but their importance does increase as their context becomes more complicated and their narrative importance grows (Warpefelt and Verhagen, 2017, p. 49; Emmerich et al., 2018, p. 143). For example, players expect to have a stronger emotional and social bond with their constant NPC companion than they do an unnamed merchant (Isbister, 2006, p. 229). If they are necessary for a game, the game's interactivity makes emotional NPCs difficult to realize because it is impossible to plan the NPCs' behaviours for every potential game scenario. Instead, one can generate emotions and/or emotion-driven behaviours as the NPCs' surroundings change.

2.4 Summary

A fundamental goal of game design is to create good player experiences, regardless of the game's scope or genre, where player engagement is one element. Playing games is a voluntary activity, predisposing players to engagement. However, players do not automatically become engaged with every game that they play—the question is not *why*, but *how* to engage players. Challenges, physical movements, sensory aspects, social interactions with other players, and narratives all have the potential to engage players. While personal preferences influence what a player finds engaging, it is a common sentiment that the game must engage them emotionally to have a lasting impact. A game narrative's NPCs can have a significant impact on the player's emotional investment and engagement if they affect the player's decisions and actions. This requires the NPCs to be believable, convincing the player of their "realness".

Believable characters convince the player of their personality and display the "illusion of life". An NPC's emotions are a key factor in this, communicating that they are self-motivated, self-aware, and care about what happens around and to them. Ultimately, deciding if, when, and how to use emotional NPCs is left to the designer.

Key Points

- The goal of game design is to create good player experiences
- Engagement is an aspect of the player experience and players are predisposed to being engaged
- Evidence suggests that a game must emotionally engage a player to have a long-lasting effect on them
- Game narratives and their characters can be an effective way to emotionally engage a player
- The Non-Player Characters (NPCs) of a game's narrative can significantly impact a player's emotional engagement if they are believable
- Believable characters with emotion can show the player that they are self-motivated, self-aware, and care about what happens around and to them
- It is the game designer's decision to determine if their game needs a narrative, any characters, and if their NPCs require emotional behaviour

Chapter 3

Meet Emotion (Briefly)

> I wish you'd just tell me rather than trying to engage my enthusiasm because I haven't got one.
>
> Marvin the Paranoid Android, *The Hitchhiker's Guide to the Galaxy*

Before giving emotion to Non-Player Characters (NPCs), it is prudent to understand what that means. This is not as simple as it seems. Like immersion, no one truly knows what emotions are (Ortony, 2022, p. 9). Are they explanations for why people behave in certain ways or are they classification schemes that people impose on their perception of the world (Barrett, 2006, p. 46)? There might not even be a "real" meaning to the term "emotion" (Dörner, 2003, p. 75). People typically find it difficult to descriptively articulate them (Clore and Ortony, 2002, p. 53), likely because it is not always clear what an emotion state is (Ortony, 2022, p. 9). It might not even refer to a uniform entity (Hudlicka, 2014b, p. 22). People often use it to reference a broad range of mental states (De Byl, 2015, p. 2; Sloman et al., 2005, p. 208), and have trouble distinguishing between bodily sensations, cognitive states, and affective states (Feldman, 1995, p. 815; Oatley, 1992, p. 75). This is not an issue for daily use but it is for scientific study (Ortony, 2022, p. 9). "Emotion" might be best described as a fuzzy set of definitions (Russell, 1980, p. 1165; Sloman et al., 2005, p. 209, 211), which inevitably leads to borderline cases defying classification (Smith and Lazarus, 1990, p. 611). This fundamental, unanswered question on the nature of emotion makes specifying a computational model difficult. To begin, it is useful to know what emotion is, how it differs from other types of affect, and what its potential functions are (Scherer, 2010b, p. 10). This helps clarify what to model (Hudlicka, 2014a, p. 297), directing an affective theories analysis to determine which ones best fit a CME's requirements (Lisetti and Hudlicka, 2015, p. 99; Osuna et al., 2020, p. 4).

3.1 The Form of Emotion[1]

While there is no agreed-on, precise definition of emotion, researchers agree on a fuzzy working definition and typical examples of emotions, which are sufficient for meaningful comparisons between theories without favouring any single one (Reisenzein et al., 2013, p. 248–249). An **emotion** is a short-term affective state representing the coordinated physiological and behavioural response of the brain and body to events that an organism perceives as relevant (Jeon, 2017, p. 4; Frijda, 1986, p. 249; Scherer, 2000, p. 138–139; Broekens, 2021, p. 349; Smith and Kirby, 2001, p. 121).

Some researchers hypothesize that each emotion has a *signature*—a coordinated response pattern it typically causes in an organism (Hudlicka, 2019, p. 133; Scherer, 2001, p. 108) including: behavioural and expressional characteristics; somatic and neurophysiological factors that prepare the body for action; cognitive and interpretive evaluations that give rise to the emotion; and experiential and subjective qualities unique to the individual. Elements of the signature can be innate or learned (Carlson and Hatfield, 1992, p. 6). Emotions are also characterized by their: high intensity relative to other types of affect (e.g. personality, mood); tendency to come and go quickly; association with a specific triggering event, object, or person; and clear cognitive contents (Jeon, 2017, p. 4; Scherer, 2000, p. 139–140; Broekens, 2021, p. 350). These attributes distinguish emotion from other types of affect. However, there is general agreement that each affect type interacts with emotion, influencing individual experiences:

- **"Affect"** is a general term for any body-linked state that influences the mind (Frijda and Scherer, 2009). A general affective state is typically weaker than an emotion state (Jeon, 2017, p. 5). Since this is a nebulous concept, the scope is on the more specific **"core affect"** (Västfjäll et al., 2002, p. 20, 27; Russell, 2009, p. 1264–1266; Scarantino, 2009, p. 948), defined as "...a state of pleasure or displeasure with some degree of Arousal" (Barrett and Bliss-Moreau, 2009, p. 170).

- **Feelings** are conscious mental representations and interpretations of an emotional response that follow emotions evolutionarily and experientially (Jeon, 2017, p. 4; Scherer, 2009b, p. 184; Scherer, 2000, p. 139), but are not critical for understanding emotional behaviours (Fellous, 2004, p. 40) as they are personal reflections on affective states (Frijda, 1986, p. 251–252). Feelings are ill-defined from a modelling perspective (Hudlicka, 2019, p. 133), and rarely appear computationally.

- **Moods** are enduring, less intense, and more diffuse states than emotions (Frijda, 2009, p. 258; Jeon, 2017, p. 4; Hudlicka, 2019, p. 133; Scherer, 2000, p. 140; Broekens, 2021, p. 351) with no focused object (Clore and Ortony, 2002, p. 54). Their presence is typically unclear to the experiencing individual and often have a more prolonged influence on an individual's cognition and behaviours.

- **Attitudes, Opinions, Sentiments, and Relations** are enduring emotional dispositions towards objects and people, formed over repeated exposures and appraisals of the same stimulus (Broekens, 2021, p. 351). These help structure an individual's relationships, which can influence their knowledge of and plans concerning that stimulus (Oatley, 2000, p. 81).

- **Personality** is a set of stable affective traits (Revelle and Scherer, 2009, p. 304; Hudlicka, 2014a, p. 300; Jeon, 2017, p. 5; Scherer, 2000, p. 141, Broekens, 2021, p. 351) that influence affective processes.

3.2 The Function of Emotion

Historically, people viewed emotionality and rationality as mutually exclusive concepts (Damasio, 2002, p. 12; de Sousa, 1987, p. 1). Psychologists have now come to view affect as an integral element in a healthy cognitive system that developed evolutionarily, likely a result of co-evolution with perceptual, cognitive, and motor abilities (Fellous, 2004, p. 40), whose purpose might be to improve adaptive action beyond what information can achieve alone, uniting the informational, attentional, and motivational effects of emotion. Emotion provides essential functions including homeostasis regulation, reproductive and survival behaviours, and adaptive behaviours in complex and uncertain environments (Hudlicka, 2014a, p. 301). Affect and emotion are now assumed to have many potential roles, including:

- Rapid resource mobilization and allocation (Izard, 1977, p. 108; Hudlicka, 2014a, p. 303)
- Goal management (Hudlicka, 2019, p. 133)
- Decision-making via goal-directed processes (Frijda, 1994, p. 118; Lewis and Todd, 2005, p. 215; Reisenzein et al., 2013, p. 251), likely directed by the underlying appraisal dimensions (Lerner and Keltner, 2000, p. 485)
- Influencing judgments and risk assessments (Izard, 1977, p. 109; Lerner and Keltner, 2000, p. 485; Storbeck and Clore, 2007, p. 1226–1227; Hudlicka, 2019, p. 133)
- Attention (Izard, 1977, p. 108; Lewis and Todd, 2005, p. 215–216; Storbeck and Clore, 2007, p. 1226; Hudlicka, 2019, p. 133)
- Memory (Storbeck and Clore, 2007, p. 1226; Hudlicka, 2019, p. 133)
- Learning and information acquisition (Hudlicka, 2019, p. 133)
- Multi-level interpersonal communication and regulation that is simple but highly impactful (Fellous, 2004, p. 41)

Clearly affect and emotion are part of a functioning system. But what about emotions that do not make sense? Emotions indicate dispositions and sensitivities to certain events and a process of relevance signalling for deliberative actions. In this view, dysfunctional responses might indicate a functional system that has overtaxed resources (Frijda, 1994, p. 121), is unusually sensitive, has ineffective coping strategies, and/or conflicting responses which results in undesirable and non-functional side effects such as a reduced resource pool for the duration of the emotional episode (Reisenzein et al., 2013, p. 251–252). Mood could also cause dysfunctional responses by amplifying a low intensity emotion (Siemer and Reisenzein, 2007, p. 28), the intensity of the current emotion which could impact unrelated memories and processes (Lerner and Keltner, 2000, p. 476–477), or to maladaptive patterns in the emotion-cognition-action patterns (Izard and Ackerman, 2000, p. 254; Clore and Ortony, 2002, p. 49). Distinguishing between the concept of emotion and its individual elements means that assuming the adaptive function of emotions does not imply that all emotions serve that function.

3.3 Summary

Although there is no agreement on what emotions even are, a working definition and the collection of agreed-on examples is sufficient for meaningful affective research. This should also be sufficient for creating believable NPCs with emotions. Emotion differs from other types of affect in its duration, intensity, and focus:

- Emotion is shorter than moods, attitudes, and personality but longer than affect
- Emotion is more intense than affect, moods, and attitudes, whereas personality is typically not associated with intensity in this way

- Emotion relates to a specific event, person, or object at a given point in time, whereas the associations of attitudes develop over time, and affect and mood have no focus at all
- Feelings are reflections on these states, implying that mechanisms outside the affective system trigger them

Emotions also affect different aspects of behaviour, including goal management, memory functionality, and attention. Knowing this makes it clearer what a Computational Model of Emotion (CME) might need in its design.

Key Points

- An emotion is a short-term affective state representing the physiological and behavioural response of the brain and body to perceived opportunities and threats
- Emotion is part of a healthy cognitive system, likely developed during evolution to serve adaptive responses
- Emotions are a feature of an adaptive system, but some emotions can be maladaptive

Chapter 4

On Designing Emotion Engines

As you see, there's no escape and resistance is futile!

Mingy Jongo, *Banjo-Tooie*

A crucial ingredient in the success of human-like or believable behaviours in Non-Player Characters (NPCs) is their *plausibility*, meaning that they make sense to players (Broekens et al., 2016, p. 216–217). This is directly influenced by the *psychological validity* of those behaviours. This means that it must ground itself in Affective Science, the interdisciplinary study of affective phenomena, related processes, and its influencing factors (Davidson et al., 2003, p. xiii). Many systems for creating emotional game characters acknowledge this, building on existing psychological theories (Yannakakis and Paiva, 2015, p. 462).

Just as believability does not equal intelligence, plausibility does not necessarily mean "normal" or appropriate behaviours (Broekens et al., 2016, p. 217)—it also encompasses exaggerated or intentionally broken ones. Affective Science supports this because it includes models of undesirable and abnormal behaviours. This provides opportunities to design unbalanced or mentally ill characters as a game's design requires. Basing a computational design in affective science also helps identify relevant empirical data and model validation methods, enable communication with other researchers, and increase the design's reusability potential (Hudlicka, 2014a, p. 305). This has resulted in a class of software systems, called Computational Models of Emotion (CMEs), that are influenced by affective science (Section 4.1). An exploration of a typical CME design process reveals unique development steps (Section 4.2) and any applied software engineering practices.

4.1 Computational Models of Emotion[1]

Affective Computing introduces emotion as a concern in programs so that they may recognize and respond to human users more intelligently (Picard, 1997, p. 3, 50). There are three main affective computing tasks (Scherer, 2010b, p. 4; Fathalla, 2020, p. 2) that enable this human-centred approach:

- *Emotion Recognition*, to capture user information like speech and gesture to infer the user's current affective state,

[1]Content up to and including the definition of CME © 2022 IEEE. Reprinted with permission from Smith and Carette (2022, p. 1793).

- *Emotion Generation*, to produce an affective state given the current program and environment state, and
- *Emotion Effects on Behaviour*, to change a program's behaviour (e.g. facial expressions, gestures, or movements) given its affective state.

Infrequently, the list includes another task: *Emotion Effects on Cognitive Processes* or *Cognitive Consequences of Emotions* (Lisetti and Hudlicka, 2015, p. 100).

A *Computational Model of Emotion (CME)* is a software system that is influenced by emotion research, embodying at least one emotion theory as the basis for its stimuli evaluation, emotion elicitation, and emotional behaviour generation mechanisms (Osuna et al., 2020, p. 2, 14). This theoretical foundation helps define a CME's mechanisms, components, phases, and architecture which software engineering techniques and methods can implement (Osuna et al., 2021, p. 139).

Broadly, there are two types of CME with different foci in both requirements and validation: research-oriented and domain-specific/applied (Wehrle and Scherer, 1995, p. 600–601; Hudlicka, 2019, p. 130–131; Osuna et al., 2020, p. 4–6).

- *Research-oriented* systems emulate structures, processes, and mechanisms with the goal of understanding their design and structure in biological agents. CME designers extract requirements directly from affective theories and/or models—informing what mechanisms it must have, their order, and other aspects that are characteristic of that theory/model—to test hypotheses about affective phenomena and their eliciting mechanisms and processes. A research-oriented system is valid if it corresponds to the modelled phenomenon in both structure and function (i.e. validates a hypothesis about what structures produce a phenomenon). In software engineering terms, research-oriented systems are white-box models because they must have explainable behaviours and mechanisms for their outputs to enable validation. Examples include ACRES (Frijda and Swagerman, 1987), EMA (Gratch and Marsella, 2004), and ELSA (Meuleman, 2015).
- *Domain-specific* or *applied* models aim to produce specific aspects of affective phenomena and do not care about the specific structures, processes, and mechanisms behind them. Designers extract requirements from the qualities and behaviours that their CME should produce. This often relates to the CME's intended application domain (e.g. video games, conversational agents for health). Domain-specific systems are valid if it meets the designer and end-user's performance criteria, which can vary between domains (e.g. criteria for believability, effective user interactions). In software engineering terms, these systems are black-box models because it does not matter how they produce outputs if they have the desired effects. Examples include GAMYGDALA (Popescu et al., 2014), Em (Reilly, 1996), and APF (Klinkert and Clark, 2021).

Building game development tools for believable NPCs "with emotion" requires *domain-specific* CMEs because its ability to engage players determines its validity rather than how closely it resembles true affective phenomena. In general, domain-specific CMEs have fewer design constraints than research-oriented systems because they are not strict models of affective phenomena (Sloman et al., 2005, p. 233). This affords CME designers freedom to choose any combination of theories and/or models they wish, and make the assumptions and design decisions necessary to realize it as a computational model that existing research might not be able to support—an unavoidable task when working with informally defined theories (Marsella et al., 2010, p. 21, 23; Hudlicka, 2019, p. 130). Domain-specific CMEs are also likely to be significantly less complex than research-oriented ones because their "realism" is proportional to the complexity of their models (de Rosis et al., 2003, p. 83; Osuna et al., 2021, p. 139). "Realism" might even be detrimental to a domain-specific CME (Reilly, 1996) (see Chapter 5.5.3 for a discussion). For example, a game developer might exaggerate their NPCs' behaviours—which is at odds with "realism"—to improve their believability for player interactions and, consequently, player engagement. Taken together, this implies that domain-specific CMEs are unlikely to be exactly alike, even if they target the same domain.

4.2 A Software Engineering Approach to CME Development

CME development typically follows a general set of steps (Osuna et al., 2020, p. 2):

1. Choose one or more emotion theories/models as the design foundation and translating them into formal languages
2. Implement the theories/models and other software artifacts necessary to meet design requirements while addressing missing information in the theories/models
3. If applicable, integrate the CME into a larger cognitive agent architecture
4. Test that the CME produces the expected behaviours

However, many CME designs appear to be *ad hoc*—they do not systematically apply design methods or techniques, nor follow a well-defined development sequence (Marsella et al., 2010, p. 21; Osuna et al., 2020, p. 14). In some cases, they do not systematically apply emotion theories/models (Scherer, 2021, p. 291). This makes it difficult to reuse CME components (Reisenzein et al., 2013, p. 261), compare different CMEs, and extend or scale them (Osuna et al., 2020, p. 14–15).

As a software system, CMEs would benefit from a disciplined software engineering approach (Ghezzi et al., 2003). It offers systematic development processes and proven design tools which would help address issues around CME comparisons, and support desirable software qualities such as: reusability; modularity, which influences understandability; flexibility and scalability, which influence maintainability; and interoperability (Osuna et al., 2023, p. 60). This would also encourage the creation of multi-disciplinary teams for CMEs with a broader design focus (Hudlicka, 2014b, p. 21; Osuna et al., 2021, p. 141). The software design process—requirements analysis, design, implementation, and verification and validation—can define CME development stages to show potential areas for improvement and increase the likelihood of creating a well-designed system.

4.2.1 Requirements Analysis

A CME's requirements restrict the number, type, and nature of its components (Rodríguez and Ramos, 2015, p. 441, 449), essentially defining the design process boundaries. CME development tends to use a two-stage requirement gathering process:

1. A high-level requirement specification—including stakeholder and user needs—sets the system's goals, identifying which affective theories and/or models could achieve them (Lisetti and Hudlicka, 2015, p. 99; Osuna et al., 2020, p. 4; Scherer, 2021, p. 281); then
2. Identifying which of those theories/models fit the system's goals best by systematically comparing them and analyzing existing CMEs (Hudlicka, 2014b, p. 20) to generate functional and non-functional requirements.

Many requirements-related pitfalls concern the scope of the Affective Science literature, which has diverse perspectives and lacks common terms to discuss them (Marsella et al., 2010, p. 21; Osuna et al., 2020, p. 15). Affective theories/models often have abstract, natural language descriptions that leave them unsystematically and informally defined (Gratch and Marsella, 2015, p. 54; Jones et al., 2011, p. 657). This makes it difficult to identify which theories/models suit a CME's requirements without making, typically subjective (Rodríguez and Ramos, 2015, p. 449–450), assumptions about unspecified behaviours (Elliott, 1992, p. 15). These problems are so prevalent that a group of psychologists and computer scientists called for the deconstruction of emotion theories into basic assumptions to translate them into a common system, language, or architecture (Reisenzein et al., 2013, p. 261). This also means that there is "...a lack of guidelines to determine which theory of emotion should be used to ensure a successful development of a CME" (Osuna et al., 2020, p. 15).

Another common pitfall—which the informal nature of affective theory/model descriptions are at least partially to blame—is the tendency to use high-level descriptions for the final version of a CME's requirements (Osuna et al., 2020, p. 15), leaving questions as to how the requirements realize design goals and influence subsequent development stages. Developers should write the requirements at a level that establishes a context for finding potential opportunities to use software design patterns that promote desirable software qualities (Osuna et al., 2021, p. 143–144).

Choosing a Domain-Specific CME's Foundations

A systematic method for deciding which theories to use helps minimize the pitfall consequences by making design decisions traceable. For domain-specific CMEs, the choice of theories/models follows from the desired system behaviours and qualities. Expanding on the described two-stage requirement gathering process, I propose a four-stage methodology to serve as a guideline for examining and choosing affective theories/models for domain-specific CMEs:

1. Using the CME's high-level requirements/design goals and other domain knowledge (e.g. game type, target player interactions, NPC embodiment), define the CME's design scope
2. Using the CME's design scope and high-level requirements/design goals, identify broad groups of affective theories/models that could serve those needs
3. Using the CME's high-level requirements/design goals, examine each theory/model within those groups to see "how well" they satisfy those requirements by:
   (a) Examining each theory/model with respect to the high-level requirement/design goal and recording pertinent information
   (b) Using the recorded information to assign each theory/model a *score* representing their relative suitability for that requirement/goal
   (c) Tallying those scores to evaluate a theory's overall "suitability" for satisfying the high-level requirements/design goals
4. Choose a theory/model or set of theories/models to use for the CME's design using the "suitability" scores, potentially influenced by factors such as domain knowledge, ease of formalization (requires experimentation), existing CME designs, and/or personal preference (see a proposed process in Chapter 7.2)

This methodology relies on *document analysis*, which developers commonly use for CME requirements analysis (Osuna et al., 2020, p. 4). Each stage aligns with a component of document analysis (Bowen, 2009, p. 32):

- The analysis context is defined by the high-level requirements and derived design scope,
- Thematic analysis of affective theories/models identifies the broad theory groups
- Content analysis organizes theories/models within those groups into levels of requirement "satisfaction" by identifying pertinent aspects of theories/models directly from the affective science literature, and
- Drawing recommendations/conclusions from the gathered data is the process of choosing a theory or set of theories for the CME

This methodology is specific to domain-specific CMEs—which focus on *what* they must do rather than *how* they must do it—because their development begins by defining desirable qualities and tasks it should have *before* choosing affective theories and/or models. It offers a structured approach to establish and justify a CME's foundations and encourages the documentation of assumptions and choices necessary for replicability and reuse (see Chapters 6, 7, and 8 for example applications of this methodology).

Based on one's understanding of the requirements and Affective Science literature, this methodology has many potential outcomes that might all be useful. One should also not expect to create a strictly "correct" implementation of those theories and/or models. Even the OCC theory, created with computational tractability in mind, lacks a standard implementation (Ortony et al., 2022, p. 218, 229). It is also impossible to model, or even to choose, theories without running into the subjectivity pitfall. Despite this, deeply ingraining the primary literature in this methodology is beneficial for: helping CME developers identify assumptions and decisions in existing CMEs that are not part of the affective theory/model, informing decisions to reuse, build on, or emulate aspects of that CME; to gain familiarity with the domain to more easily identify aspects of a theory/model that can "be flexible" while remaining faithful to its intention; and to establish psychological validity, which directly influences the plausibility—and subsequent believability—of the CME's outputs.

4.2.2 Design

Software development often divides design efforts into the high-level architecture and the low-level modules (Osuna et al., 2020, p. 8, 16). CME development appears to use these design stages, but it is difficult to determine if there was a guiding methodology or if it was mostly *ad hoc*. CME designs tend to have an architecture to show connections between modules—though the approach can differ widely—and do not always document module interfaces or internal data structures (Osuna et al., 2020, p. 11, 14). This contributes to the difficulty in comparing different systems.

The inability to compare CMEs that use similar underlying theories/models largely disappears when they have components with identical modularization points (Marsella et al., 2010, p. 26, 31, 38). If done correctly, deciding which modules to include and how to connect them contain most of a CME's design differences. This kind of modularization encourages reusability and allows independent, empirical assessments of design decisions using software metrics and quality attributes. Recent work towards a CME-focused software architecture with software design patterns for each component (Osuna et al., 2021), a reference architecture (Osuna et al., 2023), and a framework for supporting affective and cognitive component communication (Osuna et al., 2022) is beginning to address these issues.

4.2.3 Implementation

There is generally little to no documented information about a CME's implementation process, making it difficult to replicate them (Osuna et al., 2020, p. 13, 16). CMEs sometimes report their—often object-oriented—implementation language, but not the followed practices. It also is uncommon to find open-source versions of CMEs, though some do exist (e.g. Becker-Asano (2017), Schultz (2014), Gebhard et al. (2015), Warpefelt and Eladhari (2015), Broekens and van Hal (2016), Dias (2015), Guimarães et al. (2021), Kriegel (2013), and Kriegel and Dias (2013)). These issues concern the broader scientific computing community, where there are acknowledged characteristics for improving the reproducibility and replicability of code (Benureau and Rougier, 2018).

4.2.4 Verification and Validation

There are no known standards or benchmarks for verifying or validating CMEs (Osuna et al., 2020, p. 16; Hudlicka, 2014b, p. 21), nor is there evidence of robustness testing (Osuna et al., 2020, p. 13) or methods for comparing CMEs (Broekens, 2021, p. 373–374). Other researchers also often have difficultly replicating a CME's validation because its testers did not formally report the process (Osuna et al., 2023, p. 63). Testers often have difficultly adapting verification techniques to CMEs because it is usually a question of how realistic or convincing the resulting affective behaviours are rather than their technical functionality (Osuna et al., 2020, p. 13–14, 16).

Test cases, usually called example scenarios or simulations, are a useful technique for validation. They have been widely used to verify that CMEs meet their requirements as defined from the underlying emotion theories. However, developers run tests in specific environments and under specific conditions and there is no standard framework for designing or running the tests. Should a framework exist, it would not be possible to use the same one for both research-oriented and domain-specific CMEs due to differing validation criteria (Section 4.1). However, CMEs of the same domain should be able to use the same test cases and would also be an avenue for comparison. A design framework would also allow for parallel test case creation, making test suite development more objective, verifiable, reusable, and—consequently—build confidence in the soundness of the test suite. A design process would also make test suite development feasible. It is unclear how many test cases are necessary for evaluating a CME for generating believable emotion, but one designer claims that they analyzed approximately 600 scenarios for a model with twenty-six emotions (Elliott, 1998, p. 21–22)—an average of 23 per emotion.

It is not enough to test a CME's implementation (i.e. satisfies its technical specification) because that cannot determine if it *behaves* as expected (i.e. satisfies its external requirements). This requires acceptance tests derived from data and/or behaviours specified independently of specific theories, models, and/or CMEs. They must be reproducible and specific enough for implementation, and to build confidence that the test cases are reasonable for CME validation.

Building Acceptance Test Cases for Evaluating Emotion Believability

CMEs generating or portraying aspects of believable agent emotions must focus on what makes emotion *believable*, not how it functions in biological beings. Storytellers—such as novelists, playwrights, and actors—are an excellent source for such tests because they know how to express emotion believably in their characters (Reilly, 1996, p. 10; Oatley, 1992, p. 123). Building test cases from stories with characters is possible when testers know (Smith and Carette, 2019, p. 123):

1. A character's narrative design (goals, motivation, current state, etc.),

2. Aspects of the current world state relevant to that character, and

3. That character's emotional reaction to the world state.

The "expected output" of an acceptance test case is a character's emotional reaction to a situation, phrased using known behavioural and expressive characteristics of emotion kinds/categories or affective dimensions. The character's narrative design and the current world state are inputs—the factors causing the character's emotional reaction. These are less clear and one must infer them from narrative elements. This inference step makes a methodology important for replicability due to the inherent subjectivity of character and story interpretation. Specifically, the methodology must guide the development of subjective interpretations from an objective investigation of a character, like a detective at a crime scene (Kusch, 2016, p. 14, 20), to systematically identify and organize salient aspects of a character to support deductions about them. I propose a five-stage methodology for building acceptance test cases from stories:

1. Using the CME's target domain, identify a source medium (e.g. literature, film, theatre) to gather information from
2. Using the source medium and the CME's expected emotion kinds, build *profiles* for each emotion using knowledge of how storytellers encode them in their medium and—to build in some psychological validity—information from Affective Science
3. From an instance of the source medium, choose a character to analyze and identify data collection "trigger points" (e.g. changes in a character's emotion):
   (a) Using the "profiles", identify the emotion and record elements of the "profile" that apply to the character in that moment
   (b) Record elements of the scene that might have contributed to the emotion's elicitation (i.e. "transient" knowledge)
4. At the end of data collection, organize the information and infer "persistent" knowledge about the character, deducible from observations such as the character's tendencies to act (e.g. always greeting a certain entity when they appear) and patterns of elements across scenes (e.g. the character is only calm when they have a particular item)
5. Translate natural language descriptions into formal statements (e.g. "close to death" could become "$\texttt{health} \leq 5$ `units`"), recording how statements from the character analysis map to mathematical representations

This methodology relies on *character studies/analyses*, a literary analysis tool for examining a character's external aspects (e.g. physical description, relationships/social status, actions, dialogue) to deduce their internal ones (e.g. personality, motivations, emotions) (Hébert, 2022, p. 22, 154, 158, 188–189). Many aspects of literary works also apply to theatre. In the broadest sense, a character is an actor in a performance (medium) who delivers their lines (dialogue) following stage directions (storyteller-planned actions). Therefore, source mediums do not have to be strictly literary ones. This process offers a structured method for structuring test case information and helps build confidence in the test cases' validity (see Chapters 11 and 12 for a demonstration of this methodology).

Test Case Input Types

Recalling that believable characters must appear self-motivated, aware of what is happening around them, and react appropriately in the context while adhering to their personality (Chapter 2.3), the "data" that contributes to a character's emotion state can be split into two groups:

1. Local data that changes between scenarios (i.e. aware of what is happening around them, react appropriately in the context), and

2. Global data that does not change or changes very slowly (i.e. self-motivated, adhering to their personality)

where the latter improves the coherence of the character's behaviours (Ortony, 2002, p. 189–190, 203). Consequently, test case inputs are either "transient" (i.e. local) knowledge about *what is happening to* a character and "persistent" (i.e. global) knowledge *about* them.

"Transient" Knowledge Emotion is a short-term state related to events (Chapter 3.1). Knowing how a story event changes the "world state" is necessary to understand how the event affects a character. As the "world" evolves independently, emotion evaluation happens concurrently with each event that is significant to one or more characters.

Audiences build conceptual models of a character's internal state from their visible *actions* (Thomas and Johnston, 1995). Therefore, collecting the following "transient" knowledge relies on a careful examination of story events and their impact on the characters:

- The character's action(s) and dialogue,
- The character's physical state (e.g. injuries), and
- If other characters and/or entities (e.g. the environment) are present/related to the character's action(s):
  - The character's relation to them,
  - Their action(s) and dialogue (actual or the character's assumption of them), and
  - Their physical state.

"Persistent" Knowledge To understand what events a character deems *relevant* (Chapter 3.1), they must possess some static—or very slowly changing—attributes such as personality and goals. These help explain a character's motivation and their world perception, which is "persistent" knowledge because it is tied to the character rather than the "world". "Persistent" information is usually implicit and must be inferred from multiple sets of "transient" knowledge. Therefore, this process is easier when the character appears frequently in the narrative (i.e. main characters).

A character's important actions are the ones that they deem *useful*, interpreted as actions the character does while attempting to obtain or preserve a *desirable* (to themselves) "world state". *How* a character performs those actions is also important because it illustrates how they perceive the world. From this, it is possible to deduce the following "persistent" knowledge about a character:

- Goal(s)/motivations, ranked by relative priority to the character,
- Personality traits, and
- Principles and preferences.

4.2.5 Implications for CME Development

A common thread linking these CME development issues is a lack of documentation, which developers must create alongside the design process—not after (Parnas et al., 1994, p. 949):

- Requirements analysis must be more rigorous, capturing assumptions and design decisions, and showing a clear path from the CME's high-level design goals to specific functional and non-functional requirements for easy reference during development (Parnas and Clements, 1986, p. 253, 255)

- CME architecture and module development should localize each system function to one module or a related family of modules (Parnas et al., 1985, p. 260–261) to encourage desirable software qualities like reusability, verifiability, and maintainability (Smith and Lai, 2005, p. 108)

- Implementations—even systematic ones (Parnas et al., 1994, p. 948)—and associated documentation must be made available so that others can reproduce, test, and compare existing systems

- Verification and validation must go beyond test cases to build confidence in the CME's capabilities (Ghezzi et al., 2003, p. 270), which documentation can aid by showing how developers verified it and how the CME realizes its design goals, and revealing additional elements to test such as performance (Parnas and Clements, 1986, p. 252)

4.3 Summary

The success of believable NPCs with "emotion" hinges on the plausibility of their behaviours. Psychological validity influences their plausibility, requiring their grounding in Affective Science. By definition, a CME—a software system that represents some aspect of affective processing based on one or more affective theories/models—meets this need. Historically, CME development has typically been informal and/or poorly documented. Drawing from the systematic and disciplined field of software engineering can alleviate these issues. To forward this effort, I have proposed:

- A document analysis-based methodology for choosing a domain-specific CME's underlying affective theories/models based on their high-level requirements/design goals and domain knowledge

- A character analysis/study-based methodology for deriving acceptance test cases from characters in professionally-crafted stories

These methodologies target domain-specific CMEs because a tool for enhancing NPC believability via "emotional" behaviours requires a domain-specific CME rather than a research-oriented one, which might work against "believability". Its goals should focus on system behaviour as it relates to NPC believability rather than specific affective phenomena. The need for psychological validity still mandates that the design's foundation use at least one affective theory and/or model.

Key Points

- The plausibility of Non-Player Character (NPC) behaviour is essential to their success as "emotional" agents and can include exaggerated, undesirable, and/or abnormal behaviours
- Plausibility is directly influenced by psychological validity—the grounding of the behaviours in Affective Science
- Affective Computing introduces emotion as a concern in programs to improve their interactions with human users
- A Computational Model of Emotion (CME) is a software system that at least one affective theory/model inspires and represents at least one part of affective processing
- Research-oriented CMEs test hypotheses about affective phenomena and their underlying mechanisms, whereas domain-specific CMEs aim to mimic affective phenomena without worrying about the true nature of the mechanisms
- CME development appears to be *ad hoc*, and would benefit from a software engineering approach and more rigorous documentation practices
- The proposed methodology for choosing theories during requirements analysis for domain-specific CMEs uses document analysis for systematically analyzing emotion theories using the CME's high-level requirements, derived design scope, and other relevant domain knowledge
- The proposed methodology for building acceptance test cases for domain-specific CMEs uses character analyses/studies for systematically collecting data from stories and translating them into formal, implementable statements
- Recent research on software design patterns, a reference architecture, and a communication framework is promising for improving the rigour of CME architecture and module design
- Existing guidelines in the scientific computing community for improving the reproducibility and replicability of code are also applicable to CME implementation, which developers tend to under-report
- Improving the documentation of CME development would make each development stage more rigorous, make it possible to begin comparing CMEs, and promote desirable software qualities such as reusability, verifiability, and maintainability

Chapter 5

Affective Theories in Computational Models[1]

Scanning...scanning...

Cyborg, *Zack Snyder's Justice League*

Choosing emotion theories for CME creation is difficult because each theory typically focuses on a subset of emotion process stages and has their own assumptions on how different components integrate and how to differentiate emotions (Scherer, 2010b, pp. 10–11). Given the large number of emotion theories available (we've seen at least 27), trying to understand them all is unrealistic. By first focusing on families of theories, grouped by core assumptions or focus (Scherer, 2010b, pp. 11, 20), one can identify a subset of theories that might satisfy a CME's requirements, including their level of empirical validation and how they might be used together. We choose to focus on emotion generation and some aspects of emotion effects on behaviour because the relevant literature is vast.

This survey explores 67 CMEs that are stand-alone applications (e.g. GAMYGDALA (61)) or part of a broader system (e.g. in Kismet (53)). Its aim is to give an overview of some affective theories that appear in CME designs and the reasons for that choice[2]. Seeing affective theories in context has two advantages. First, CMEs translate theories into concrete computational representations, thus dispelling the fuzziness of the theories' natural language presentations. The second and greater advantage is that a CME targeted at a specific application domain will illustrate the underlying theory's strengths and how it could be mechanized. In practice, designers often combine theories—sometimes implicitly—to achieve the desired CME functionality because single theories do not address all aspects of emotion or the available empirical data (Hudlicka, 2014b, pp. 10). The role assigned to a theory in a CME could be an indicator of its strengths.

Section 5.1 reviews the survey's scope and methods, then Section 5.2 organizes CMEs into categories by the creator's original intent to help give context for their design decisions. Next, Section 5.3 presents how CMEs use theories for emotion representation, elicitation, and expression. In Section 5.4 we examine the theories that appear in CMEs at least five times (Table 5.1) to synthesize commonalities and strengths. We also note theory combinations. Section 5.5 explores other information that could be useful for designing CMEs. We use abbreviations—some of them our own—throughout the survey to increase the legibility of the text.

 Consequently, this chapter refers to Ortony et al. (1988) rather than Ortony et al. (2022).

[2]See Broekens (2021, pp. 370–372) for some historical context too.

Table 5.1: Overview of the Main Theories Used in Surveyed CMEs © 2022 IEEE

Theory	Abbr.	References
Izard	Iz.	Izard et al. (1993); Izard (1993); Izard and Ackerman (2000)
Ekman	Ek.	Ekman (2007); Ekman et al. (2002)
Plutchik	Plu.	Plutchik (1980, 1984)
Valence & Arousal	V-A	Brosch and Moors (2009), (Fowles, 2009), (Wundt, 1912)
Pleasure-Arousal-Dominance Space	PAD	Mehrabian (1996b)
Frijda	Frj.	Frijda (1986); Frijda and Zeelenberg (2001)
Lazarus	Laz.	Lazarus (1991)
Scherer	Sch.	Scherer (2001)
Roseman	Ros.	Roseman et al. (1996); Roseman (2011, 2018)
Ortony, Clore, & Collins	OCC	Ortony et al. (1988); Ortony (2002); Ortony et al. (2005)
Smith & Kirby	S & K	Smith et al. (1996); Smith and Kirby (2001)
Oatley & Johnson-Laird	O & JL	Oatley and Johnson-Laird (1987); Johnson-Laird and Oatley (1992); Oatley (1992, 2000)
Sloman	Slo.	Sloman et al. (2005)
Damasio	Dam.	Damasio (1995)
LeDoux	LD	LeDoux (1998)

5.1 Survey Scope and Methods

We only include CMEs that generate emotion due to our focus. Our search protocol follows the PRISMA-S guidelines (Rethlefsen et al., 2021)[3]. Fifteen systems are direct iterations of prior designs[4]. Prior systems are not surveyed unless they are sufficiently different (i.e. use different emotion theories, have differing designer intents) to warrant exploration. Prior systems that are not psychologically grounded (e.g. based on physical brain structures, empirical data) are also omitted, though mentioned when important ideas are borrowed from them.

We found 166 CMEs accompanied by a published description. We removed one because its bibliographic data was uncertain. Our selection protocol is partially based on citations, which take time to accumulate, so recent papers (2020 and later) were examined by hand for scope fit. Two of seven did. Of those from 2019 or earlier, 73 had strictly more than our threshold of 1.5 Citations per Year (C/Y). We included all CMEs with C/Y > 2.5 in the survey, and an additional handful chosen subjectively as they seemed to bring something interesting to the discussion. We made an exception for ELSA (26) with 0.43 C/Y due to its unique implementation of Sch., and for Scherer's involvement in its creation (see Section 5.4.2). We survey 67 CMEs in total.

[3]See Appendix A.1 for the full protocol.
[4]See Appendix A.2 for CME "genealogy".

5.2 Classifying CMEs

We group CMEs by application domain according to the *creator's documented intent* (Table 5.2) because this would have guided their selection of emotion theories. These categories are not exclusive—someone could use a CME successfully in a different domain.

- *Multi-Purpose* CMEs (Systems 1–18) are not limited to one domain. These systems: explicitly list multiple, sufficiently different potential uses (Hudlicka, 2019; Elliott, 1992, p. 3–6; El-Nasr et al., 2000; Salichs and Malfaz, 2012); name a general type of CME environment (Becker-Asano, 2008, p. 10; Velásquez, 1998; Ushida et al., 1998; Prendinger et al., 2004; Petta, 2002; Lisetti and Gmytrasiewicz, 2002; Kshirsagar and Magnenat-Thalmann, 2002; Duy Bui, 2004; Shvo et al., 2019; Castellanos et al., 2018; Jain and Asawa, 2019, p. 60; Kazemifard et al., 2011); and allow users to integrate their own implementations of emotion theories (Alfonso et al., 2017; Dias et al., 2014).
- *Natural Language Processing* CMEs (Systems 19) read, decipher, comprehend, and analyze human language, focusing on affective content (Yanaru et al., 1997).

Table 5.2: Documented Application Domains © 2022 IEEE

Domain	Systems
Multi-Purpose	1. Affective Reasoner (AffectR), 2. Cathexis, 3. Emotion Model (EmMod), 4. FLAME, 5. SCREAM, 6. MAMID, 7. TABASCO, 8. WASABI, 9. Maggie, 10. AKR Scheme, 11. General Virtual Human (GVH), 12. ParleE, 13. Interdependent Model of Personality, Motivations, Emotion, and Mood (IM-PMEB), 14. GenIA^3, 15. InFra, 16. FAtiMA Modular (FAtiMA-M), 17. Hybrid Model of Emotion-Eliciting Conditions (HybridC), 18. GEmA
Natural Language Processing	19. SOM
Cognitive Architecture	20. Soar, 21. LIDA, 22. CLARION
Scientific Research	23. ACRES, 24. EMA, 25. Will, 26. ELSA, 27. GAMA-E
Military and Emergency Training	28. Émile, 29. EMOTION, 30. HumDPM-E, 31. JBdiEmo, 32. DETT, 33. EP-BDI, 34. MicroCrowd
Soft Skills Training	35. Puppet, 36. CBI, 37. FAtiMA, 38. TARDIS, 39. PUMAGOTCHI
Virtual Social Agents	40. Greta, 41. ALMA, 42. Eva, 43. PPAD-Algorithm (PPAD-Algo), 44. Peedy the Parrot, 45. ERDAMS, 46. TEATIME, 47. Mobile Medical Tutor (MMT), 48. Presence
Social Robots	49. Partially Observable Markov Decision Process for Cognitive Appraisal (POMDP-CA), 50. iPhonoid, 51. Ethical Emotion Generation System (EEGS), 52. Plutchik's Wheel of Emotions Inspired (PWE-I), 53. Kismet, 54. Roboceptionist (R-Cept), 55. GRACE, 56. TAME
Art and Entertainment	57. Artificial Emotion Engine™ (AEE), 58. FeelMe, 59. Socioemotional State (SocioEmo), 60. The Soul, 61. GAMYGDALA, 62. Mob Simulation (MobSim), 63. Artificial Psychosocial Network (APF), 64. MEXICA, 65. Narrative Planning with Emotions (NPE), 66. Em/Oz, 67. S3A

- *Cognitive Architectures* (Systems 20–22) implement theories concerned with the components of the mind and interactions between them (Laird, 2012; Franklin et al., 2014; Sun et al., 2016).

- *Scientific Research* CMEs (Systems 23–27) explore aspects of affect or affective system design. They are typically stricter about the system's behaviours, as they aim to test an affective theory (Frijda and Swagerman, 1987; Meuleman, 2015) or replicate observed affective phenomena (Moffat, 1997; Gratch and Marsella, 2004; Bourgais et al., 2017).

- *Military and Emergency Training* CMEs (Systems 28–34) help train personnel for emotionally-charged scenarios in consequence-free environments (Gratch, 2000; Mehdi et al., 2004; Aydt et al., 2011; Korečko et al., 2016), or run simulations where emotion is a factor (van Dyke Parunak et al., 2006; Zoumpoulaki et al., 2010; Lhommet et al., 2011).

- CMEs for *Soft Skills Training* (Systems 35–39) help train life skills that can be difficult to hone with traditional techniques, such as emotional intelligence (André et al., 2000, pp. 153), problem solving under pressure (Marsella et al., 2000), empathy (Dias and Paiva, 2005), interview skills (Jones and Sabouret, 2013), healthy eating habits, and responsibility for pets (Laureano-Cruces and Rodriguez-Garcia, 2012).

- *Virtual Social Agents* with CMEs (Systems 40–48) have a virtual embodiment, interacting with users in a conversational capacity. They focus on: believability (de Rosis et al., 2003; Gebhard, 2005; Kasap et al., 2009; Zhang et al., 2016); improving interface usability (Ball and Breese, 2000; Ochs et al., 2012; Yacoubi and Sabouret, 2018; Alepis and Virvou, 2011); or both (André et al., 2000, pp. 158).

- CMEs for *Social Robots* (Systems 49–56) are different from virtual assistants because of a robot's physical embodiment (Breazeal, 2003, p. 120). These CMEs aim to humanize robots and improve human-robot interactions by adding a social dimension to them (Kim and Kwon, 2010; Masuyama et al., 2018; Ojha and Williams, 2016; Qi et al., 2019, p. 209)—sometimes over extended time frames (Breazeal, 2003, p. 122–124; Kirby et al., 2010)—and to provide companionship (Dang and Duhaut, 2009; Moshkina et al., 2011).

- CMEs for *Art and Entertainment* (Systems 57–67) are often used for improving agent believability, changing the focus from strict adherence to psychological validity to interesting and entertaining behaviours. However, agent behaviours must remain plausible to be effective (Broekens et al., 2016, p. 216–217). There are CMEs for: developer tools (Wilson, 2000; Broekens and DeGroot, 2004; Ochs et al., 2009; Bidarra et al., 2010; Popescu et al., 2014; Durupınar et al., 2016; Klinkert and Clark, 2021); narrative planning (y Pérez, 2007; Shirvani and Ware, 2020); and agent architectures (Reilly, 1996, p. 31; Martinho et al., 2000).

5.3 Survey

We document the following tasks performed by CMEs:

- *Emotion Representation* (Table 5.3): CMEs might use a theory to specify what kinds of emotion it supports. Although several CMEs tend to use the same theory to both represent and elicit emotion, these are examined separately because differences might indicate other aspects of the theory relevant to CME design.

- *Emotion Elicitation* (Table 5.4): Since there are emotion theories that do not, or vaguely, describe the *process* of emotion generation, this use is separated from emotion representation to clarify the difference.

- *Emotion Expression* (Table 5.5): We examine affective theories selected for expression separately because they are distinct tasks. CMEs that do both generation and expression might use separate theories for each task or the same combination of theories for both.

Eight CMEs (i.e. EmMod (3), WASABI (8), FAtiMA-M (16), HybridC (17), CLARION (22), Greta (40), Presence (48), GRACE (55)) do not implement one or more theories, but instead use them as design guides. These also reveal decision rationale, so we make note of this. When a CME can be programmed with a user's choice of theories (i.e. GenIA[3] (14), InFra (15), FAtiMA-M (16), FeelMe (58)), we examine its default implementation.

5.3.1 Emotion Representation

Twenty-eight CMEs appear to use the same theory to represent *and* elicit emotion, with the decision driven by elicitation requirements (marked with a † in Table 5.3). The others make representation choices independently of elicitation or appear to start with a representation and build an elicitation process from it (see Section 5.3.2).

Four CMEs reference Plu. for emotion representation because of its ability to "create" new emotions as combinations of its emotion categories (i.e. InFra (15) (Castellanos et al., 2018, p. 35)[5], HybridC (17) alongside Iz. (Jain and Asawa, 2019, p. 63), SOM (19) (Yanaru et al., 1997, p. 217–218), and PWE-I (52)). PWE-I also uses Plu.'s emotion structure which can be implemented as a 2D space, affording emotion dynamics and interactions while also using its emotion categories (Qi et al., 2019, p. 210–211).

Kismet (53) uses a dimensional space that includes V-A to combine disparate information sources and unify the emotion elicitation process, internal representations, and facial expression generation (Breazeal, 2003, p. 133, 148, 151). However, it also found that a third dimension, *stance*, was necessary to prevent accidental activation of emotions that are similar in the simpler 2D space (Breazeal, 2003, p. 139–140). PAD, a 3D space, appears in eleven CMEs for emotion representation as a common space to define elicitation and expression mechanisms, as well as their interactions. FeelMe (58) uses PAD because "[it] argues that any emotion can be expressed in terms of values on these three dimensions, and provides extensive evidence for this claim...makes his three dimensions suitable for a computational approach. Second, since the PAD scales are validated for both emotional-states and traits, they provide a useful basis for a computational framework that consistently integrates states and traits...provides an extensive list of emotional labels for points in the PAD space" (Broekens and DeGroot, 2004, p. 212). The Soul (60) uses PAD because it is "[a] simple yet powerful model for representing emotional reactions...", "... is able to represent a broad range of emotions. It can be compared to creating a whole spectrum of colours using only red, green and blue", and "...it uses only three axes, which furthermore are almost orthogonal to each other, as we are used to, for example, in 3D space" (Bidarra et al., 2010, p. 338–339). WASABI (8) uses PAD because it felt that "...three dimensions are necessary and sufficient to capture the main elements of an emotion's connotative meaning—at least in case of simpler emotions such as primary or basic ones" (Becker-Asano, 2008, p. 58). A dimensional space also affords numerical measurements and calculations so that emotions and other types of affect can influence each other and another view of the emotion state (Becker-Asano, 2008, p. 89, 97).

[5] Inferred from InFra's (15) design goals (Castellanos et al., 2018, p. 27).

Table 5.3: Theories Used for Emotion Representation © 2022 IEEE

		Iz.	Ek.	Plu.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S&K	O&JL	Slo.	Dam.	LD
1	**AffectR†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
2	**Cathexis**	**R**	**R**	–	–	–	–	–	–	–	–	–	**R**	–	–	–
3	**EmMod**	–	**R**	–	–	–	–	–	–	–	–	–	**R**	–	–	–
4	**FLAME†**	–	–	–	–	–	–	–	–	**r**	**r**	–	–	–	–	–
5	**SCREAM†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
6	**MAMID†**	–	–	–	**r**	–	–	–	**r**	–	–	**r**	–	–	–	–
7	**TABASCO†**	–	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–
8	**WASABI**	–	**R**	**r**	–	**R**	–	–	–	–	**r**	–	–	**r**	**R**	**R**
9	**Maggie**	–	–	–	–	–	–	–	–	–	**r**[1]	–	–	–	–	–
10	**AKR**	–	**r**	–	–	–	**r**	–	**r**	**r**	**r**	–	–	–	–	–
11	**GVH**	–	**R**	–	–	–	–	–	–	–	**r**	–	–	–	–	–
12	**ParleE†**	–	–	–	–	–	–	–	–	**R** (4)	**R**	–	–	–	–	–
13	**IM-PMEB**	–	–	–	–	**r** (41)	–	–	–	–	**r**	–	–	–	–	–
14	**GenIA^3**	–	–	–	–	**r** (41)	–	–	–	–	**r** (24, 41)	–	–	–	–	–
15	**InFra**	–	–	**r**	–	–	–	–	–	–	–	–	–	–	–	–
16	**FAtiMA-M†**	–	–	–	–	–	–	–	–	–	**R** (37)	–	–	–	–	–
17	**HybridC**	**R**	**R**	**R**	–	–	–	–	–	–	–	–	r	–	–	–
18	**GEmA†**	–	–	–	–	–	–	–	–	–	**R**	–	–	–	–	–
19	**SOM**	–	–	**R**	–	–	–	–	–	–	–	–	–	–	–	–
20	**Soar†**	–	–	–	–	–	–	–	**r**[2]	–	–	–	–	–	–	–
21	**LIDA†**	–	–	–	–	–	–	–	**r**[2]	–	–	–	–	–	–	–
22	**CLARION†**	–	–	–	–	–	–	–	**r**	–	–	–	–	–	–	–
23	**ACRES†**	–	–	–	–	–	**R**	–	–	–	–	–	–	–	–	–
24	**EMA†**	–	–	–	–	–	–	–	–	–	**r** (1)	–	–	–	–	–
25	**Will†**	–	–	–	–	–	**R**	–	–	–	–	–	–	–	–	–

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Table 5.3: (*Continued.*) Theories Used for Emotion Representation © 2022 IEEE

		Iz.	Ek.	Plu.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S&K	O&JL	Slo.	Dam.	LD
26	**ELSA†**	–	–	–	–	–	–	–	**R**	–	–	–	–	–	–	–
27	**GAMA-E**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
28	**Émile†**	–	–	–	–	–	–	–	–	–	**r** (1)	–	–	–	–	–
29	**EMOTION**	–	–	–	–	–	–	–	–	–	**r** (11)[3]	–	–	–	–	–
30	**Hum-DPM-E†**	–	–	–	–	–	–	–	**r**	–	–	–	–	–	–	–
31	**JBdiEmo†**	–	–	–	–	–	–	–	–	–	**r**[4]	–	–	–	–	–
32	**DETT†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
33	**EP-BDI**	–	–	–	–	–	–	–	–	–	**r**[1]	–	–	–	–	–
34	**Micro-Crowd†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
35	**Puppet**	–	**R**	–	–	–	–	–	–	–	**R**	–	–	–	–	–
36	**CBI†**	–	–	–	–	–	–	**R**	–	–	–	–	–	–	–	–
37	**FAtiMA†**	–	–	–	–	–	–	–	–	–	**r** (24, 67)	–	–	–	–	–
38	**TARDIS**	–	–	–	–	**r** (41, 59)	–	–	–	–	**r**	–	–	–	–	–
39	**PUMA-GOTCHI†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
40	**Greta**	–	**r**	–	–	–	–	–	–	–	**r**	–	–	–	–	–
41	**ALMA**	–	–	–	–	**R**	–	–	–	–	**r**	–	–	–	–	–
42	**Eva**	–	–	–	–	**r** (41)	–	–	–	–	**r**[1]	–	–	–	–	–
43	**PPAD-Algo**	–	–	–	–	**R**	–	–	–	–	**r** (41)	–	–	–	–	–
44	**Peedy**	–	–	–	**R**	–	–	–	–	–	–	–	–	–	–	–
45	**ERDAMS**	–	–	–	–	–	–	–	–	–	**R**	–	–	–	–	–
46	**TEATIME**	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–	–
47	**MMT†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
48	**Presence**	–	–	–	–	–	–	–	–	–	**R**	–	–	–	–	–

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Table 5.3: (*Continued.*) Theories Used for Emotion Representation © 2022 IEEE

		Iz.	Ek.	Plu.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S&K	O&JL	Slo.	Dam.	LD
49	**POMDP-CA†**	–	–	–	–	–	–	–	–	**R**	–	–	–	–	–	–
50	**iPhonoid**	–	–	–	–	**r**	–	–	–	–	–	–	–	–	–	–
51	**EEGS†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
52	**PWE-I**	–	–	**R**	–	–	–	–	–	–	–	–	–	–	–	–
53	**Kismet**	**R**	**R**	**R**	**R**[5]	–	–	–	–	–	–	–	–	–	–	–
54	**R-Cept**	–	**r**	–	–	–	–	–	–	–	–	–	–	–	–	–
55	**GRACE†**	–	–	–	–	–	–	–	**r**	–	**r**	–	–	–	–	–
56	**TAME**	–	**R**	–	–	–	–	–	–	–	–	–	–	–	–	–
57	**AEE**	–	**r**	–	–	–	–	–	–	–	–	–	–	–	–	–
58	**FeelMe**	–	–	–	–	**R**	–	–	–	–	–	–	–	–	–	–
59	**SocioEmo**	–	–	–	–	**r** (41)	–	–	–	–	**R**[1] (12)	–	–	–	–	–
60	**The Soul**	–	–	–	–	**R**	–	–	–	–	**r** (41)	–	–	–	–	–
61	**GAMYGDALA**	–	–	–	–	**R**	–	–	–	–	**R**	–	–	–	–	–
62	**MobSim**	–	–	–	–	**R**	–	–	–	–	**R** (41)	–	–	–	–	–
63	**APF**	–	–	–	–	–	–	–	–	–	**r**[4] (59)	–	–	–	–	–
64	**MEXICA**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
65	**NPE**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–
66	**Em/Oz**	–	–	–	–	–	–	–	–	–	**R**	–	–	–	–	–
67	**S3A†**	–	–	–	–	–	–	–	–	–	**r**	–	–	–	–	–

R: *Reasons for choosing the theory are clear;* **r**: *Reasons are unclear; (#): System borrowed from/is influenced by System #*

† *Used as a consequence of theories chosen for emotion elicitation (Section 5.3.2).*

[1] *Based on (Ortony, 2002, p. 193), a simplified model developed by Ortony for believable "artifacts" (Kasap et al., 2009, p. 23; Salichs and Malfaz, 2012, p. 62; Ochs et al., 2009, p. 285).*

[2] *Not yet implemented (Laird and Marinier III, 2012, p. 271; Franklin et al., 2014, p. 26).*

[3] *Builds on (Egges et al., 2004, p. 2), a successor of GVH (11).*

[4] *Uses the OCCr model (Korečko et al., 2016, p. 195, 197; Klinkert and Clark, 2021, p. 702) a reinterpretation of the OCC model that aims to clarify the model's logical structure and address ambiguities (Steunebrink et al., 2009, p. 1).*

[5] *Also uses a* `stance` *dimension to measure the approachability of a stimulus (Breazeal, 2003, p. 133).*

Table 5.4: Theories Used for Emotion Elicitation © 2022 IEEE

		Iz.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S&K	O&JL	Slo.	Dam.	LD
1	**AffectR**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
2	**Cathexis**	e	–	–	–	–	–	–	–	–	–	–	**E**	**E**
3	**EmMod**	–	–	–	–	–	–	–	**e**	–	–	–	**e**	–
4	**FLAME**	–	–	–	–	–	–	**e**	**e**	–	–	–	–	**e**
5	**SCREAM**	–	–	–	–	–	–	–	**e** (66)	–	–	–	–	–
6	**MAMID**	–	**e**	–	–	–	**e**	–	–	**e**	–	–	–	–
7	**TABASCO**	–	–	–	**e**	–	**e**	–	–	**e**	–	–	–	–
8	**WASABI**	–	–	–	–	–	–	–	**e**	–	–	**e**	**E**	**E**
9	**Maggie**	–	–	–	–	**E**	–	–	**E**[1]	–	–	–	–	–
10	**AKR‡**	–	–	–	**e**	–	**e**	**e**	**e**	–	–	–	–	–
11	**GVH**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
12	**ParleE**	–	–	–	–	–	–	**E**	**E** (4, 66)	–	**e**	–	–	–
13	**IM-PMEB**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
14	**GenIA[3]**	–	–	–	–	–	–	–	**e** (24, 41, 45)	–	–	–	–	–
15	**InFra**	–	–	–	–	–	**e**	–	**e** (4)	–	–	–	–	–
16	**FAtiMA-M**	–	–	–	–	**e** (37)	**E**	–	**E** (37)	–	–	–	–	–
17	**HybridC**	–	–	–	–	–	**E**	**E**	**E**	–	–	–	–	–
18	**GEmA**	–	–	–	–	–	–	–	**E**	–	–	–	–	–
20	**Soar**	–	–	–	–	–	**e**[2]	–	–	–	–	–	–	–
21	**LIDA**	–	–	–	–	–	**e**[2]	–	–	–	–	–	–	–
22	**CLARION**	–	–	–	–	–	**e**	–	–	–	–	–	–	–
23	**ACRES**	–	–	–	**E**	–	–	–	–	–	–	–	–	–
24	**EMA**	–	–	–	–	**e**	–	–	**e** (1, 28)	–	–	–	–	–
25	**Will**	–	–	–	**E**	–	–	–	–	–	–	–	–	–
26	**ELSA**	–	–	–	–	–	**E**	–	–	–	–	–	–	–

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Table 5.4: (*Continued.*) Theories Used for Emotion Elicitation © 2022 IEEE

		Iz.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S&K	O&JL	Slo.	Dam.	LD
27	**GAMA-E**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
28	**Émile**	–	–	–	–	**E**[2]	–	–	**e** (1, 66)	–	**e**	**e**	–	–
29	**EMOTION**	–	–	–	–	–	–	–	**e** (11)[3]	–	–	–	–	–
30	**HumDPM-E**	–	–	–	–	–	**e**	–	–	–	–	–	–	–
31	**JBdiEmo**	–	–	–	–	–	–	–	**e**[4]	–	–	–	–	–
32	**DETT**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
33	**EP-BDI**	–	–	–	–	–	–	–	**e**[1]	–	–	–	–	–
34	**MicroCrowd**	–	–	–	–	–	–	–	**E**	–	–	–	–	–
35	**Puppet**	–	–	–	–	–	–	–	**E**	–	–	–	–	–
36	**CBI**	–	–	–	–	**E**	–	–	–	–	–	–	–	–
37	**FAtiMA**	–	**e**	–	–	**e** (24)	–	–	**e** (24, 67)	–	–	–	–	–
38	**TARDIS**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
39	**PUMAGOTCHI**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
40	**Greta‡**	–	–	–	–	–	–	–	**e**	–	**e**	–	–	–
41	**ALMA**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
42	**Eva**	–	–	–	–	–	–	–	**e**[1]	–	–	–	–	–
43	**PPAD-Algo**	–	–	**E**	–	–	–	–	**e** (41)	–	–	–	–	–
45	**ERDAMS**	–	–	–	–	–	**E**	**e**	**E** (1, 66)	–	–	–	–	–
46	**TEATIME‡**	–	–	–	**E**	–	–	**E**	–	–	–	–	–	–
47	**MMT**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
48	**Presence**	–	–	–	**e**	–	–	–	**E**	–	–	**e**	**e**	–
49	**POMDP-CA**	–	–	–	–	–	–	**E**	–	–	–	–	–	–
50	**iPhonoid**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
51	**EEGS**	–	–	–	–	–	**e**	–	**e**	**E**	–	–	–	–
53	**Kismet**	–	–	–	–	–	–	–	–	–	–	–	**E**	–

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Table 5.4: (*Continued.*) Theories Used for Emotion Elicitation © 2022 IEEE

		Iz.	V-A	PAD	Frj.	Laz.	Sch.	Ros.	OCC	S&K	O&JL	Slo.	Dam.	LD
55	**GRACE**	–	–	–	–	–	**e**	–	**e**	–	–	–	–	–
58	**FeelMe**	–	–	–	–	–	**e**	–	–	**e**	–	–	–	–
59	**SocioEmo**	–	–	–	–	–	–	–	**E** (28, 66)	–	–	–	–	–
60	**The Soul‡**	–	–	–	–	–	–	–	**e** (41)	–	–	–	–	–
61	**GAMYGDALA**	–	–	–	–	–	–	–	**E** (66)	–	–	–	–	–
62	**MobSim**	–	–	–	–	–	–	–	**E**[5]	–	–	–	–	–
63	**APF**	–	–	–	–	–	–	–	**e**[4] (59)	–	–	–	–	–
64	**MEXICA**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
65	**NPE**	–	–	–	–	–	–	–	**e**	–	–	–	–	–
66	**Em/Oz**	–	–	–	–	–	–	–	**E**	–	–	–	–	–
67	**S3A**	–	–	–	**E**	–	–	–	**e**	–	–	–	–	–

E: *Reasons for choosing the theory are clear;* **e**: *Reasons are unclear;* (#): *System borrowed from/is influenced by System #*

‡ *Used as a consequence of theories chosen for emotion representation (Section 5.3.1).*

[1] *Based on (Ortony, 2002, p. 193), a simplified model developed by Ortony for believable "artifacts" (Kasap et al., 2009, p. 23; Salichs and Malfaz, 2012, p. 62; Ochs et al., 2009, p. 285).*

[2] *Not yet implemented (Laird and Marinier III, 2012, p. 271; Franklin et al., 2014, p. 26; Gratch, 2000, p. 331).*

[3] *Builds on (Egges et al., 2004, p. 2), a successor of GVH (11).*

[4] *Uses the OCCr model (Korečko et al., 2016, p. 195, 197) a reinterpretation of the OCC model that aims to clarify the model's logical structure and address ambiguities (Steunebrink et al., 2009, p. 1).*

[5] *Process derived from (Bartneck, 2002).*

Table 5.5: Theories Used for Emotion Expression © 2022 IEEE

		Iz.	Ek.	Plu.	V-A	PAD	Frj.	Laz.	Ros.	OCC	S&K	Slo.	Dam.	LD
1	**AffectR**	–	–	–	–	–	–	–	–	x[1]	–	–	–	–
2	**Cathexis**	–	–	–	–	–	–	–	–	–	–	–	x	–
3	**EmMod**	–	x	–	–	–	–	–	–	–	–	–	x	–
5	**SCREAM**	–	x	–	–	–	–	–	–	x[2]	–	–	–	–
7	**TABASCO**	–	–	–	–	–	X	x	–	–	–	–	–	–
8	**WASABI**	–	X	–	–	–	–	–	–	–	–	–	–	–
10	**AKR**	–	x	–	–	–	x	–	–	–	–	–	–	–
11	**GVH**	–	X	–	–	–	–	–	–	–	–	–	–	–
12	**ParleE**	X	X	–	–	–	–	–	–	–	–	–	–	–
14	**GenIA**[3]	–	–	–	–	–	–	x (24)	–	x[2]	–	–	–	–
15	**InFra**	–	–	–	–	–	–	–	–	–	–	–	–	x
20	**Soar**	–	–	–	X	–	–	–	–	–	–	–	–	–
22	**CLARION**	–	–	–	–	–	–	x	–	–	–	–	–	–
23	**ACRES**	–	–	–	–	–	X	–	–	–	–	–	–	–
24	**EMA**	–	–	–	–	–	x	x	–	–	x	–	–	–
25	**Will**	–	–	–	–	–	X	–	–	–	–	–	–	–
28	**Émile**	–	–	–	–	–	–	–	–	–	–	–	x	–
35	**Puppet**	–	X	–	–	–	–	–	–	–	–	–	–	–
36	**CBI**	–	–	–	–	–	–	X	–	–	–	–	–	–
37	**FAtiMA**	–	–	–	–	–	–	x (36)	–	–	–	x	–	–
40	**Greta**	–	X	–	–	–	–	–	–	–	–	–	–	–
46	**TEATIME**	–	–	–	–	–	–	–	X	–	–	–	–	–

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Table 5.5: (*Continued.*) Theories Used for Emotion Expression © 2022 IEEE

		Iz.	Ek.	Plu.	V-A	PAD	Frj.	Laz.	Ros.	OCC	S&K	Slo.	Dam.	LD
48	**Presence**	–	–	–	**X**	–	–	–	–	**X**	–	–	–	–
50	**iPhonoid**	–	x	–	–	–	–	–	–	–	–	–	–	–
53	**Kismet**	**X**	x	**X**	**X**[3]	–	–	–	–	–	–	–	–	–
55	**GRACE**	–	–	–	–	–	–	x	–	–	–	–	–	–
60	**The Soul**	–	**X**	–	–	**X**	–	–	–	–	–	–	–	–
66	**Em/Oz**	–	–	–	–	–	–	–	–	**X**[1]	–	–	–	–
67	**S3A**	–	–	–	–	–	–	–	–	**X** (66)	–	–	–	–

X: *Reasons for choosing the theory are clear;* **x**: *Reasons are unclear;* (#): *System borrowed from/is influenced by System #*

[1] *Based on an unpublished work which AffectR describes (Elliott, 1992, p. 50) and Em/Oz duplicates and expands on (Reilly, 1996, pp. 104).*

[2] *Based on (Ortony, 2002, p. 193, 198), a simplified model developed by Ortony for believable "artifacts" (Prendinger et al., 2004, p. 234; Alfonso et al., 2017, p. 5:5).*

[3] *Also uses a* `stance` *dimension to measure the approachability of a stimulus (Breazeal, 2003, p. 133, 140).*

Eleven of the CMEs using PAD pair it with OCC for emotion representation. GAMYGDALA (61) starts with OCC because it is "...a well-known and accepted theory of emotions, it is a componential model of emotion that fits the needs of a computational framework, components are generic enough to allow for a wide set of emotions, it accounts for both internal emotions and social relationships which in games are quite important, and most importantly many computational models have been built on it", combining it with PAD because it "...complements the OCC model..." (Popescu et al., 2014, p. 33, 37). Eight CMEs reference ALMA (41) for the combination of OCC and PAD (Shvo et al., 2019, p. 68; Alfonso et al., 2017, p. 5:17–5:18; Jones and Sabouret, 2013, p. 5; Kasap et al., 2009, p. 24; Zhang et al., 2016, p. 216–217, 224; Ochs et al., 2009, p. 289; Bidarra et al., 2010, p. 340; Durupınar et al., 2016, p. 2146–2148). ALMA maps OCC emotion categories to points in PAD space to afford interactions with other types of affect (Gebhard, 2005, p. 31), and MobSim (62) found that using PAD as an intermediary representation between elicitation and expression prevents "erratic behaviours" due to rapid changes in emotion intensity (Durupınar et al., 2016, p. 2151–2152). APF (63) does *not* reference PAD to accompany its use of OCC, but *does* create a dimensional space using Multidimensional Scaling (MDS) (Klinkert and Clark, 2021, p. 698–699).

Representing emotions with OCC *does* appear to be connected to how CMEs elicit emotions, perhaps by limiting which categories a CME includes due to the needs of the domain (i.e. Maggie (9) (Salichs and Malfaz, 2012, p. 62), GAMA-E (27) (Bourgais et al., 2017, p. 94), EMOTION (29) (Mehdi et al., 2004, p. 2), TARDIS (38) (Jones and Sabouret, 2013, p. 2), MMT (47) (Alepis and Virvou, 2011, p. 9844), GRACE (55) (Dang and Duhaut, 2009, p. 137–139), NPE (65) (Shirvani and Ware, 2020, p. 118)), but there might be other reasons too. For example, Puppet (35) and Presence (48) use OCC because it is "...readily amenable to the intentional stance, and so ideally suited to the task of creating concrete representations/models of...emotions with which to enhance the illusion of believability in computer characters." (André et al., 2000, p. 151). WASABI (8) requires an emotion representation that depends on cognition ("secondary emotions") because it "...affords a more complex interconnection of the agent's emotion dynamics and its cognitive reasoning abilities" (Becker-Asano, 2008, p. 93). It uses OCC for this, choosing a subset of emotion categories that rely on past events and future expectations (Becker-Asano, 2008, p. 87, 100). WASABI makes a clear distinction between cognitive and non-cognitive-dependent emotions, choosing simpler emotion representations from other theories, even though they are defined in OCC: *Fear* as proposed by LD due to its work on animal brain studies (Becker-Asano, 2008, p. 47, 87); and Plu. to define *Anger* as a reactive response tendency (Becker-Asano, 2008, p. 85).

CMEs also use OCC to represent emotion because it: distinguishes emotions about the self and about others ("empathetic emotions") necessary for some conversational agents like Greta (40) (de Rosis et al., 2003, p. 94, 111)[6], Eva (42) (Kasap et al., 2009, p. 21, 23), and ERDAMS (45) (Ochs et al., 2012, p. 412), social simulations like GAMA-E (27) (Bourgais et al., 2017, p. 94), EP-BDI (33) (Zoumpoulaki et al., 2010, p. 425–426), and MicroCrowd (34) (Lhommet et al., 2011, p. 91), and narrative planners like MEXICA (64) (y Pérez, 2007, p. 90) and NPE (65) (Shirvani and Ware, 2020, p. 118); represents emotion as both categories and classes of triggering conditions (i.e. PUMAGOTCHI (39) (Laureano-Cruces and Rodriguez-Garcia, 2012, p. 64), SocioEmo (59) (Ochs et al., 2009, p. 282, 285)); and its hierarchical organization of emotion categories (APF (63) (Klinkert and Clark, 2021, p. 703), Em/Oz (66) (Reilly, 1996, p. 73)).

Six CMEs that aim to express emotions via facial expressions (see Section 5.3.3) chose an emotion representation to ensure a smooth connection between them. Ek. emotion categories appear for this, as in TAME (56) "...in part because these basic emotions have universal, well-defined facial expressions, are straightforwardly elicited, and would be expected, perhaps subconsciously,

[6] Inferred from Greta's example (de Rosis et al., 2003, p. 84).

on a humanoid's face, as appearance does affect expectations" (Moshkina et al., 2011, p. 211) and AEE (57) Wilson (2000). It is possible to generate expressions from affective dimensions, but these might be more difficult than distinct categories such as those provided by Ek. (Kirby et al., 2010, p. 324). GVH (11) uses the OCC categories to define emotions, but reorganizes and expands them into the six categories defined by Ek. which "...enables us to handle relatively less number of emotional states still retaining completeness necessary for expressive conversation" (Kshirsagar and Magnenat-Thalmann, 2002, p. 108–109). Puppet (35) chose a subset of OCC emotions to match Ek. facial expressions due to evidence of the associated emotions' universality and distinctive facial expressions which children can recognize (André et al., 2000, p. 155), whereas Greta (40) also cites Ek. and OCC for their representation but adds facial expressions to match the possible emotion representation states (de Rosis et al., 2003, p. 91). Representations based on categories from Ek., Iz., Plu., and/or O & JL have also been cited for reasons such as: evidence of universality and facial expressions (Velásquez, 1998, p. 71); "...they are easy to explain and understand" (Ushida et al., 1998, p. 65); their association with evolutionary, cross-species, and social functions (Breazeal, 2003, p. 129); and their connection to emotions that are hard-wired and do not require cognitive processing ("primary emotions" in WASABI (8) (Becker-Asano, 2008, p. 84, 100), HybridC (17) (Jain and Asawa, 2019, p. 63–64)).

Three CMEs appear to choose their emotion representation before their elicitation methods because they align with the CMEs' goals. Peedy (44) represents emotion with V-A because it "...corresponds more directly to the universal responses...that people have to the events that affect them" (Ball and Breese, 2000, p. 199–200). TEATIME (46) aims to strongly connect emotion to speech acts, stating that "...emotions cannot be reduced to a label or a vector: these are only a description of the state of the individual", and therefore focuses on "...action tendency...defined as the will to establish, modify, or maintain a particular relationship between the person and a stimulus" as defined by Frj. (Yacoubi and Sabouret, 2018, p. 144, 145–150). This led it to draw from both Frj. and Ros., which emphasize action tendencies in their theories, to represent emotion. In the case of AKR (10), part of its goal is to define a taxonomy of emotion and other types of affect (Lisetti and Gmytrasiewicz, 2002, p. 594, 596–597, 599–600, 606). This lead it to pull from a range of emotion theories to represent emotion: Ek., presumably to connect to facial expressions; Sch., Ros., and OCC for appraisal variables, although Ros. is presumably for representing *Surprise*; and Frj. for action tendencies.

5.3.2 Emotion Elicitation

Three CMEs appear to choose theories for emotion elicitation based on their choice for representation (marked with a ‡ in Table 5.4) and six others elicit emotion independently of a theory with methods such as affine mapping and fuzzy inference mechanisms (SOM (19) (Yanaru et al., 1997, p. 219, 244)), Bayesian Networks (Peedy (44) (Ball and Breese, 2000, p. 204)), hard-coded values (R-Cept (54) (Kirby et al., 2010, p. 324)), and/or signal processing-based approaches (TAME (56) (Moshkina et al., 2011, p. 211), PWE-I (52) (Qi et al., 2019, p. 211–213), AEE (57) (Wilson, 2000)). The rest ground elicitation methods directly in emotion theories. Methods can be broadly grouped into cognitive and non-cognitive elicitation and a CME need not be limited to one type.

None of the CMEs implement non-cognitive elicitation alone, instead realizing it as a mechanism or process that complements cognitive elicitation. One CME, Kismet (53), uses Dam. alone to create a "mixed" elicitation system (Breazeal, 2003, p. 133–134). Six CMEs use multiple, coexisting theories for this purpose. TABASCO (7) references Sch. and S & K to create a multi-layer appraisal system which has different appraisal mechanisms for different types of information (Petta, 2002, p. 265–266, 268–269). It also applies this to a Frj.-based monitor which ensures that actions influence appraisals. The five remaining CMEs reference at least one of Slo., Dam., and LD to define a "mixed" elicitation system. Presence (48) differentiates cognitive and non-cognitive emotion processes using Slo. and Dam. so that it aligns with recent Affective Computing research (André et al., 2000, p. 160–161). It implements non-cognitive emotions using heuristics and combines Frj.'s process with OCC in a BDI model for cognitive emotion elicitation. FLAME (4) uses LD for learning non-cognitive, conditioned behaviour and Ros. and OCC for cognitive appraisal (El-Nasr et al., 2000, p. 227–228, 237–238). Cathexis (2) also uses LD for non-cognitive behaviour, this time combined with Dam. for cognitive, memory-driven emotion elicitation (Velásquez, 1998, p. 71–72). It references Iz. to differentiate between cognitive and non-cognitive emotion elicitors.

WASABI (8) references both OCC and Dam. for the division of its cognitive layer into a reactive and reasoning layer to differentiate between cognitive and non-cognitive elicitation (Becker-Asano, 2008, p. 50, 54, 84, 87, 90–92, 97–98, 102). WASABI drew assumptions about Dam.'s connection between memories and cognitive elicitation such that it could be formalized. In a separate emotion module, it uses Slo. to define a dynamics system that accepts valenced pulses as inputs and creates an "alarm" signal that is translated into PAD as a primary emotion encoded by *pleasure* and *arousal* values. WASABI uses OCC for cognitive emotion elicitation because it requires high-level reasoning, but manually codes their intensity values (Becker-Asano, 2008, p. 95, 100).

The other 51 CMEs choose to focus exclusively on cognitive elicitation. Sch. appears in the three cognitive architectures (Laird and Marinier III, 2012, p. 272–273, 277–278; Sun et al., 2016, p. 9, 11), chosen—at least in part—for its focus on the cognitive contents of emotion (Franklin et al., 2014, p. 26–27). ELSA (26) chose Sch. due to its dynamic systems view and focus on emotion as emergent phenomena of time-dependent, componential changes rather than events with specific labels (Meuleman, 2015, p. 99–102, 143). HumDPM-E (30) uses Sch. to generate emotion patterns such that each possible emotion type is assigned a value (Aydt et al., 2011, p. 74, 76). This allows HumDPM-E to define different agents based on their "susceptibility" to different emotions. MAMID (6) uses Sch., in combination with S & K, for its domain independent appraisal variables, multiple levels of resolution, multi-stage appraisals, and—potentially—because they account for some effects of emotion on cognition (Hudlicka, 2019, p. 134, 136). MAMID also draws from V-A for part of its emotion intensity specification and to serve as another perspective on the emotion state. FeelMe (58) is also based on a combination of Sch. and S & K to enable a scalable design with modular components (Broekens and DeGroot, 2004, p. 210–211, 213). It shows that this structure can be combined with dimensions from other theories, such as PAD. Although it also draws from Sch. for emotion elicitation, EEGS (51) creates a parallel appraisal process as in S & K: "The rationale behind this is that human brain is multi-processing and several evaluations occur simultaneously. This is why EEGS uses multi-threading approach to represent the true mechanism of emotion generation that occurs in humans" (Ojha and Williams, 2016, p. 236). FAtiMA-M (16), although it implements OCC as its default, generalized its design requirements so that it could represent Sch., "...one of the most complex Appraisal Theories" (Dias et al., 2014, p. 45).

Four CMEs choose theories because they provide functionality central to their design, such as CBI's (36) use of Laz. for its integration of coping in appraisal (Marsella et al., 2000, p. 301–302, 306). ACRES (23) and Will (25) chose their underlying theory—Frj.—because their aim is to implement that theory as a computational system (Frijda and Swagerman, 1987, p. 247; Moffat, 1997, p. 138, 151–152). POMDP-CA (49) uses Ros., not for its functionality, but because "[i]t has concrete definitions of criteria of cognitive appraisal and a structure that is amenable to computational implementation" (Kim and Kwon, 2010, p. 268).

Twenty-six CMEs use OCC alone to define rules and/or conditions for emotion elicitation, both independently of an architecture (Prendinger et al., 2004, p. 230; Kshirsagar and Magnenat-Thalmann, 2002, p. 109, 112; Shvo et al., 2019, p. 68; Kazemifard et al., 2011; Mehdi et al., 2004, p. 4–5; Jones and Sabouret, 2013, p. 4; Laureano-Cruces and Rodriguez-Garcia, 2012, p. 63; Gebhard, 2005, p. 33; Kasap et al., 2009, p. 23; Alepis and Virvou, 2011, p. 9841; Masuyama et al., 2018, p. 217, 220; Popescu et al., 2014, p. 37–39; Klinkert and Clark, 2021, p. 698, 702; y Pérez, 2007, p. 90; Shirvani and Ware, 2020, p. 117, 121) or integrated into a Belief-Desire-Intention (BDI) design (Alfonso et al., 2017, p. 5:2, 5:4–5:5, 5:12, 5:17–5:18; Bourgais et al., 2017, p. 92; van Dyke Parunak et al., 2006, p. 993–994; Zoumpoulaki et al., 2010, p. 424; Lhommet et al., 2011, p. 90; André et al., 2000, p. 153–154; de Rosis et al., 2003, p. 88, 94–95, 97; Ochs et al., 2012, p. 417). It is not always clear why CMEs use OCC, but at least four reference its computational tractability (Duy Bui, 2004, p. 135–136; Jain and Asawa, 2019, p. 66; Lhommet et al., 2011, p. 89) and/or prevalence in Affective Computing (Popescu et al., 2014, p. 37). Em/Oz (66) is explicit in its reasoning, stating that it chose OCC because it was "...designed to be implemented computationally...reasonably simple to understand...", and because Em/Oz's users "...will not have much formal psychology training..." (Reilly, 1996, p. 28, 52–54, 59–60). The emphasis on computational tractability and intuitiveness motivated other versions of OCC (e.g. Ortony (2002)) which appear in CMEs (Salichs and Malfaz, 2012, p. 62; Korečko et al., 2016, p. 195, 197). MobSim (62) claims that OCC allows one to "...formally define the rules that determine an agent's evaluation of its surrounding events and relationships with other agents, [providing] a suitable basis for crowd simulation applications" and uses Bartneck (2002) to aid in its mechanization of OCC (Durupınar et al., 2016, p. 2149–2150). SocioEmo (59) uses the OCC version in Ortony (2002), partially because "[g]ame developers are usually not specialists of AI [Artificial Intelligence] or cognitive psychology. This guided us toward models which are relatively simple to use" (Ochs et al., 2009, p. 282, 285). GEmA (18) uses OCC for "...events and actions assessment [because] it includes comprehensive local and global variables to compute intensity of emotions and methods for [assessing] events and actions." (Kazemifard et al., 2011, p. 2642). AffectR (1) is less clear, but its focus on *reasoning* about an agent's emotion might be the motivation (Elliott, 1992, p. 27, 30). Both AffectR and Em/Oz have influenced later CMEs, such as ParleE (12) (Duy Bui, 2004, p. 117–125), EMA (24) (Gratch and Marsella, 2004, p. 282–283, 285), Émile (28) (Gratch, 2000, p. 326–329), and ERDAMS (45) (Ochs et al., 2012, p. 421–422).

Fifteen CMEs also use OCC for emotion elicitation but combine it with other theories for their unique strengths, such as:

- Emotion intensity functions based on a PAD vector space (PPAD-Algo (43) (Zhang et al., 2016, p. 217, 223–224)), single dimensions like *arousal* (FAtiMA (37) (Dias and Paiva, 2005, p. 131)), and explicit plan representations in Slo. and/or O & JL (ParleE (12) (Duy Bui, 2004, p. 117–125), Émile (28) (Gratch, 2000, p. 328))

- Ros. for defining eliciting conditions for *Surprise* (ParleE (12) (Duy Bui, 2004, p. 118–119, 135–136), HybridC (17) (Jain and Asawa, 2019, p. 66)) or *Anger* (ERDAMS (45 (Ochs et al., 2012, p. 417)))

- Appraisal variables from Sch. (InFra (15) (Castellanos et al., 2018, p. 30, 32), HybridC (17) (Jain and Asawa, 2019, p. 66), ERDAMS (45) (Ochs et al., 2012, p. 416), EEGS (51) (Ojha et al., 2018, p. 214–216), GRACE (55) (Dang and Duhaut, 2009, p. 137–138))

- Elicitation process from Frj. because it "...complements the OCC model" (S3A (67) (Martinho et al., 2000, p. 48))

- Laz. process (FAtiMA-M (16) (Dias et al., 2014, p. 44, 46–48), EMA (24) (Gratch and Marsella, 2004, p. 272)), coping (Émile (28) (Gratch, 2000, p. 331), FAtiMA (37) (Dias and Paiva, 2005, p. 130–134)), or emotion themes (Maggie (9) (Salichs and Malfaz, 2012, p. 60)) which are integrated into emotion elicitation
- Dam. to define a deliberative architecture layer that relies on cognition (EmMod (3) (Ushida et al., 1998, p. 63))
- O & JL to frame cognition as a knowledge transformation process to drive cognitive appraisals (Greta (40) (de Rosis et al., 2003, p. 94))

5.3.3 Emotion Expression

Twenty-nine emotion-generating CMEs also specify how the emotion state is expressed. Two CMEs draw from emotion theories to define an interface between internal emotion states and external behaviour systems (e.g. InFra (15) uses LD to define an emotion-to-expression interface (Castellanos et al., 2018, p. 27)) and Presence (48) uses OCC emotion types and V-A values to annotate actions such as speech and body gesture generation (André et al., 2000, p. 161–162)). One CME relates their potential emotions to the functions they serve (Kismet (53) references Iz. and Plu. for this (Breazeal, 2003, p. 129)), but eleven reference action tendencies—"...readiness for different actions having the same intent" and that "...account for behaviour flexibility" (Frijda, 1986, p. 70–71).

CMEs use four emotion theories to define action tendencies (e.g. Laz. in FAtiMA (37) (Dias and Paiva, 2005, p. 131, 134), Ros. in TEATIME (46) (Yacoubi and Sabouret, 2018, p. 149–150)), the most commonly referenced ones being Frj. and OCC. AKR is unclear in its choice to use Frj. for this (Lisetti and Gmytrasiewicz, 2002, p. 596–597), whereas TABASCO (7)—which uses an underlying system that is "very close to the functionality" of Frj.—compares the action tendencies to "flexible programs" that allow behaviour variations and can be influenced by feedback processes (Petta, 2002, p. 267). ACRES (23) is an implementation of Frj. (Frijda and Swagerman, 1987, p. 247). With Will as ACRES's successor (Moffat, 1997, p. 138, 146), Frj.'s use in these two CMEs is unsurprising.

Two CMEs use a "simplified" version of OCC (Prendinger et al., 2004, p. 234; Alfonso et al., 2017, p. 5:5–5:6) that includes a hierarchy of response tendencies grouped by type (Ortony, 2002). The hierarchy might be a simplification of unpublished work intended for the full theory, which AffectR (1) and Em/Oz (66)—which S3A (67) builds on (Martinho et al., 2000, p. 52–53)—incorporate (Elliott, 1992, p. 50–53; Reilly, 1996, p. 86, 100, 104). The hierarchy elements are not uniquely associated with OCC emotion categories, so the hierarchy can be implemented to allow the categorization of display mechanisms—encouraging modular development—and assign the same behaviour to different tendencies, affording more control over emotional displays.

CMEs targeting specific domains typically specify what types of behaviours their CMEs produce. At least nine systems intended for face-to-face interactions with people use facial expressions to convey emotion. Ek. is often referenced for this. For example, GVH (11) is concerned with the facial representation of virtual humans and uses Ek.'s facial expression specification because they are "...recognized as universal by many facial expression and emotion researchers" (Kshirsagar and Magnenat-Thalmann, 2002, p. 108–109). Puppet (35) chose Ek. due to evidence of the associated emotions' universality and distinctive facial expressions that children can recognize (André et al., 2000, p. 155). ParleE (12) cites the universality of Ek. and Iz.'s given facial expressions, building a generation system on FACS (Duy Bui, 2004, p. 142–143, 146), which documents facial muscles with respect to expressions (Ekman et al., 2002). Although unclear, several other CMEs also seem to cite Ek. for its work on facial expressions (Becker-Asano, 2008, p. 84, 100; Ushida et al., 1998, p. 66; Lisetti and Gmytrasiewicz, 2002, p. 596–597[7]; Masuyama et al., 2017, p. 740), potentially in connection to FACS (de Rosis et al., 2003, p. 88–89, 91). Kismet (53) and The Soul (60) use Ek. to define points in dimensional models so that facial expressions can be procedurally generated (Breazeal, 2003, p. 140, 143; Bidarra et al., 2010, p. 338, 340–343). SCREAM (5) references Ek.'s rules for when emotions are outwardly displayed given social and interaction contexts ("display rules") to regulate when their CME can show their emotions (Prendinger et al., 2004, p. 231–232).

Specific effects of emotions on behaviour can also refer to the effects that emotions have on other processes within or directly connected to the CME. Cathexis (2), EmMod (3), and Émile (28) reference Dam. to specify how emotion influences decision-making and planning (Velásquez, 1998, p. 72; Ushida et al., 1998, p. 63; Gratch, 2000, p. 330). EMA (24) draws from Frj. and S & K to define attentional focus necessary for coping (Gratch and Marsella, 2004, p. 286, 297).

CMEs tend to use Laz. when coping itself is central to the CME's purpose (CBI (36) (Marsella et al., 2000, p. 302, 306)) whose design has been adopted by others (FAtiMA (37) (Dias and Paiva, 2005, p. 131, 134)), and because it can be implemented with a planner when viewed as a "planful process" (TABASCO (7) (Petta, 2002, p. 267)). EMA (24) and GRACE (55) are unclear in their reasons for choosing Laz. for coping (Gratch and Marsella, 2004, p. 272, 278; Dang and Duhaut, 2009, p. 136, 138). CLARION (22) uses Laz. for coping so that emotions can influence decision-making, goal management, and regulatory processes (Sun et al., 2016, p. 10, 12). GenIA^3 (14) is more modest in its use of Laz.-based coping, allowing it to return to a previous emotion state and/or modify the agent's beliefs (Alfonso et al., 2017, p. 5:5–5:6). Emotions can also influence: learning, such as in Soar's (20) use of V-A to define reward signals for reinforcement learning because the dimensions can be unified with appraisal theories (Laird and Marinier III, 2012, p. 279–280); and emotion-driven plan selection such as the use of Slo. in FAtiMA (37) (Dias and Paiva, 2005, p. 134).

5.4 Observations from the Survey

Surveying CMEs and the affective theories they use brought out some commonalities. We discuss some *use trends* for each theory and *psychologist influences*.

5.4.1 Use Trends

The CMEs use a variety of theories for different purposes (Table 5.6). It is not always clear why CMEs use particular theories. However, there are clear trends in *how* CMEs use affective theories. Even in CMEs without a documented choice rationale, these uses align with different aspects of the theories. This is indicative of their strengths, which tend to be similar within each perspective.

We use the broad categories of Lisetti and Hudlicka (2015)—*discrete*, *dimensional*, *appraisal*, and *neurophysiologic*—to organize emotion theories. Other ways are available, such as Scherer (2021, p. 280).

Discrete Theories

These appear when emotion "types" must be clearly distinguished. This reflects a strength of discrete theories, which build a small set of emotion categories that are theorized to have evolved via natural selection (Hudlicka, 2014a, p. 305). The discrete perspective is associated with the most empirical evidence of observed emotion effects to emotions (Hudlicka, 2014b, p. 10). However,

[7]This decision is inferred.

Table 5.6: Number of Uses of Emotion Theories © 2022 IEEE

	Emotion Representation	Emotion Elicitation	Emotion Expression	Total
OCC	42	46	6	94
Ek.	12	–	11	23
Sch.	8	15	–	23
PAD	13	1	1	15
Frj.	3	7	5	15
Laz.	1	6	7	14
Ros.	5	7	1	13
Dam.	1	5	3	9
V-A	3	2	3	8
Plu.	6	–	1	7
S & K	2	4	1	7
Iz.	3	1	2	6
O & JL	2	3	–	5
Slo.	1	3	1	5
LD	1	3	1	5

discrete theories do not give many details on emotion generation processes, so they are often combined with another theory or used in hand coded designs (e.g. R-Cept (54) (Kirby et al., 2010, p. 324)). This is due to a core assumption that emotions are innate, hard-wired features with dedicated neural circuitry which circumvents cognitive processing (Reisenzein et al., 2013, p. 250). There are differences in the definition of "primary" emotions but these are not mutually exclusive (Ortony, 2022, p. 2–3). However, they do change which emotions are considered "basic". Ek. and Iz. are part of the "biologically basic" view, which tend to focus on facial expressions as indicators of primality, whereas Plu. is part of the "elemental" view that seeks emotions that cannot be defined with other emotions (i.e. "mixtures" of other emotions). Still, identifying and labelling emotion categories helps delimit them, making it easier to talk about them both formally and informally (Broekens, 2021, p. 353; Scherer, 2021, p. 286).

Izard (Iz.) Although it does not tend to appear by itself, CMEs use Iz. to define facial expressions along side Ek. (e.g. ParleE (12)) and "mixed" emotions and the functional role of emotions with Plu. (e.g. HybridC (17) and Kismet (53)). This is likely because Iz. shares some of the same assumptions with them (Izard, 1977, p. 64–65, 83, 85–92, 97). However, there could be untapped potential in Iz., such as its differentiation between cognitive and non-cognitive emotion elicitors (e.g. Cathexis (2)).

Ekman (Ek.) This theory is common in CMEs that express emotions via facial expressions (Section 5.3.3), and often use Ek.'s emotion categories to ensure a one-to-one mapping from internal state to facial configuration. This aligns with Ek.'s focus (Ekman, 2007, p. 1) and the resulting FACS (Ekman et al., 2002), which breaks the face down into individual muscles and shows how they can combine into expressions. This makes Ek. a strong candidate, potentially "...the de facto standard for analysis and description of facial expressions, and serves as the foundation of...the synthesis of emotion expressions in virtual agents and robots." (Hudlicka, 2014b, p. 4).

Ek. could be combined with: Iz. (e.g. ParleE (12)), which shares similar views (Ekman, 2007, p. 3) and also has a system for identifying facial expressions (Izard, 1995); and O & JL (e.g. Cathexis (2)) as there is deliberate overlap in their "primary" emotion categories (Johnson-Laird and Oatley, 1992, p. 209, 217).

Plutchik (Plu.) Plu. appears most often when CMEs want to represent "mixed" emotions as combinations of emotion categories, which allows a CME to add "more" emotion types. This is unsurprising, as Plu. "...has one of the better developed theories of emotion mixes" (LeDoux, 1998, p. 113) and experiments have shown that laypeople tend to agree on the components of emotion "mixtures" (Plutchik, 1984, p. 204–205). Plu. identifies its "primary" emotions from evidence of a finite set of adaptive behaviours that aim to maintain internal homeostasis by acting on the environment (Plutchik, 1984, p. 203, 215). This effectively connects behaviours to action tendencies (Frijda, 1986, p. 72) and motivations (Scherer, 2010b, p. 13), which can help specify an emotion's function (e.g. WASABI (8), Kismet (53)).

Using self-reports on the meanings of emotion words, Plu. arranges its emotion categories on a circumplex (Plutchik, 1984, p. 204). This affords the use of arbitrarily chosen axes because they are only reference points (Plutchik, 1997, p. 13), which can serve as affective dimensions. The result is a 3D colour space analogy—with intensity as the third dimension—that is familiar to computer scientists (Becker-Asano, 2008, p. 21). There is also evidence that the circumplex can act as a common space for different types of affect (Plutchik, 1997, p. 30–31), which can help visualize affective dynamics using Plu.'s colour analogy (e.g. PWE-I (52)).

Dimensional Theories

These appear when CMEs need a simple and effective emotion model, as another perspective of emotion categories, and/or as a common space for modelling different affective phenomena and their interactions. The dimensional perspective's strength lies in its description of affect in a simple way—usually two or three dimensions (Lisetti and Hudlicka, 2015, p. 97)—where any affective phenomena, including emotions (Hudlicka, 2014b, p. 9), can be mapped. However, the dimensions can lose information about an emotion state if it has a higher information resolution than their dimensions can represent (Broekens, 2021, p. 353; Schaap and Bidarra, 2008, p. 172). This might not be appropriate for all CMEs. Dimensional theories focus on what kind of mental states emotions are, how to construct them, and how they fit into a general taxonomy of mental states (Reisenzein et al., 2013, p. 250). Consequently, they say little about how to generate emotions and what their effects are (Hudlicka, 2014b, p. 10), making them unsuitable for defining a complete computational model (Reisenzein et al., 2013, p. 250).

Valence-Arousal (V-A) The *valence* and *arousal* dimensions are the two most widely agreed on affective dimensions (Picard, 1997, p. 168) and are common in dimensional theories (Scherer, 2021, p. 280). They form a simple model that captures most affective phenomena, including aspects of emotion, in a numerical form that is computationally efficient and can be used in emotion intensity functions (e.g. MAMID (6)), as inputs to other CME processes (e.g. Soar (20)), and to coordinate emotion expression modalities (e.g. Presence (48)) and/or generation (e.g. Kismet (53)).

The ability to represent different kinds of affective information can make V-A useful for combining disparate information sources and external behaviour systems with a single representation, helping them work in concert so that the CME "...not only does the right thing, but also at the right time and in the right manner" (Breazeal, 2003, p. 151). However, two dimensions might not be enough to distinguish between every emotion a CME might need (Breazeal, 2003, p. 139–140). This implies that V-A is only ideal for CMEs with a set of emotions that are conceptually easy to distinguish both as internal representations and external expressions.

Pleasure-Arousal-Dominance Space (PAD) PAD is similar to V-A. Its *pleasure* dimension fills the same role as *valence*, and *arousal* is shared by both theories. The third dimension, *dominance*, distinguishes emotions such as *Anger* and *Fear* that are otherwise indistinguishable (i.e. have similar *valence* and *arousal* values) by quantifying how much control one believes they have (i.e. one tends to feel that they have low control when experiencing *Fear*, and high control in *Anger*) (Mehrabian, 1996b, p. 263–264). The empirical nature and ability to map emotions to three continuous dimensions might make PAD easy to understand using parallels to RGB colour space (Bidarra et al., 2010, p. 339) and "...suitable for a computational approach" (Broekens and DeGroot, 2004, p. 212).

As with V-A, CMEs often choose PAD to specify a simple model for representing emotion and its interactions with other types of affect (e.g. CMEs 41, 50, 58) that can also be used in numerical-based functions such as emotion intensity (e.g. PPAD-Algo (43)), affective dynamics (e.g. WASABI (8)), facial expression generation (e.g. The Soul (60)) and behaviour mediation (e.g. MobSim (62)), or as an alternate view of emotion categories (e.g. WASABI (8), GAMYGDALA (61)). PAD's pervasiveness in CMEs suggests its usefulness for creating a unified space for multiple types of affect and interfacing between theories. Caution is required as soundness depends on how rigorously concepts are matched.

Appraisal Theories

CMEs often use these theories (Lisetti and Hudlicka, 2015, p. 97; Gratch and Marsella, 2015, p. 55). This might be due to the theories' ability to comprehensively represent the complexity of emotion processes, receiving consistent empirical support for their hypothesized mechanisms (Scherer, 2021, p. 281–282). However, they are based on cognition and CMEs seeking to use these theories must be able to account for it (Broekens, 2021, p. 354).

Appraisal theories emphasize distinct components of emotion, including appraisal dimensions or variables (Lisetti and Hudlicka, 2015, p. 97). Analyzing stimuli for meaning and consequences with respect to an individual produce values for these variables (Reisenzein et al., 2013, p. 250; Smith and Ellsworth, 1985, p. 819), regardless of process sophistication (Gratch and Marsella, 2004, p. 273) and independent of biological processes (Arbib and Fellous, 2004, p. 559). Appraisals are continuous and change with the situation, the individual's behaviours, and their attempts to appraise the situation differently (Siemer and Reisenzein, 2007, p. 28). This can account for the personal, transactional, and temporal character of emotion with respect to a changing environment, applied coping strategies, and continuous appraisals. This makes appraisal theories of particular interest for decision-making, action selection, facial animations, and personality (Gratch and Marsella, 2004, p. 274). However, there is little empirical data associating individual appraisal variables to expressive behaviours or behavioural choices (Hudlicka, 2014b, p. 10).

Frijda (Frj.) CMEs tend to use Frj. to explicitly connect emotions to action tendencies (e.g. TEATIME (46)) and define an action-driven appraisal process (e.g. CMEs 7, 23, 25). This aligns with Frj.'s proposal that emotions—outputs of a continuous information processing system—are changes in action readiness (Frijda, 1986, p. 453, 466). "Action readiness" refers to motivational states which are associated with goals rather than actions or behaviours (Frijda and Zeelenberg, 2001, p. 143). Frj.'s description of action tendencies appears to transfer to designs that do not implement its appraisal process (e.g. AKR (10), Presence (48)), since many of the identified action tendencies are associated with an emotion label (Frijda, 1986, p. 87–90).

The conceptualization of emotion elicitation as an information processing system is a useful analogy and can provide the necessary mechanization framework for structure-oriented theories like Ros. (e.g. TEATIME (46)) and OCC (e.g. S3A (67)). It is also possible to abstract and apply different elements independent of the broader theory, such as implicit appraisal checks (e.g. TABASCO (7)), information filtering (e.g. S3A (67)), and mechanisms whose behaviour changes with the system state (e.g. EMA (24), TAME (56)).

Lazarus (Laz.) CMEs tend to use Laz. to specify coping behaviour, a deliberative process whereby the individual can suppress action tendencies and choose other strategies to influence the current situation (Smith and Lazarus, 1990, p. 628). The appearance of Laz. in this context is unsurprising, as coping plays a critical role in the theory (Lazarus, 1991, p. 39–40). Coping can be incorporated directly into the appraisal process as an influencing factor (e.g. CMEs 14, 24, 36) and to plan agent behaviours (e.g. CMEs 7, 22, 28, 55). FAtiMA (37) successfully paired Laz. with a separately defined component for quick, reactionary behaviours. The coping models in EMA (24), Émile (28), and CBI (36) have been particularly influential for other CMEs (Marsella et al., 2004, p. 353; Traum et al., 2005).

Laz. also describes a reappraisal process to explain the continuous and responsive nature of the emotion system (Lazarus, 1991, p. 134). This is directly tied to coping which can affect changes in an individual's interpretation of the environment. This concept has also appeared alone in CMEs that reprocess information after deliberative processes like coping (e.g. FAtiMA-M (16), FAtiMA (37)), which could result in different emotions compared to purely reactive systems.

Another feature of Laz. is its connection between relational themes and emotions (Lazarus, 1991, p. 122) which treats appraisal as a comprehensive unit rather than a set of individual dimensions. This emulates discrete categories, allowing CMEs to treat each emotion separately (e.g. Maggie (9)).

Scherer (Sch.) Sch. tends to appear where CMEs need multi-level and/or multi-stage appraisals (e.g. CMEs 6, 7, 58), allowing them to use different appraisal mechanisms and/or sources of variable complexity together. These features are inherent in Sch. (Scherer, 2001, p. 99, 103). Notably, the list of CMEs that use Sch. include the cognitive architectures (e.g. CMEs 20–22). This is likely because Sch. "...is the most elaborate appraisal theory, [and] doesn't necessarily make it the most suitable starting point for an affective computing researcher" (Gratch and Marsella, 2015, p. 58). FAtiMA-M (16) explicitly mentioned this complexity in their requirements to ensure that it could support Sch. if desired. ELSA (26) calls itself a neural network (NN), which makes it difficult to understand (Meuleman, 2015, p. 143–144), but aligns with NN-based illustrations of connections and activation patterns in Sch. (Scherer, 2001, p. 105).

CMEs can simplify Sch. by only using its appraisal variables (e.g. AKR (10))—sometimes combining them with variables from other theories like OCC (e.g. CMEs 15, 17, 45, 51)—or take inspiration from its process model to connect emotion generation to other subsystems (e.g. GRACE (55)). HumDPM-E (30) cleverly leverages Sch.'s "modal" emotions (Scherer, 2001, p. 113), allowing it to produce and store different emotions simultaneously. This suggests that some CMEs can comfortably use pieces of Sch. independent of the complete theory.

Roseman (Ros.) CMEs commonly use Ros. to define *Surprise* as an emotion because they use other theories—usually Sch. and/or OCC—that do not explicitly define it (e.g. 10, 12, 17). These unions appear to be sound. OCC agrees with Ros. that *unexpectedness* elicits *Surprise* (Ortony et al., 1988, p. 32), and Sch.'s *suddenness* variable in the novelty check appears to do a comparable evaluation (Scherer, 2001, p. 95). *Anger* is an emotion that Ros. shares with OCC, but it limits its scope to events caused by other agents, which a CME might find more helpful (e.g. ERDAMS (45)). Ros. can also help define action tendencies and map emotions to them (e.g. TEATIME (46), combined with Frj.).

Choosing Ros. is partially driven by its computational tractability. POMDP-CA (49) cites this, also noting that—of the two theories identified in Picard (1997) for cognitive appraisal—Ros. systematically built a model between appraisal variables and emotions from empirical studies (Roseman et al., 1996, p. 267–268) which makes it more plausible (Kim and Kwon, 2010, p. 265). The larger issue is that Ros. does not specify an emotion generation process. CMEs have compensated for this by using Markov Models (e.g. POMP-CA (49) (Kim and Kwon, 2010, p. 267)), fuzzy logic (e.g. FLAME (4) (El-Nasr et al., 2000, p. 227–228)), and combining Ros. with process-based theories like Sch. (e.g. HybridC (17)) and Frj. (e.g. TEATIME (46)).

Ortony, Clore, and Collins (OCC) This is the most used (Bourgais et al., 2017, p. 91; Dang and Duhaut, 2009, p. 136; Lim et al., 2012, p. 292) and widely accepted theory in affective computing (Mehdi et al., 2004, p. 1) despite cautioning that "...we view each emotion specification, or characterization, as a *proposal* rather than as an empirically established fact." (Ortony et al., 1988, p. 87–88) and not being as popular in psychology (Gratch and Marsella, 2004, p. 278).

The widespread use of OCC is partially due to its hierarchical emotion structure and event-driven eliciting conditions (Ortony et al., 1988, p. 18–19) (e.g. CMEs 5, 17, 18, 33, 34, 39, 47, 61–64) which feels familiar to computer scientists (Becker-Asano, 2008, p. 44; Gratch and Marsella, 2015, p. 57) and is more amenable to computation than other theories (Picard, 1997, p. 195; Broekens, 2021, p. 362; Hudlicka, 2014b, p. 8; Ortony et al., 1988, p. 2, 181–182). There has been significant strides towards refining (Bartneck, 2002), formalizing (Steunebrink et al., 2009; Steunebrink et al., 2012), and re-framing OCC for applications like agent believability (Ortony, 2002). A further benefit of OCC's comparison to a computational approach is that it can be easier to understand without a background in psychology (Ochs et al., 2009, p. 282; Reilly, 1996, p. 28). This might make it more "clear and convincing" (Masuyama et al., 2017, p. 741) than other appraisal theories.

OCC's structure also shows which variables contribute to an emotion's intensity, proposing that it is evaluated with a weighted function (Ortony et al., 1988, p. 69, 82). Unfortunately, it does not propose what those weights should be, nor the function's nature. CMEs have compensated by designing a separate tool for empirically deriving intensity parameters (e.g. ALMA (41) (Kipp et al., 2011, p. 209), The Soul (60)), translating OCC emotion categories to a dimensional space (e.g. PPAD-Algo (43)), defining their own functions or values from OCC variables with no clear empirical basis (e.g. CMEs 4, 8, 9, 18, 32, 42, 45, 47, 50, 51, 61, 64, 66, 67), or not concerning themselves with intensity at all (e.g. CMEs 1, 27, 39).

Strictly speaking, the weighted function used by these CMEs is not an intensity function. OCC proposes that a weighted combination of the variables leading to an emotion category along the hierarchy is an *emotion potential*—a higher potential means a higher chance of experiencing that kind of emotion (Ortony et al., 1988, p. 81–82). The *difference* between an emotion threshold and this value is its intensity, which MMT (47) incorporates (Alepis and Virvou, 2011, p. 9844). CMEs have also used this difference modulate to simulate other types of affect (Becker-Asano, 2008, p. 92–93; Ushida et al., 1998, p. 65–66; Duy Bui, 2004, p. 119; Kazemifard et al., 2011, p. 2645; Dias et al., 2014, p. 48; Dias and Paiva, 2005, p. 131; de Rosis et al., 2003, p. 103, 109–110; Martinho et al., 2000, p. 51).

Ironically, OCC's authors believe that computers *cannot* have emotion but it is still useful to reason about them: "...we do not consider it possible for computers to experience anything until and unless they are conscious. Our suspicion is that machines are simply not the kinds of things that can be conscious...There are many AI endeavours in which the ability to understand and reason about emotions or aspects of emotions could be important" (Ortony et al., 1988, p. 182). AffectR (1) adheres to this when reasoning about another agent's actions (Elliott, 1992, p. 27). One could also view narrative planners (e.g. MEXICA (64), NPE (65)) as an exercise in reasoning about character emotions. However, OCC can be applied to emotion generation as well (Picard, 1997, p. 195), also shown by AffectR, because the process of reasoning about emotions could be understood as reasoning about the emotional significance of an event to the agent (Prendinger et al., 2004, p. 230). The focus on reasoning makes OCC amenable to an intentional stance, which enhances agent believability (André et al., 2000, p. 151–152), because users can "see" the agent's thought processes.

The "fortunes of others" emotions (e.g. *Happy-For*) might be unique to OCC which rely on evaluations of how *someone else* feels. These are critical for empathetic agents (e.g. Greta (40), ERDAMS (45)) and agents that model relationships (e.g. CMEs 27, 33, 34, 42, 59, 61, 63–65). However, OCC omits *Surprise*—which is important for some CMEs—because they believe that it is not inherently positive or negative (Ortony et al., 1988, p. 32). Instead, they categorize it as a cognitive state tied to a global *unexpectedness* variable. CMEs that need *Surprise* draw from Ros. (e.g. ParleE (12), HybridC (17)) because it shares this hypothesis and explicitly defines *Surprise* as an emotion (Roseman et al., 1996, p. 269).

A shortcoming of OCC is a lack of emotion elicitation processes. This is a deliberate omission because OCC views it as a general cognitive psychology problem, but stresses the role of cognition in such processes (Ortony et al., 1988, p. 2). CMEs have realized OCC in plan-based systems (e.g. CMEs 12, 24, 28, 37, 64, 65), which are a step towards explainable behaviours. They provide context for elicited emotions (Gratch, 2000, p. 328), aligning with the OCC's focus on reasoning about emotions (Ortony et al., 1988, p. 182). Another approach, supported by Ortony et al. (2005), is to integrate OCC in a biologically-inspired approach (e.g. Maggie (9), IM-PMEB (13)) or architecture (e.g. EmMod (3), WASABI (8)) due to OCC's reliance on cognition. CME commonly use a BDI-inspired system or architecture to account for cognitive activities (e.g. CMEs 14, 27, 31–35, 45), but this can make the CME difficult to modify if it is integrated too deeply into the host architecture (de Rosis et al., 2003, p. 111–112). Other approaches include combining OCC with process-oriented theories like Frj. (e.g. S3A (67)) or Sch. (e.g. HybridC (17), GRACE (55)), other resources such as Picard (1997) (e.g. AKR (10)), and fuzzy logic (e.g. CMEs 4, 15, 38, 39). Many CMEs set their emotion model between input and output modules to mediate their interactions (e.g. CMEs 11, 29, 37, 41, 42, 50, 59, 63). If the goal is not to create "correct" behaviours, this strategy is sufficient if it meets the CME's other design goals (Reilly, 1996, p. 44–45).

Smith & Kirby (S & K) This theory only seems to appear when CMEs want to integrate multiple, parallel input sources into one unit for appraisal, which is its distinguishing feature (Smith and Kirby, 2001, p. 129–130).

S & K always appears with Sch. to combine appraisal information from sources on multiple levels of resolution (e.g. CMEs 6, 7, 51, 58). This might be because Sch. is better validated (Smith and Kirby, 2001, p. 129) and computationally tractable. Scherer also draws parallels between sequential check registers and S & K's integrated appraisal (Scherer, 2001, p. 105, 120). Another possibility for this pairing is a misconception that Sch. is strictly a sequential appraisal process (Ojha and Williams, 2016, p. 236) when it is not (Scherer, 2001, p. 100, 103).

An exception is EMA (24), which combines S & K with Frj. to define an attention mechanism (Gratch and Marsella, 2004, p. 286). This is likely because Frijda and Zeelenberg (2001, pp. 149) compares its "blackboard control structure" to S & K's appraisal register. This suggests that CMEs can combine S & K with other theories that have some comparable work to the appraisal register concept.

Oatley & Johnson-Laird[8] (O & JL) CMEs use O & JL to define what emotions they support and connect emotion intensity to changes in computational plans. O & JL typically have a supporting role for defining emotions in CMEs with Ek. as the main theory present for defining CME emotions (e.g. CMEs 2, 3, 17). This connection is sound, as O & JL considered Ek. as evidence when identifying their set of basic emotions (Oatley, 1992, p. 57–61).

O & JL propose that there is no emotion process, arguing that emotions are states entered at plan junctures, that might include conflicts between different goals, agents, and resource demands (Oatley, 1992, p. 22, 24–25, 31–36). CMEs have taken this information to define emotion intensity in relation to an agent's goals and plans (e.g. ParleE (12), Émile (28)). This also frames cognition as a knowledge transformation process, which is amenable to computation (e.g. Greta (40)).

Perhaps the most useful element of O & JL is its focus on the social and communicative role of emotions (Oatley and Johnson-Laird, 1987, p. 41–42). This has implications for multi-agent applications with affective content because each agent is an independent module in a larger system (Oatley, 1992, p. 178, 181–182). Conversational agents might also benefit from this view, which casts conversations as a form of mutual planning. As the field of social affective agents progresses, O & JL could come to play a larger role in the field.

Neurophysiologic Theories

Biological neural circuitry and brain structures inspire the *neurophysiologic* theories of affect, which offer a grounded view of how emotion systems might be organized and connected to the body (Lisetti and Hudlicka, 2015, p. 98–99). They tend to appear when a CME wants to distinguish between reactive, non-cognitive and deliberative, cognitive emotion processes. All three theories claim mechanisms for fast, "stupid" reactions and slower, deliberative plans that people collectively call "emotions" (Sloman et al., 2005, p. 230; Damasio, 1995, p. 133; LeDoux, 1998, p. 161–165).

Sloman[9] (Slo.) Slo. conceptualizes emotion as a product of a central information-processing system, distinguishing between types of emotion based on their architectural requirements (Sloman et al., 2005, p. 204, 211). CMEs use this distinction to specify elicitation mechanisms with varying performance requirements (e.g. WASABI (8), Presence (48)). The distinction also makes it possible to specify individual aspects of a CME such as goal importance for emotion intensity functions (e.g. Émile (28)) and emotion-driven plan selection (e.g. FAtiMA (37)).

WASABI (8) explicitly models aspects of Slo. for emotion elicitation using signal impulses that "disturb" its homeostatic state (Becker-Asano, 2008, p. 90). Slo. views these "disturbances"

[8]Although it does not name appraisal dimensions, O & JL talk about evaluating events relevant to plans and goals such that changes in achievement probability induce emotions (Oatley, 1992, p. 50). Therefore, it is grouped with the appraisal theories.

[9]Since Sloman views the brain as an information processing system (Sloman et al., 2005, p. 206–207), it is grouped with the neurophysiologic theories.

as a kind of emotion (Sloman et al., 2005, p. 230) which could be useful for CMEs that do not have deliberative processes. When deliberative processes are needed, Slo. might be particularly amenable to BDI-based CMEs because it explicitly references "beliefs", "desires", and "intentions" as architectural features (Sloman et al., 2005, p. 208).

Damasio (Dam.) Dam. proposes two emotion types: innate, evolution-based primary emotions and learned, cognition-driven secondary emotions that trigger the primary system (Damasio, 1995, p. 131–139). CMEs use this to motivate multiple, coexisting emotion elicitation processes (e.g. 2, 8, 48).

Two of Dam.'s features have proven useful for CMEs. One is emotion's influence on decision-making (Damasio, 1995, p. 126, 128) which can drive the design of CME behaviour (e.g. Cathexis (2), Émile (28)) and/or the design of connections between emotion elicitation and cognitive processes (e.g. EmMod (3)). Directly related to decision-making, the second feature is the Somatic Marker Hypothesis (SMH) which describes how secondary emotions are learned and connected to the primary emotion system (Damasio, 1995, p. 137, 145, 174). CMEs have used the SMH as-described to elicit emotions from memories via learned associations between stimuli and emotions (e.g. Cathexis (2)) and as a clever way to mark different types of inputs with common information to coordinate further functions (e.g. Kismet (53)).

Damasio posits that CMEs *cannot* use this theory because of the biological connection between the mind and body (Damasio, 1995, p. 249–250), suggesting that Dam. cannot be implemented in agents without a physical body. However, there is a version of SMH that bypasses the body (Damasio, 1995, p. 155–158) which WASABI (8) uses successfully in a virtual agent (Becker-Asano, 2008, p. 50, 56).

LeDoux (LD) LD views emotions as biological functions with different neural systems that evolution maintained across species (LeDoux, 1998, p. 106–107, 171). It proposes that each emotion has a mechanism programmed to detect and react to innate stimuli relevant to the system's function (LeDoux, 1998, p. 134, 143, 161–163, 165, 175–176). This suggests that some emotions like *Fear* do not necessarily require higher reasoning to elicit (e.g. WASABI (8)) and they could be a direct map to behaviours (e.g. InFra (15)). This proposal also sets the stage for LD's work on emotional conditioning mechanisms—specifically *Fear* (LeDoux, 1998, p. 127–128)—suggests methods for emotional learning in CMEs (e.g. FLAME (4)).

Damasio and LeDoux applaud each other's—mutually relevant—work (Damasio, 1995, p. 133; LeDoux, 1998, p. 250, 298). One focuses on the "low road" (i.e. non-cognitive) and the other on the "high road" (i.e. cognitive) which could explain their co-use or connection in some CMEs (e.g. Cathexis (2), WASABI (8)).

5.4.2 Psychologists Directly Involved in CME Design

Translating a psychological theory into a CME is difficult because it involves formalizing informal concepts and documenting hidden assumptions (Marsella et al., 2010, p. 22–23). CMEs designed with the participation of the theory's creator stand out as being "truest" to the theory.

Frijda supervised the development of both ACRES (23) and the Will architecture (25). ACRES is designed as a partial test of its functionality, treating the theory as a design specification (Frijda and Swagerman, 1987, p. 237, 247). Will—the spiritual successor of ACRES—proposes a reasonable extension of Frj.: emotion, moods, sentiments, and personality are related by focus and duration (Moffat, 1997, p. 135–136, 138). This is convenient for CMEs as it shows that these affective types can share the same underlying structure. Scherer directly influenced the design of

ELSA (26) which is particularly relevant as its purpose is to show that Sch.—which takes an information systems view on emotion processes (Scherer, 2001, p. 103)—can be implemented and used as a research tool (Meuleman, 2015, p. 142–143). Ortony provided direct supervision for AffectR (1) (Elliott, 1992, p. iv) which presumably makes it the most faithful account of OCC emotion generation processes and action tendency hierarchy.

In other cases, theory creators acted as consultants to CME designers (Becker-Asano, 2008, p. vii; Petta, 2002, p. 281; Gratch and Marsella, 2004, p. 303; Gratch, 2000, p. 332; Marsella and Gratch, 2009, p. 89) and/or drew from other CMEs that were developed under that creator's guidance (Gratch, 2000, p. 325). Caution must be used in evaluating their faithfulness to the theories, as it is usually not documented what parts relied on consultation and which did not.

5.5 Discussion

In our examination of these CMEs, we also found design decisions and trade-offs relevant to *implementing theories*, *how CMEs could combine theories from different perspectives*, *CME realism versus efficiency*, and *other sources of design influence*.

5.5.1 Implementing Theories

Implementing an affective theory is challenging. Some theories—Frj., Sch., OCC, O & JL, and Slo.—were explicitly designed to be computationally tractable (Frijda and Swagerman, 1987, p. 247; Scherer, 2021, p. 279; Ortony et al., 1988, p. 181; Oatley and Johnson-Laird, 1987, p. 30; Sloman, 1987, p. 231) while others—like Dam. and LD—argue that their theories *cannot* be computationally realized (Damasio, 1995, p. 249–250; LeDoux, 1998, p. 41, 176). Regardless, they have been implemented. Nonetheless, how accurately a CME adheres to a theory and/or observed emotion phenomenon tends to be directly proportional to how complex the CME is.

Neurophysiologic theories might be more plausible than appraisal theories (Velásquez, 1998, p. 72–73) and better align with current findings (André et al., 2000, p. 160). However, they require modelling parts of the brain and body, which this is neither feasible nor desirable for many CMEs. Furthermore, the resulting system will not necessarily be accurate due to gaps in our understanding of anatomical structures and functions (although complete accuracy might not be useful to anyone (Gratch and Marsella, 2015, p. 60)).

Appraisal theories might be best suited for CMEs as they touch on all components and phases of emotion processing (Scherer, 2010b, p. 13). They are also relatively easy to implement as they are often rule-based (Picard, 1997, p. 225) and built on information processing analogies (Gratch and Marsella, 2015, p. 59). While some have integrated neurophysiologic aspects, this increases their complexity. For example, empirical test of Sch. have been relatively successful in predicting different patterns in emotion processes (Scherer, 2001, p. 93, 103, 117–118) but it is very complex and involves implementations of components like the Autonomic Nervous System (ANS) and memory while allowing for multiple levels of information processing. This might be why Sch. is favoured by cognitive architectures and research CMEs like CLARION (22) and MAMID (6), whose assumptions closely follow Sch.'s (Hudlicka, 2019, p. 136; Sun et al., 2016, p. 6). These systems purposefully sacrifice computational efficiency for accuracy since their aim is to study emotion phenomena. This complexity also makes them are to explain and debug (Meuleman, 2015, p. 143–144).

5.5.2 How CMEs Could Combine Perspectives

Some theories are easily combined as they share a perspective based on coherent assumptions. For example, Izard, Ekman, and Plutchik agree on the function of at least four primary emotions—*Joy/Happiness*, *Sadness*, *Anger*, and *Fear*—and their ability to interact to produce what people recognize as other, more complex, emotions (Izard and Ackerman, 2000, p. 254, 258–259; Ekman, 2007, p. 69; Plutchik, 1984, p. 200, 204–205). Similar overlaps exist in the appraisal theories' evaluation dimensions and how they label distinct combinations. The dimensional theories, V-A and PAD, are also obviously compatible—one could directly layer V-A over the P-A plane. By staying within one perspective, a CME design can use the individual strengths of each theory with little worry of conflicting assumptions or views.

Combining theories from *different* perspectives poses a more complex challenge, but often necessary to address all aspects of affect needed in the design. For example, OCC is frequently combined with Ek.—which focuses on automatic, hard-wired appraisals rather than evaluations (Ekman, 1999, p. 51)—to produce facial expressions from cognitively-evaluated events (Kshirsagar and Magnenat-Thalmann, 2002, p. 109; Jain and Asawa, 2019, p. 66; André et al., 2000, p. 155; Masuyama et al., 2017, p. 740–741). This connection is presumably due to the OCC's association of characteristically similar "linguistic tokens" with each emotion (Ortony et al., 1988, p. 1–2, 87–88). By finding similar words, one can fit the discrete theories' emotions into the OCC structure. However, this relies on subjective interpretations, and even the given lists lack empirical validation (Ortony et al., 1988, p. 172–176). More pressingly, emotions of the same name might represent different concepts. *Fear* and *Anger* in OCC, as with many appraisal theories, are complex emotions requiring flexible, cognitive evaluations (Becker-Asano, 2008, p. 85, 87) but the same emotions in discrete theories are simpler, triggered by inflexible hard-wired systems. While they might be expressed with the same physiological changes, behaviours, and expressions, their eliciting mechanisms are not of the same kind (Scherer, 2010b, p. 15–16). Whether or not this distinction is important for a CME, it should still be addressed as it affects how accurately the theories are modelled. Similar considerations must be made when attempting to align the dimensional theories with the dimensions of appraisal theories and locating discrete emotions in dimensional space.

These conceptual mismatches does not mean that there are "correct" and "incorrect" theories or that they are incompatible, especially considering how they overlap and converge on the role of emotion (Scherer, 2010b, p. 10–11, 14–15; Broekens, 2021, p. 352, 354–355; Scherer, 2021, p. 281). Rather, they are different views—perspectives—of a complete system, each focusing on different aspects of emotions (Frijda, 1986, p. 259). Emotion systems seem to rely on both fast, primary and deliberative, secondary emotions (Picard, 1997, p. 70). This idea of two emotion types is present in some affective theories, such as Izard (1993, p. 74), Ekman (1999, p. 51), Frijda and Zeelenberg (2001, p. 155), Scherer (2001, p. 102), and Smith and Kirby (2000a, p. 93), and is also supported by empirical investigations of the brain (Damasio, 1995, p. 136–139; LeDoux, 1998, p. 177–178). Some CMEs have explicitly modelled these two "pathways", including Becker-Asano (2008, p. 98), Velásquez (1998, p. 73), Ushida et al. (1998, p. 63), and André et al. (2000, p. 160). Correspondingly, one way that each perspective could be assigned roles in CME designs to address different aspects of emotion generation is:

- *Neurophysiologic theories* provide guidelines for how to unite disparate emotion processing pathways into a coherent system,
- *Discrete theories* drive the creation of a limited set of fast, hard-wired (Broekens, 2021, p. 366) reactions to specific stimuli ("primary emotions", "low road"),

- *Appraisal theories* drive the deliberative, slower systems for emotion elicitation that require planning and/or reasoning ("secondary emotions", "high road") that can account for language and sociocultural factors, allowing for a broader range of identifiable emotions, and

- *Dimensional theories* provide a common space for merging the outcomes of each emotion pathway in the spirit of appraisal registers (Scherer, 2001, p. 105; Smith and Kirby, 2000a, p. 93) while allowing other types of affect to interact with emotion.

5.5.3 CME Realism versus Computational Efficiency

For CMEs that focus on agent believability, enforcing realism and rational intelligence can be detrimental to their goals (Reilly, 1996, p. 11). These systems typically interact with users in (soft) real-time, so efficiency is more important than accuracy. Being able to test and debug models is also important. For example, dimensional theories are arguably the simplest to implement efficiently. However, they also have the lowest affective resolution. Nevertheless they are considered "universal" and individual emotion "points" can be labelled as needed (Scherer, 2010b, p. 12, 15). However, since they do not define emotion generation, the designer must determine how much of it they want to implement.

Efficient implementation of *believable* but not necessarily sound emotion generation can be done in myriad ways: with metadata (Prendinger et al., 2004, p. 236; Gebhard, 2005, p. 33); concepts like Bayesian Networks (Kshirsagar and Magnenat-Thalmann, 2002, p. 108; Ball and Breese, 2000, p. 204), Markov Models (Lisetti and Gmytrasiewicz, 2002, p. 603; Duy Bui, 2004, p. 115), and fuzzy logic (El-Nasr et al., 2000, p. 229; Castellanos et al., 2018, p. 29–30; Jones and Sabouret, 2013, p. 3, 7; Laureano-Cruces and Rodriguez-Garcia, 2012, p. 68); and AI techniques like behaviour trees and goal-oriented action planning (Klinkert and Clark, 2021, p. 698). Other theories—typically appraisal—are also conscripted, but might not be modelled in full (Popescu et al., 2014, p. 36; Reilly, 1996, p. 52). CMEs have also improved their efficiency by considering their target domain's limitations, which might require fewer emotion categories (Salichs and Malfaz, 2012, p. 58; Kshirsagar and Magnenat-Thalmann, 2002, p. 109; Mehdi et al., 2004, p. 2), and appraisal variables (Yacoubi and Sabouret, 2018, p. 150; Shirvani and Ware, 2020, p. 118), while others are able to scale as needed (Prendinger et al., 2004, p. 239; Castellanos et al., 2018, p. 27; Dias et al., 2014, p. 44; Moshkina et al., 2011, p. 217; Broekens and DeGroot, 2004; Popescu et al., 2014, p. 35). As these have all found some success in achieving their goals, this further emphasizes that accuracy is not always necessary. This opens up the design space to create a CME that behaves "well enough" for its intended tasks.

5.5.4 Other Sources of Design Influence

Several systems strengthen or extend their chosen theoretical foundations by supporting it with other comparable or complementary theories (Lisetti and Gmytrasiewicz, 2002, p. 594, 599–600, 606; Castellanos et al., 2018, p. 27; Jain and Asawa, 2019, p. 63–64; Yanaru et al., 1997, p. 218, 247; de Rosis et al., 2003, p. 91; Breazeal, 2003, p. 129; Wilson, 2000). Some cite additional work to support perceived short-comings in a foundational theory (El-Nasr et al., 2000, p. 223, 233–234, 239) or formally define concepts[10] (Kim and Kwon, 2010, p. 269). Yet other CMEs use additional sources to connect emotions with other system components, such as social variables (Bourgais et al.,

[10]POMDP-CA (49), which uses Weaver (1948) to define *unexpectedness*, similar to *suddenness* in Sch. (Scherer, 2001, p. 95). This is necessary to appraise *Surprise* in both Ros. (Roseman et al., 1996, p. 267) and OCC (Ortony et al., 1988, p. 126).

2017, p. 93; Kasap et al., 2009, p. 22; Ochs et al., 2009, p. 288; Klinkert and Clark, 2021, p. 698) and emotion contagion (Aydt et al., 2011, p. 77; Lhommet et al., 2011, p. 91; Durupınar et al., 2016, p. 2151).

Emotion theories do not address all aspects of emotion generation, such as emotion intensity and cognitive organization. Other sources of information are needed. Three stand out: the work of Picard (Picard, 1997), Minsky's theory (Minsky, 1986), and empirical data.

A pioneer of Affective Computing, Picard offers a computer science-friendly view of emotion, proposing models and ideas for CMEs that often guide the selection of their underlying emotion theories. AKR (10) references them to justify its use of Markov Models for emotion dynamics (Lisetti and Gmytrasiewicz, 2002, p. 603). IM-PMEB (13), FAtiMA (37), and SocioEmo (59) reference Picard to define an emotion intensity decay function (Shvo et al., 2019, p. 68; Dias and Paiva, 2005, p. 130–131; Ochs et al., 2009, p. 289). Presence (48) cites Picard for their separation of primary and secondary emotion processing channels, motivating its use of Slo. and Dam. (André et al., 2000, p. 160). Greta (40) cites Picard's "tub of water" metaphor, comparable to Plu., for addressing coexistent emotions in its design considerations (de Rosis et al., 2003, p. 99). TAME (56) uses Picard for defining emotion dynamics as a system response (Moshkina et al., 2011, p. 211).

Minsky offers a model of human intelligence amenable to AI. Since many emotion theories—especially appraisal theories—rely on cognition, Minsky's *Society of Mind* presents a way to model it. O & JL explicitly draw parallels to it (Oatley and Johnson-Laird, 1987, p. 32, 39). EmMod (3) cites Minsky as the main inspiration for its architecture, producing complex behaviours via the interactions of many, simple units (Ushida et al., 1998, p. 63). Cathexis (2) compares its models of secondary emotions to Minsky *k*-lines, connecting primary emotions to encountered stimuli (Velásquez, 1998, p. 73).

Empirical data, as the best source for replicating observable phenomena, has been used for: defining degrees of emotion positivity and negativity (Ojha and Williams, 2017, p. 4) and emotion effects (Hudlicka, 2019, p. 136); deriving emotion intensity functions (Ochs et al., 2012, p. 419); quantifying the relationship between emotion intensity, desires, and expectations (El-Nasr et al., 2000, p. 232; Duy Bui, 2004, p. 125); and gesture models (Marsella et al., 2000, p. 302). Some systems have moved to purely data-driven approaches (e.g. Ojha et al. (2019), Bai et al. (2021)).

5.6 Summary[11]

We have examined how CMEs from different application domains use emotion theories for emotion generation (i.e. for emotion representation and elicitation) and expression. We found that each type of emotion theory filled a similar role regardless of the domain: *discrete* theories define which emotions a CME can represent and express, and how it does so; *dimensional* theories can provide a simple and powerful representation that describes emotion numerically and with respect to other types of affect; *appraisal* theories chiefly drive the elicitation process; and *neurophysiologic* theories unite the reactionary and deliberative emotion views, tying them to measurable body states.

These roles can be complementary. Appraisal theories seem the best starting point for emotion generation CMEs, as they explicitly describe emotion processes and are relatively easy to implement. Discrete theories can improve a CME's comprehensibility, and dimensional theories are useful for their quantitative representation of emotions (and other types of affect) in a common space. The neurophysiologic theories can contribute to emotion process definitions, but tends to increase a CME's overall complexity—they should be used with care. Generally, the less realistic that generated emotions need to be, the more efficient a CME can be.

[11] "Conclusion" in Smith and Carette (2022).

There are even more theories (e.g. see (Scherer, 2021, p. 280–281)), models, and data to draw from for CME designs. For example, if one is considering V-A then they might consider Russell (1980) too due to their similarities. Lastly, future CMEs might get inspiration from unlikely places (e.g. Nallaperuma and Karunananda (2011)). This survey aims to be a resource for creating new CME designs, providing a practical view of *some* emotion theories and existing CMEs to borrow from and build on.

Key Points

- It is common for CME designs to combine theories that have overlapping concepts or when a chosen theory does not meet all of the CME's design requirements
- Discrete theories—such as Izard, Ekman, and Plutchik—are commonly used to define what emotion kinds a CME can generate
- Dimensional theories like V-A and PAD Space appear when a CME wants to represent different types of affect in a common space or to provide an alternate view of emotions
- Appraisal theories—Frijda, Lazarus, Scherer, Roseman, OCC, Smith & Kirby, and Oatley & Johnson-Laird—appear in CMEs to define variables that map an evaluation of the world to emotion kinds and to specify the emotion generation process
- Neurophysiological inspired theories such as Sloman, Damasio, and LeDoux appear to distinguish between innate and deliberative emotion generation or when emotions must influence planning
- Nearly all of the surveyed CMEs used at least one appraisal theory

Part II

Enter the EMgine

Warning: Game Corruption.

Main Frame Game Voice, *Reboot*

Good to see you again!

This part gives an account of EMgine's design and development. "Start Your EMgine: Requirements and Scope" (Chapter 6) reviews EMgine's high-level requirements and design scope, then begins describing the process for choosing its underlying emotion theories and models. The process concludes in "Support Your EMgine: The Requirements Choose the Theories" (Chapter 7). Additional examples of this process in "Interlude: Choosing Theories for Other CMEs" (Chapter 8) demonstrate how changes in high-level requirements and design scope can change the outcome of the theory selection process. "Spec Your EMgine: Defining the Pieces" (Chapter 9) describes EMgine's models and their documentation method, followed by "Build Your EMgine: Some Assembly Required" (Chapter 10) that describes its architecture design, along with its documentation method, and relevant implementation details. And last, but never least, "Gather Your Tools: Defining Acceptance Test Case Templates" (Chapter 11) and "Inspect Your EMgine: Extending Acceptance Test Case Templates" (Chapter 12) details the steps taken to build acceptance test cases that borrow elements from EMgine's models, yet exist independently of EMgine itself.

And now, the main event: Enter the EMgine!

Chapter 6

Start Your EMgine: Requirements and Scope

Everything that follows, is a result of what you see here.

Dr. Lanning's Hologram, *I, Robot (2004)*

Here, the design of EMgine begins in earnest. EMgine is a Computational Model of Emotion (CME) for emotion generation that strives to create a more engaging player experience via believable Non-Player Characters (NPCs). Based on the proposed requirements analysis process (Chapter 4.2.1), the first step is defining high-level requirements (Section 6.1). These guide the definition of EMgine's scope (Section 6.2) and which broad groups of emotion theories could support it (Section 6.3). This ensures that EMgine builds on theories that serve its larger design goals, embedding support for them at the core of its design.

The theories and models examined are the same as those found in the survey of existing CMEs (Chapter 5) because it already organizes emotion theories by perspective—discrete, dimensional, appraisal, and neurophysiological—based on their general agreement about some aspects of emotion such its representation (e.g. kinds, dimensions).

While one need not be an expert in Affective Science or psychology to reproduce this example, it does require some understanding of the material to be able to recognize, interpret, and synthesize pertinent information to draw conclusions from. This might involve reading additional material in both affective science (e.g. Sander and Scherer (2009)) and computing (e.g. Picard (1997)) to contextualize terms and concepts. It might also involve—as is common in document analysis (Bowen, 2009, p. 32)—iteratively skimming, reading, and interpreting the literature until enough information is available to draw conclusions (i.e. choose theories) from.

6.1 Requirements and the Game Designer

While CME designers do take emotion theories and the needs of the application domain into consideration, they rarely consider future users (Osuna et al., 2020, p. 15). In particular, game designers/developers attempting to create emotional NPCs have specific needs that CME designers must integrate early in the design process (Ghezzi et al., 2003, p. 162–163) to improve the chances of a CME's adoption.

Although game developers do see the potential player experience (PX) improvements of emotional NPCs (Prasertvithyakarn, 2018; Yannakakis and Togelius, 2015, p. 328), some believe that there is no player demand (Broekens et al., 2016, p. 218) and doubt that there would be sufficient return on investment. One should also consider how a CME might introduce unnecessary game design restrictions. For example, relying on a specific agent architecture (Broekens et al., 2016, p. 218) and generating a specific set of emotion kinds (e.g. *Joy*, *Sadness*) could be problematic, as they might not be compatible with many games in both technical and design capacities. By extension, when and how to implement emotion in NPCs should also be the developer's decision (Mascarenhas et al., 2022, p. 8:13). There also appears to be a link between the "authoring experience" and the adoption rate of potential solutions (Guimarães et al., 2022, p. 5). These concerns prompt several requirements that a game development-oriented CME must have to have a chance of being adopted, collected here into two broad groups—*flexibility* requirements (RF) and *ease-of-use* requirements (RE)[1].

Flexibility High-Level Requirements

Flexibility is about making EMgine adaptable so that it can meet game designer needs (Reilly, 1996, p. 30). The aim is for EMgine to be applicable to a range of game designs while avoiding making decisions for the game developer. These requirements include:

RF1 Independence from an agent architecture so that designers can choose how to integrate EMgine into their game (Loyall, 1997, p. 25–26; Rodríguez and Ramos, 2015, p. 443; Broekens et al., 2016, p. 218)

RF2 Allowing the game designer to choose which of EMgine's tasks to use, as well as when and how to use them (Mascarenhas et al., 2022, p. 8:13; Guimarães et al., 2022, p. 20)

RF3 Allowing the customization or redefinition of EMgine's preexisting configuration parameters (Reilly, 1996, p. 30; Guimarães et al., 2022, p. 20) such as the definition of time and emotion decay rates

RF4 Allowing designers to integrate new components into EMgine that influence or are influenced by emotion (Rodríguez and Ramos, 2015, p. 450; Castellanos et al., 2019, p. 353), such as mood, personality, motivations, culture, gender, and physical state

RF5 Allowing designers to choose which kinds of emotion EMgine produces (i.e. which emotions an NPC can have) (Hudlicka, 2014a, p. 331), (e.g. *Anger*, *Joy*)

RF6 Allowing designers to specify how to use EMgine's outputs to accommodate different ways of expressing emotion and/or using emotion as an influence to external systems (Loyall, 1997, p. 86)

RF7 Allowing designers to use EMgine with NPCs of different complexities (Broekens et al., 2016, p. 220), e.g. a *Pac-man* ghost (Namco, 1980) and a *Skyrim* citizen (Bethesda Game Studios, 2011) might not require the same type and/or quantity of information to evaluate if they are experiencing an emotion

RF8 Being resource/time efficient and scalable to minimize EMgine's impact on overall game performance (Popescu et al., 2014, p. 42)

[1]EMgine's software requirements specification (SRS) documents these as nonfunctional requirements. The full specification is at https://github.com/GenevaS/EMgine/blob/main/docs/SRS/EMgine_SRS.pdf.

Ease-Of-Use High-Level Requirements

Ease-of-use concerns the usability of EMgine and showing how it supports game development. These requirements include:

RE1 Hiding the complexity of emotion generation so that game designers do not have to be knowledgeable of affective science or computing to use EMgine (Reilly, 1996, p. 28; Broekens et al., 2016, p. 220; Guimarães et al., 2022, p. 5)

RE2 Providing a clear and understandable Application Programming Interface (API) or similar that shows how to use the different aspects of EMgine (Broekens et al., 2016, p. 218)

RE3 Minimizing authorial burden as game developers add NPCs to their game (Guimarães et al., 2022, p. 5)

RE4 Allowing EMgine's outputs to be traceable and understandable (Loyall, 1997, p. 86; Guimarães et al., 2022, p. 5, 19–20)—critical for testing—by providing ways to view the range, intensity, and causes of emotion per NPC, per NPC group, and per game world area (Broekens et al., 2016, p. 219–220)

RE5 Giving developers the option to automate the storing and decaying of EMgine's internal emotion state (Loyall, 1997, p. 86)

RE6 Showing that EMgine improves PX, since a subpar design could be a detriment to the overall game and would not be useful for game development

RE7 Providing examples as to how EMgine can create novel game experiences (Broekens et al., 2016, p. 221)

Note that this is not a static list—it is intended to change as more information emerges. These requirements are also theory-agnostic, so any affective theory/model that supports them is a reasonable choice. They might also be applicable to other game entities that are not NPCs because they describe what the CME must allow game developers to do, not what they must create.

6.2 Defining EMgine's Scope

A CME's design scope (i.e. analysis context) describes *what* it should do, which must be coherent with its requirements. Here, EMgine considers what general Affective Computing tasks it must do, what an NPC's embodiment might be, and what emotion components EMgine should give NPCs. This helps judge the suitability of broad groups of emotion theories (Section 6.3).

While it is tempting to dismiss some theories based on design scope alone, it is too early to make these decisions. Some theories might not explicitly suit the design scope, but they might help define an interface between EMgine and external modules to support *Allowing the Integration of New Components* (RF4).

Figure 6.1 illustrates the flexibility requirements' influence on EMgine's design scope. EMgine automatically considers all requirements to be in scope, although the ease-of-use requirements did not contribute to the design at this point. Boxes with outgoing solid arrows point to boxes they conflict with, and are therefore eliminated from EMgine's scope. Conversely, dotted arrows indicate

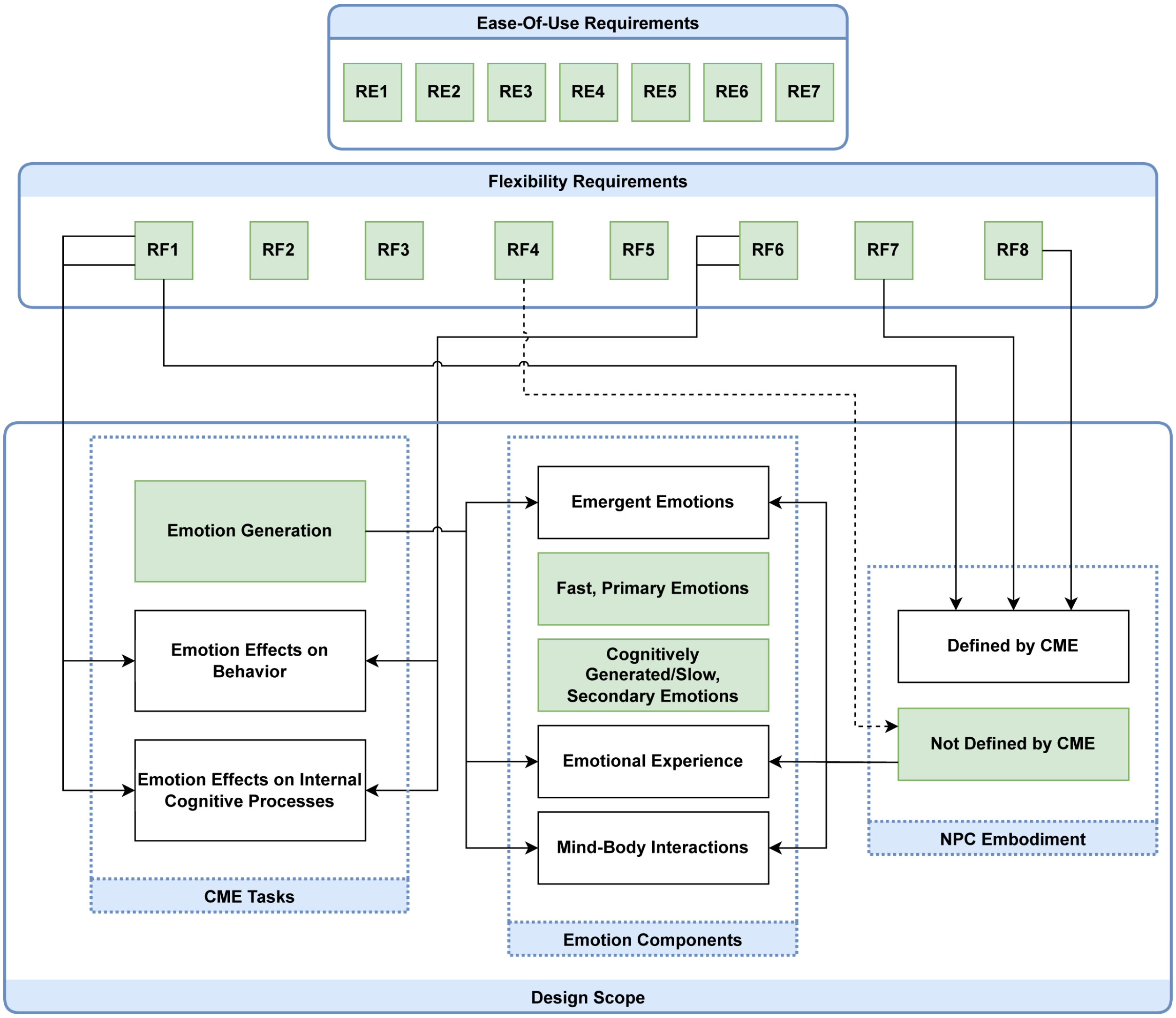


Figure 6.1: Overview of Influences on EMgine's Design Scope Showing the Connection to the High-Level Requirements (Shaded boxes are within scope; Solid arrows indicate conflicts with, dotted arrows indicate support for)

support for a box/component. Shaded boxes without incoming solid arrows and are therefore within EMgine's scope.

6.2.1 CME Tasks

Affective Computing tasks (Chapter 4.1) of relevance to NPCs "with emotion" include:

- *Emotion Generation* to produce an emotion state given the current program and environment state
- *Emotion Effects on Behaviour* to change a NPC's "observable" behaviour (e.g. facial expressions, gestures, or movements) given an emotion state, and

- *Emotion Effects on Internal Cognitive Processes* or *Cognitive Consequences of Emotions* to change a NPC's internal processing behaviours.

Since it only produces emotion states, EMgine should focus on *emotion generation* alone. In terms of the design scope, this means that it excludes anything outside of taking inputs for evaluation and producing an emotion state. EMgine leaves these tasks to other modules which might not be available. Consequently, the tasks *Emotion Effects on Behaviour* and *Emotion Effects on Internal Cognitive Processes* are out of scope. There are other reasons to exclude these tasks from EMgine's scope: they both conflict with *Allowing Developers to Specify How to Use Outputs* (RF6), as they decide what to do based on a given emotion state and even suggesting an association between behaviours and emotions encodes an assumption about how the game designer should use them (Gratch and Marsella, 2015, p. 57); and it could also conflict with *Independence from an Agent Architecture* (RF1) depending on the implemented behaviours and effects.

6.2.2 NPC Embodiment

EMgine should not impose constraints on an NPC's embodiment, which would make it dependent on what components and/or processes that NPC has. Doing so could violate several requirements, including *Independence from an Agent Architecture* (RF1), *Ability to Operate on Different Levels of NPC Complexity* (RF7), and—potentially—*Be Efficient and Scalable* (RF8). Instead, and in support of the requirement to *Allow the Integration of New Components* (RF4), it should be simple to integrate EMgine with external modules at its input and output points.

6.2.3 Emotion Components

Emotions have multiple components that affect different aspects of behaviour and experience (Hudlicka, 2019, p. 133; Scherer, 2001, p. 92). Based on evidence from psychology and neuroscience, there are up to five components in computers "with emotions" (Picard, 1997, p. 60–70). A CME need not have all of these components to be effective for its job, "just like simple animal forms do not need more than a few primary emotions..." (Picard, 1997, p. 68):

- *Emergent Emotions* attributed to the system based on their "observable" behaviours,
- *Fast Primary Emotions*, the hard-wired and potentially inaccurate responses to innate knowledge elicited by fundamental mechanisms (e.g. instinctual fear of pain),
- *Cognitively Generated/Slow Secondary Emotions*, those emotions that require some level of reasoning to elicit (e.g. learned fear of public speaking),
- *Emotional Experience*, comprised of cognitive awareness of emotions being experienced, physiological changes, and subjective feelings—requiring self-awareness and consciousness to identify—and
- *Mind-Body Interactions*, the interactions between emotions and other cognitive and non-cognitive system components (e.g. bidirectional interactions between emotions and decision-making).

Emergent Emotions are out of scope because they depend on *Emotion Effects on Behaviour* (Section 6.2.1), which is itself out of scope. These would fall to game developers as part of *Allowing Developers to Specify How to Use Outputs* (RF6). *Emotional Experience* is also out of scope because NPCs do not necessarily have to reason *about* their emotions to interact with players. *Mind-Body*

Interactions are also out of scope due to their reliance on external components and processes which are not reliably available due to the lack of restrictions on NPC embodiment (Section 6.2.2).

Both the *fast primary emotions* and *cognitively generated/slow secondary emotions* are within EMgine's scope because they describe two ways of generating emotion. The Affective Science literature supports modelling these as distinct processes (e.g. Damasio (1995); LeDoux (1998)), and would also integrate some support for the *Ability to Operate on Different Levels of NPC Complexity* (RF7), and—potentially—*Be Efficient and Scalable* (RF8). Game developers can choose to use both, only primary—best for smaller games with few emotional stimuli—or only secondary emotions—for NPCs that have some planning or reasoning abilities—as their game requires.

6.3 Examining Perspectives of Emotion

With its design scope defined, EMgine examines broad groups of emotion theories (i.e. "themes" for thematic analysis) to see if they could support it and the high-level requirements. For this example, EMgine defines groups following the themes/perspectives from the CME survey (Chapter 5.4) which found that the perspectives frequently appear in specific roles in CME designs:

- Discrete theories[2] for defining a representation of an emotion state with clearly distinguishable categories and consequences of that state (e.g. facial expressions)
- Dimensional theories for creating simple models of emotion, viewing emotion categories from a different perspective, and defining a common space for representing different kinds of affect (e.g. emotion, personality, mood) and their interactions
- Appraisal theories for defining emotion processes and mechanisms
- Neurophysiological theories[3] guide architecture-related decisions that distinguish between *fast, primary emotions* and *cognitively generated/slow, secondary emotions*

EMgine uses these observations as a starting point to determine which ones warrant an exploration of individual members (Chapter 7). Figure 6.2 shows the conclusions. EMgine automatically considers all requirements to be in scope. Boxes with outgoing solid arrows point to boxes they conflict with, and therefore do not support EMgine's scope. Conversely, dotted arrows indicate support for a box/component. Shaded boxes might be useful for EMgine's design, warranting a closer examination.

6.3.1 Discrete Theories

One of the core features of the discrete theories is the definition of distinct emotion kinds, like *Fear* and *Anger*, that are recognizable by a set of observable features (e.g. facial expression, typical behaviours). This "...fits with the way we talk about emotion every day...people automatically and effortlessly perceive emotion in themselves and others..." (Barrett, 2006, p. 47–48). While true facial expressions (Barrett et al., 2019, p. 46) and survival-based behaviours (Barrett and Finlay, 2018, p. 177) are likely more variable and context-dependant than originally thought, caricatures of emotions are the most unambiguous depictions of them. Animators use these to amplify the believability of their characters (Gard, 2000; Loyall, 1997, p. 2; Williams, 2001, p. 315–316)[4]. NPCs

[2] Rodríguez and Ramos (2015) call these *hierarchical theories*.

[3] Although they rarely appear (Lisetti and Hudlicka, 2015, p. 98; Rodríguez and Ramos, 2015, p. 451).

[4] The animated movie *Inside Out* credits Dr. Ekman as a scientific advisor (Paul Ekman Group, 2021).

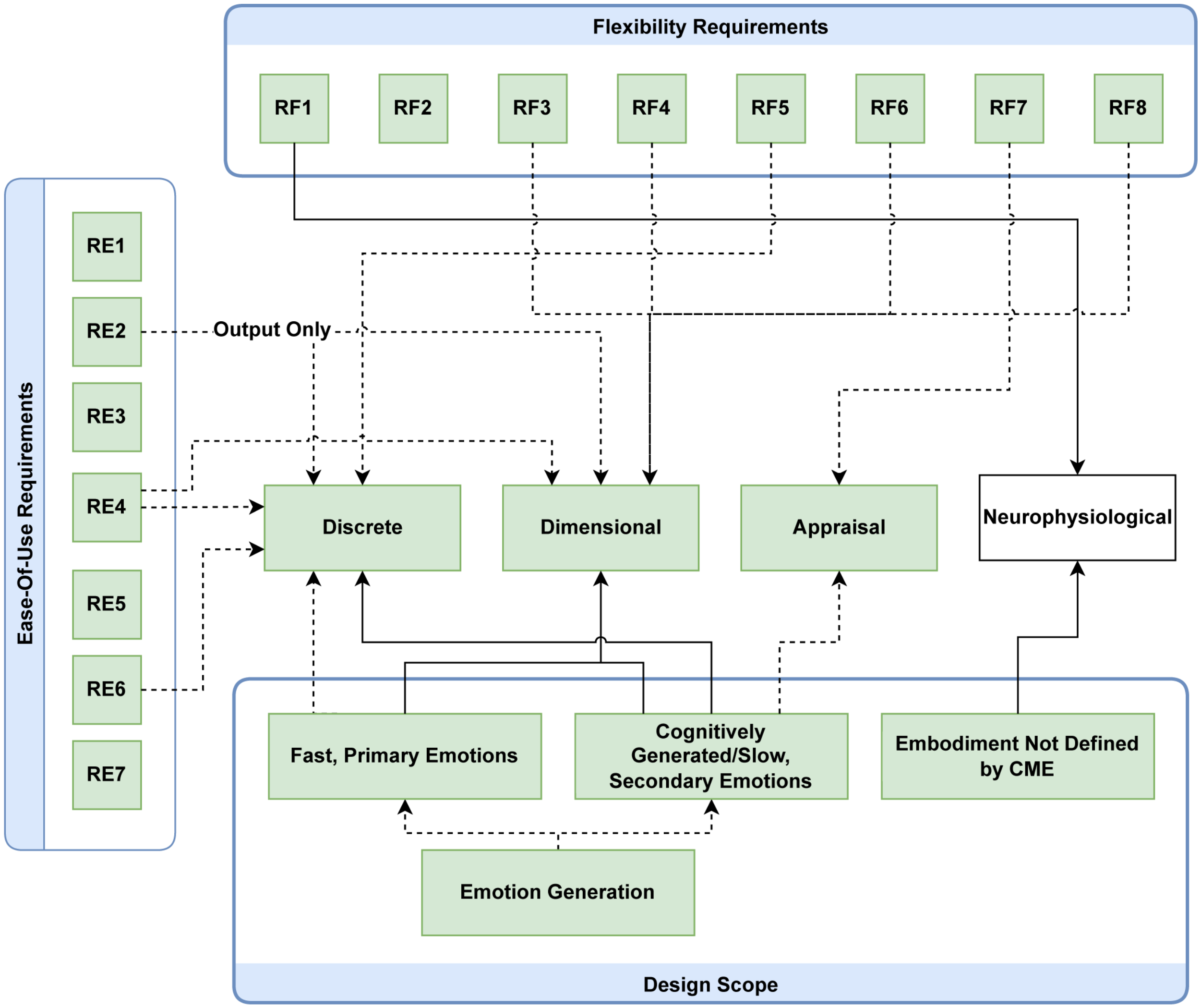


Figure 6.2: Overview of Influences on EMgine's View on Perspectives of Emotion Showing the Connection to the High-Level Requirements and Design Scope (Shaded boxes are in scope; Solid arrows indicate conflicts with, dotted arrows indicate support for)

are also animated characters, so they also benefit from exaggerated expressions (Livingstone, 2006, p. 5). This suggests that players could recognize which emotion an NPC is expressing based on emotion kinds, which is useful for creating player studies for *Showing that EMgine improves PX* (RE6).

The simplicity offered by emotion kinds also suggests that the discrete theories have a greater chance of being understood by game developers, which they can use to convey the intended internal state of an NPC to players (Broekens, 2021, p. 352–353). This implies excellent support for several requirements, including *Allowing developers to choose which kinds of emotion EMgine produces* (RF5), *Providing a clear and understandable API* (RE2) for outputs, and *Allowing EMgine's outputs to be traceable and understandable* (RE4).

The discrete theories propose that innate, hardwired circuits or programs elicit emotions (Ortony, 2022, p. 41; Scherer, 2021, p. 280). While this is within the scope of *fast, primary emotions*

(Section 6.2.3), they are unable to define *cognitively generated/slow, secondary emotions* because there are no clearly defined processes or mechanisms to do so. This makes discrete theories unable to satisfy many of EMgine's requirements such as *Allowing the game developer to choose which of EMgine's tasks to use* (RF2), *Allowing the customization or redefinition of the EMgine's preexisting configuration parameters* (RF3), *Hiding the complexity of emotion generation* (RE1), *Providing a clear and understandable API* (RE2) for inputs, *Allowing EMgine's outputs to be traceable and understandable* (RE4), and *Allowing developers the option to automate the storing and decaying of EMgine's emotion state* (RE5). However, they cannot conflict with these requirements either.

Although they cannot satisfy EMgine's needs alone, the benefits of discrete theories might outweigh their lack of emotion elicitation processes. Therefore, EMgine examines the discrete theories individually with respect to each high-level requirement.

6.3.2 Dimensional Theories

These theories can more easily distinguish between different emotions (Scherer, 2010b, p. 12; Smith and Ellsworth, 1985, p. 813) using a small number of continuous dimensions. The dimensional theories view emotion as an individual's interpretation of their current "core affect" (Broekens, 2021, p. 353) (i.e. elementary affective feelings). While any point in dimensional space is part of "core affect" (Lisetti and Hudlicka, 2015, p. 97), it is possible for individuals to verbally label points representing their subjective feeling of an emotion (Scherer, 2010b, p. 12). This creates an effect of "plotting" emotion kinds (e.g. as in discrete theories) as points in the space, implying that the dimensional theories could also support *Providing a clear and understandable API* (RE2) for outputs and *Allowing EMgine's outputs to be traceable and understandable* (RE4). However, emotions defined by dimensions alone might be more difficult to label with everyday language (Johnson-Laird and Oatley, 1992, p. 213) implying that they are harder to understand intuitively than discrete emotion kinds without supplemental qualitative information.

"Core affect" can also relate other psychological constructs such as personality and thought (Broekens, 2021, p. 353), making dimensional theories ideal for creating seamless interaction dynamics, *Allowing developers to integrate new components into EMgine that influence or are influenced by emotion* (RF4). The nature of dimensions also affords a more granular way to define emotion-driven responses, affording more ways for *Allowing developers to specify how to use EMgine's outputs* (RF6).

The numerical nature of dimensional theories could also support requirements like *Allowing the customization or redefinition of EMgine's preexisting configuration parameters* (RF3), and are likely to *Be efficient and scalable to minimize the overall impact on game performance* (RF8). As a bonus for CME development, these theories are convenient to implement (Rodríguez and Ramos, 2015, p. 440).

The dimensional theories "...say comparatively little...about how the different emotions are produced, and what useful or other effects they have..." (Reisenzein et al., 2013, p. 250). This makes them, like the discrete theories, unable to satisfy or conflict with EMgine's ability to produce *cognitively generated/slow, secondary emotions.* Unlike the discrete theories, the dimensional theories cannot define *fast, primary emotions* either.

Given the number of requirements they could support compared to those they cannot, EMgine examines the dimensional theories individually with respect to each high-level requirement. However, like the discrete theories, it is unlikely that they could support EMgine's needs sufficiently on their own.

6.3.3 Appraisal Theories

Appraisal theories propose that emotions arise from evaluations of the relationship between an individual's well-being and their environment rather than the environment's objective qualities (Smith and Kirby, 2000a, p. 86). This naturally accounts for individual differences since someone can appraise a situation differently than another (Smith and Kirby, 2009a, p. 1353). These theories often conceptualize more than one emotion processing pathway (Smith and Kirby, 2001, p. 129), allowing for flexible behaviours with different response times. This implies that appraisal theories do not conflict with the requirement to have both *fast, primary emotions* and *cognitively generated/slow, secondary emotions* in EMgine's design scope (Section 6.2.3). However, these theories mainly focus on the link between cognitive processing and emotion elicitation (Broekens, 2021, p. 354) so EMgine should only rely on them to define *cognitively generated/slow, secondary emotions*. The existence of multiple processing pathways implies the potential for variable levels of component complexity in multi-component emotion generation depending on the information available to the CME. This supports *Allowing developers to use EMgine on different levels of NPC complexity* (RF7).

Since the appraisal perspective is the only one that addresses the *cognitively generated/slow, secondary emotions* aspect of the design scope, EMgine must incorporate it. This is unsurprising: appraisal theories appear the most frequently in Affective Computing (Lisetti and Hudlicka, 2015, p. 97; Gratch and Marsella, 2015, p. 55) compared to discrete, dimensional, and neurophysiological theories. They can be relatively simple to realize computationally and often meet several CME requirements concerning input evaluation, emotion elicitation, and emotion response generation (Rodríguez and Ramos, 2015, p. 439). However, *which* of the appraisal theories EMgine should use is less clear so it must examine them more closely.

6.3.4 Neurophysiological Theories

Although they support the inclusion of the *fast, primary emotions* and *cognitively generated/slow, secondary emotions* components in the design scope (Section 6.2.3), processes and mechanisms in neurophysiological theories rely on the surrounding agent architecture (Sloman, 1987, p. 218, 225–226), learning mechanisms (e.g. Somatic Marker Hypothesis (Damasio, 1995, p. 179–180)), and/or the body's somatic and visceral responses (Damasio, 1995, p. 249–250; LeDoux, 1998, p. 41, 176). Since the *Mind-Body Interactions* emotion component is beyond the scope of EMgine (Section 6.2.3), and consequently cannot truly support *Independence from an Agent Architecture* (RF1), EMgine should not use theories from the neurophysiological perspective. There might be variations of these theories that could work, but the effort necessary to determine this is beyond the current scope.

6.4 Summary

Without criteria to measure with, choosing affective theories for EMgine is ineffectual. To ensure that EMgine embeds its focus in the design, the criteria are its high-level requirements and scope. The high-level requirements capture some of the needs of game designers, categorized as:

- Flexibility requirements, such that designers can adapt the CME to a variety of games, and
- Ease-of-use requirements, to minimize the burden of its use during development.

EMgine's scope is emotion generation alone. This means that it ignores any tasks concerned with expressing emotion, reasoning about emotion, or defining interactions between emotions and other components. There are also no assumptions about NPC embodiment to maximize EMgine's flexibility. Within the emotion generation task, EMgine should be able to generate fast, reactive emotions and slow, cognitively driven ones. Designing these independently allows game designers to control them individually for maximal flexibility.

Examining the theories broadly as perspectives shows that the neurophysiological theories are not suitable for satisfying EMgine's requirements. Therefore, EMgine only further examines theories from the discrete, dimensional, and appraisal perspectives with respect to high-level requirements.

Key Points

- Defining the high-level requirements and scope of EMgine provides a framework for choosing which affective theories to use
- One must consider the game designer's needs to increase a CME's chance of being adopted in practice
- The high-level requirements of a CME for believable NPCs include those that make the CME flexible and easy to use and guide the selection of affective theories that form the CME's theoretical foundation
- EMgine's scope includes *fast, primary emotions* and *slow, secondary emotions* within the *emotion generation* task with no assumptions about NPC embodiment
- The *discrete*, *dimensional*, and *appraisal* theoretical perspectives on emotion are likely to be the most helpful for EMgine's design, whereas the *neurophysiological* theories are not ideal due to conflicts with some high-level requirements

Chapter 7

Support Your EMgine: The Requirements Choose the Theories

Scan complete.

Baymax, *Big Hero 6*

With the broad "themes" of emotion theories identified, EMgine proceeds to examine theories (Table 7.1) within those themes to see "how well" they satisfy each high-level requirement individually given EMgine's design scope and domain of NPC behaviour for player engagement (i.e. content analysis stage in document analysis). It does this by identifying features of each theory and interpreting their "ability" to support a high-level requirement (Section 7.1). This data guides the final selection process (i.e. drawing recommendations/conclusions, Section 7.2). *This analysis is, in part, subjective* because a judgment—however well-supported by evidence from the literature—is made without true objective measures or methods. A different understanding of the requirements and evolution of Affective Science could produce variations in the results.

7.1 Approaching Theory Analysis

EMgine divides its high-level requirements into *system-level*, which applies to EMgine as a whole, and *component-level* for requirements that only apply to specific pieces of EMgine (Table 7.2). The analysis assigns categories for component-level requirements solely to appraisal theories because they concern process-related elements that discrete and dimensional theories do not address. Each

Table 7.1: Theories Analyzed for EMgine

Perspective	**Theories**
Discrete	Ekman & Friesen (Ek.), Izard (Iz.), Plutchik (Plu.)
Dimensional	Valence-Arousal (V-A), PAD Space (PAD)
Appraisal	Frijda (Frj.), Lazarus (Laz.), Scherer (Sch.), Roseman (Ros.), Ortony, Clore, and Collins (OCC), Smith & Kirby (S & K), Oatley & Johnson-Laird (O & JL)

Appendix B has notes about these theories/models

Table 7.2: Summary of High-Level Requirement Division

		System	Component
RF1	*Independence from an Agent Architecture*	✓	
RF2	*Choosing Which Tasks to Use*		✓
RF3	*Customization of Existing Task Parameters*		✓
RF4	*Allowing the Integration of Components*	✓	
RF5	*Allowing Designers to Choose What Emotions an NPC can Have*	✓	
RF6	*Allowing Developers to Specify How to Use CME Outputs*	✓	
RF7	*Ability to Operate on Different Levels of NPC Complexity*	✓	
RF8	*Be Efficient and Scalable*	✓	
RE1	*Hiding the Complexity of Emotion Generation*		✓
RE2	*Having a Clear API (Input)*		✓
RE2	*Having a Clear API (Output)*	✓	
RE3	*Minimizing Authorial Burden*	Excluded from analysis	
RE4	*Traceable CME Outputs*		✓
RE5	*Allowing the Automatic Storage and Decay of the Emotion State*		✓
RE6	*Showing that Emotions Improve the Player Experience*	✓	
RE7	*Providing Examples of Novel Game Experiences*	✓	

theory has unique elements which might make it better or worse for satisfying a particular requirement. The analysis notes these. However, is not unusual for theories from the same perspective to satisfy a requirement equally well. In these cases, the requirement examination treats these theories as a collective unit. Since the perspective-level analysis showed that the neurophysiological theories are ill-suited for EMgine, it does not analyze them in detail.

7.1.1 Scoping Some Requirements

While most of the high-level requirements do not need additional scoping for this analysis, some do to better focus on what information to search for.

The analysis separates *Providing a clear and understandable API* (RE2) into two—Input and Output—to get a better feel for each theory's usefulness and to acknowledge that some theories are better for emotion expression such as Ekman & Friesen.

The requirement for *Allowing the Integration of New Components* (RF4) is broad and EMgine should scope it for its initial design. New EMgine components could be non-affective—such as attention—and affective—like personality—in nature. Integrating non-affective components should be theory-agnostic because they are in separate components of mind (American Psychological Association, 2020a). From a software engineering perspective, one could view the mind as a system with distinct, interacting subsystems. Modular interfaces that control interactions between EMgine—the affective subsystem—and components from other subsystems would support this concept while also supporting EMgine's requirements for *Independence from an Agent Architecture* (RF1) and *Allowing Developers to Specify How to Use Outputs* (RF6). Integrating other affective components would depend on EMgine and its foundational theories, limited to only those components that its emotions or other types of affect can represent and connect to.

This requirements analysis focuses on three other types of affect as defined in Chapter 3.1: "core" affect, mood, and personality. Of these, it prioritizes personality because it is necessary for creating the consistent and coherent agent behaviours that influence believability (Reilly, 1996, p. 26; Loyall, 1997, p. 19; Ortony, 2002, p. 203).

Finally, the analysis excludes *Minimizing authorial burden* (RE3) because it focuses on helping game developers manage the creation of an increasing NPC population which is agnostic of the underlying theories.

7.1.2 Making Notes About and Scoring Emotion Theories

With these more specific high-level requirements, examining each theory with guidance from individual requirements produces a set of notes. After reviewing the notes, each theory has an assigned *score* describing its relative "suitability" for that requirement (Table 7.3). This step is somewhat subjective because the evaluations do not have true objective measures or methods. As an example, notes about the dimensional theories and RF5 are here, while the rest are in Appendix C. Tables 7.4, 7.5, 7.6, and 7.7 summarize the scores for each theory and requirement.

Table 7.3: Summary of Scoring Categories

Score Category	**Symbol**	**Definition**
Strong	☆☆☆	The theory appears to satisfy the requirement in a clear, understandable way and is likely to aid in EMgine's usability
Good	☆☆	The theory appears to satisfy the requirement and is somewhat defined
Weak	☆	The theory describes ways that *could* satisfy the requirement, but it is not fully defined or could make EMgine harder to use
Disqualified	–	The theory does not seem likely to be able to satisfy the requirement, or it violates other requirements when it can (including psychological validity)

Dimensional Theories: Allowing Designers to Choose What Emotions an NPC can Have (RF5)

Neither V-A or PAD strictly enforce the inclusion of specific emotion types. Instead, the use of dimensions allows for an infinite number of affective states. While this trivially supports the ability to *Allow Designers to Choose What Emotions an NPC can Have* (RF5), the dimensional theories might not be practical for EMgine on their own. Instead, point locations representing named emotions guide the addition of specific ones. This removes the burden of deciding where an emotion's location in dimensional space is from game designers if they do not want to do so themselves.

- **V-A** (☆)
  - Space represented by Valence and Arousal only represents part of an emotion episode (Yik et al., 2002, p. 90; Roseman, 2011, p. 441; Lisetti and Hudlicka, 2015, p. 97)
  - Not ideal → some emotions, like *Anger* and *Fear*, are difficult to differentiate without additional information
    - Might be some of the most common emotions that a game designer will use → could be the *only* two emotions required in some games (e.g. NPCs in oppositional First Person Shooters (FPSs) due to the game's pace and the limited time and ways that players interact with them)
  - Adding new emotions cannot be adequately contained in V-A
- **PAD** (☆☆)
  - Accompanied by a list of 151 emotion labels (Mehrabian, 1980, p. 42–45) identified from empirical data → notes their average location in PAD space and the standard deviation in the data
  - List is still finite and cannot account for cultural differences, might not cover all of the affective states that a game designer needs → list is long enough that there is a reasonable chance that a game designer can find all the affective state labels that they require
  - Prone to interpretation errors, as the designer's definition and the definition used to locate points in PAD space might not be the same → designers can make their own judgments of the suitability of a term based on its coordinates, potentially violating *Hiding the Complexity of Emotion Generation* (RE1)

Table 7.4: Support for System-Level **Flexibility** High-Level Requirements

		Ek.	Iz.	Plu.	V-A	PAD	Frj.	Laz.✒	Sch.	Ros.	OCC	S&K	O&JL
RF1	*Independence from an Agent Architecture*	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆	–	☆☆	☆☆☆	☆☆☆	☆☆☆
RF4	*Allowing the Integration of Components*✍	☆	☆☽	☆☆☽	☆☆☆♃	☆☆☆♃	☆☆☆	☆	☆	☆	☆☆☆	☆	☆☆☆
RF5	*Allowing Designers to Choose What Emotions an NPC can Have*	☆	–	☆☆☆	☆	☆☆	☆	☆	☆☆	☆☆	☆☆	☆	☆☆☆
RF6	*Allowing Developers to Specify How to Use CME Outputs*	☆☆	☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
RF7	*Ability to Operate on Different Levels of NPC Complexity*	☆☆	☆☆	☆☆	☆	☆	☆	☆☆☆	☆☆☆	☆☆	☆☆	☆☆☆	☆☆
RF8	*Be Efficient and Scalable*	☆☆	☆☆	☆☆	☆	☆	☆☆♀	☆☆☆	☆☆	☆	☆☆	☆☆☆	☆☆☆

See Table 7.3 for score category descriptions.

✒ *Excludes the Coping Process because it is part of action generation.*

✍ *Strictly focusing on "core" affect, mood, and personality.*

☽ *Natively supports integration with Personality.*

♃ *Personality integration based on the Five Factor Model (OCEAN).*

♀ *Might improve if some factors are not necessary for implementation scope.*

Table 7.5: Support for System-Level **Ease-of-Use** High-Level Requirements

		Ek.	Iz.	Plu.	V-A	PAD	Frj.	Laz.✒	Sch.	Ros.	OCC	S&K	O&JL
RE2	*Having a Clear API (Output)*	☆☆☆	☆	☆☆	☆	☆	☆☆	☆☆☆	☆	☆☆☆	☆☆	☆☆☆	☆☆☆
RE6	*Showing that Emotions Improve the Player Experience*	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆	☆	☆☆	☆☆
RE7	*Providing Examples of Novel Game Experiences*	☆	☆	☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆

See Table 7.3 for score category descriptions.

✒ *Excludes the Coping Process because it is part of action generation.*

Table 7.6: Support for Component-Level **Flexibility** High-Level Requirements

		Frj.	Laz.[†]	Sch.	Ros.	OCC	S&K	O&JL
RF2	*Choosing Which Tasks to Use*	☆	☆	☆☆☆	–	☆☆	☆☆	☆☆
RF3	*Customization of Existing Task Parameters*	☆☆☆	–	☆☆	–	☆☆	☆☆	☆☆

See Table 7.3 for score category descriptions.
[†] *Excludes the Coping Process because it is part of action generation.*

Table 7.7: Support for Component-Level **Ease-of-Use** High-Level Requirements

		Frj.	Laz.[†]	Sch.	Ros.	OCC	S&K	O&JL
RE1	*Hiding the Complexity of Emotion Generation*	☆☆☆	☆☆☆	☆☆☆	☆☆	☆☆	☆☆	☆☆
RE2	*Having a Clear API (Input)*	☆☆	–	☆☆	☆☆	☆	☆☆	☆☆☆
RE4	*Traceable CME Outputs*	☆☆☆	☆☆☆	☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
RE5	*Allowing the Automatic Storage and Decay of the Emotion State*	☆☆	☆☆	☆☆	–	☆☆	☆☆	☆☆

See Table 7.3 for score category descriptions.
[†] *Excludes the Coping Process because it is part of action generation.*

7.2 Theory Selection

After examining theories from the perspective of a high-level requirement, EMgine can compare their scores for their relative suitability (i.e. drawing recommendations/conclusions). For each requirement, counting occurrences of the score categories assigned to each theory gives them a "rank" relative to the others (Tables 7.4, 7.5, 7.6, and 7.7). This means that choosing theories that best serve a high-level requirement becomes a min/max problem where the goal is to maximize the number of *Strong* and *Good* scores while minimizing the *Weak* and *Disqualified* ones. More sophisticated analyses are not possible because the score categories are *nominal/categorical data*—code assignments representing a "suitability" attribute—so mathematical operations on them do not yield meaningful information (MacKenzie, 2013, p. 134–135).

If there is only one requirement, it is a straightforward selection process that could result in few theories to pick from. Choosing one of those theories requires some additional experimentation to see how well one can formalize them and which ones might be preferable. In practice, it is likely that there are multiple requirements to satisfy.

Choosing theories when there are multiple requirements means finding a balance between those theories that strongly satisfy some, but often not all, requirements. In some cases, it might be necessary to choose a theory that satisfies a high-priority requirement strongly and a low-priority one weakly. Referencing the CME's design scope helps with requirement prioritization and guides the theory selection task.

7.2.1 Choosing Only One Theory

If a CME design can use only one theory as its foundation (e.g. limiting design complexity, target game is relatively simple) the decision process is simple: pick the theory that most strongly satisfies the most requirements in priority order.

If this was the case for EMgine, eliminating the theories that have *Disqualified* scores in Tables 7.4, 7.5, 7.6, and 7.7 leaves Frijda, OCC, Smith & Kirby, and Oatley & Johnson-Laird. Of these, only Smith & Kirby and Oatley & Johnson-Laird have *Good* or *Strong* scores for the prioritized requirements. Either of these could be good choices, but experimenting with Oatley & Johnson-Laird for its suitability should be first because it has only *Good* and *Strong* scores for all requirements whereas Smith & Kirby have a few *Weak* scores for non-prioritized requirements.

7.2.2 Choosing Multiple Theories

It would be ideal if there was a single theory to explain affective phenomena. However, creating one theory of affect would require reconciling narrowly defined existing theories and their architectural assumptions (Lisetti and Hudlicka, 2015, p. 99). Instead of trying to create one unified model of emotion, one can combine theories to address different modelling needs.

If a CME can use more than one theory, the selection process becomes more difficult. One tactic would be to immediately eliminate theories that cannot satisfy a requirement (i.e. have a *Disqualified* score), but this might eliminate a theory that is well-suited in other aspects. For example, Tables 7.4, 7.5, 7.6, and 7.7 (no assigned score implies *Disqualified*) shows that the discrete and dimensional theories have considerably more *Disqualified* scores (6 to 7) than the appraisal theories (0 to 3). This is unsurprising because those requirements relate to the *process* of emotion generation, which reinforces the discrete and dimensional theories' inability to satisfy the need for *cognitively generated/slow, secondary emotions* specified in EMgine's design scope (Chapter 6.2). However, by choosing theories by this information alone we might prematurely eliminate theories that we could use to specify some requirements very well (e.g. PAD Space for integrating multiple types of affect). Choosing theories based on occurrences of *Strong* scores creates a similar problem, where a theory might be excellent for a few requirements but a poor choice for many others. Instead, the *coverage* achieved by the *set* of chosen theories must satisfy all prioritized requirements. It also becomes possible to build better support for non-prioritized requirements due to overall requirements coverage, unlike in the single-theory example (Section 7.2.1).

Finding such a set of theories benefits from a systematic decision-making process where information about the CME's high-level requirement scores and their derivation justifies each step (Figure 7.1):

(A) Prioritize ("sort") the high-level requirements using the CME's design scope, then go to B.

(B) Choose one theory or model that most strongly satisfies the high-level requirements in priority-order, then go to C.

(C) Decide if the CME can use more than one theory and/or model in its design.

  (a) If NO (e.g. limiting design complexity, target application is relatively simple), then go to H.

  (b) If YES, then go to D.

(D) Decide if the CME can use theories and/or models from *different* perspectives (e.g. discrete, dimensional, appraisal) in its design (see Section 7.2.2 for discussion).

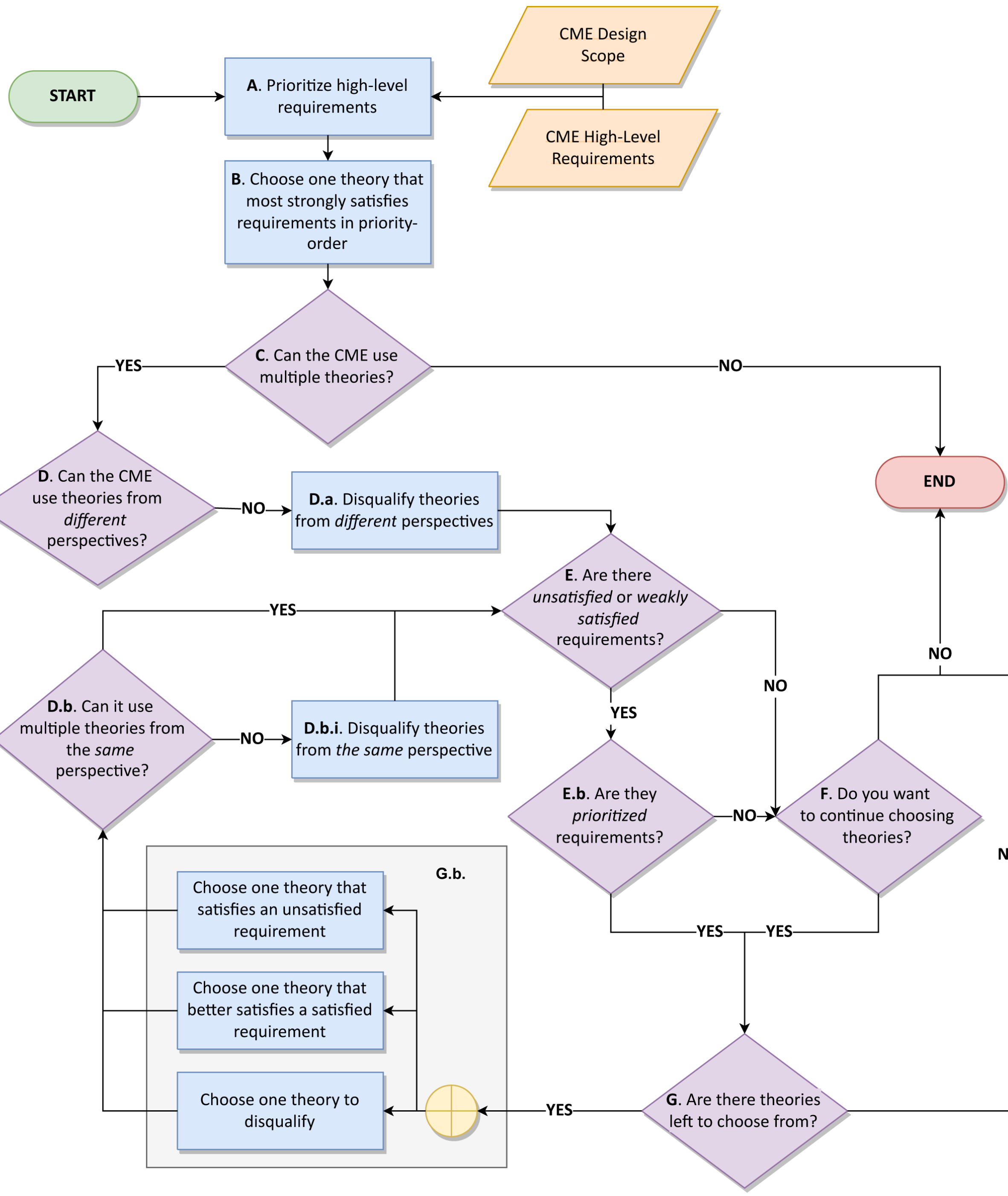


Figure 7.1: Overview of the Proposed Decision Process for Choosing a CME's Emotion Theories/Models

(a) If NO, disqualify all theories from the perspectives that the initial theory/model *does not* belong to and go to E.

(b) If YES, decide if the CME can use more than one theory and/or model from the *same* perspective in its design.

(i) If NO, disqualify all theories from the perspectives that the initial theory/model *does* belong to and go to E.

(ii) If YES, then go to E.

(E) Determine if there are any unsatisfied or weakly satisfied requirements.

(a) If NO, then go to F.

(b) If YES, determine if they are priority requirements.

(i) If NO, then go to F.

(ii) If YES, then go to G.

(F) Decide if the decision-making process should continue. Requirement priority, time constraints, and personal preference influence this decision.

(a) If NO, then go to H.

(b) If YES, then go to G.

(G) Determine if there are still emotion theories and/or models to choose from.

(a) If NO, then go to H.

(b) If YES, do one of:

- Choose a theory/model that satisfies an unsatisfied requirement, in priority-order, then go to D.b.
- Choose a theory/model that satisfies an already satisfied requirement more strongly, in priority-order, then go to D.b.
- Disqualify a theory/model, then go to D.b.

(H) End the process.

The decision-making process terminates after satisfying all prioritized requirements and the process is voluntarily stopped, or when there are no theories and/or models left to choose from because they have already been chosen or disqualified. This process also works for designs that can only use one theory because steps A., B., and C. are the same as those described in Section 7.2.1.

Can You Combine Theories From Different Theoretical Perspectives?

Depending on the CME's intended purpose, it is possible to combine theories from different perspectives in a single design. The discrete, dimensional, and appraisal perspectives are complementary[1] (Broekens, 2021, p. 354–355) and capture key features of emotion phenomena (Figure 7.2). Theorists from different perspectives generally agree that emotions are part of a coherent, organized system that largely serves adaptive functions (Smith and Kirby, 2001, p. 121). People should, instead, view each perspective as an alternate conceptualization of the same ideas with their own explanations, scope, and empirical data (Hudlicka, 2014a, p. 306–307). Consequently, and as shown

[1] Appraisal and discrete theories appear to be especially compatible (Reisenzein et al., 2013, p. 250).

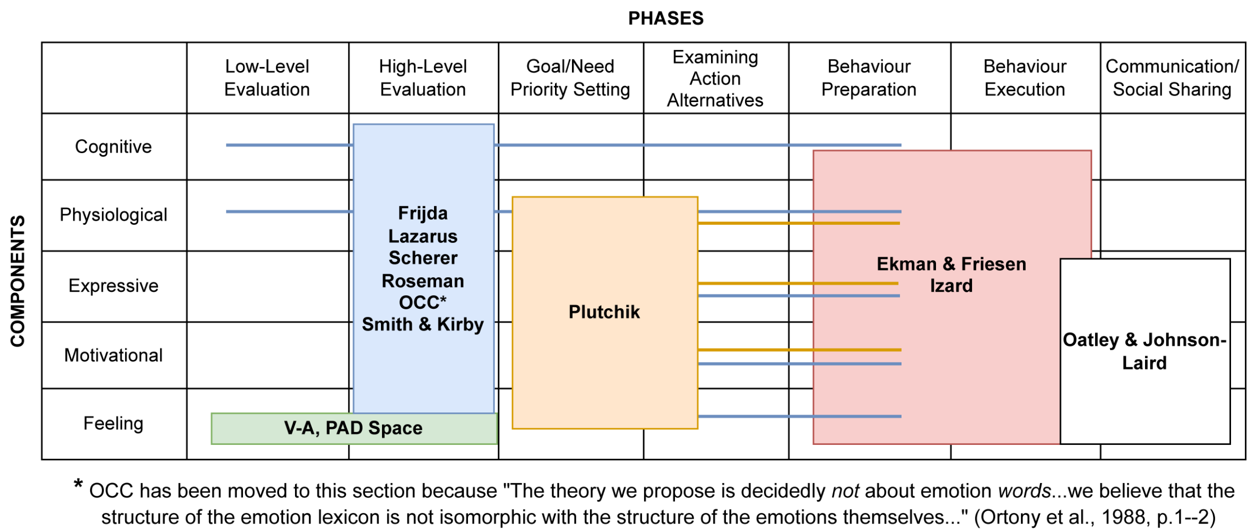


Figure 7.2: Coverage of Different Perspectives for Emotion Processes and Components (Adapted and Modified from Scherer (2010b, p. 11))

by the perspective-level analysis (Chapter 6.3), they provide different degrees of support for modelling emotion processes that designers can combine to address gaps in models. It is not surprising that CME designs, at least implicitly, combine multiple theories in their design (Hudlicka, 2014b, p. 10).

The complementary nature of these theoretical perspectives implies that choosing theories from different perspectives can support different functions and provide better support for more requirements than any perspective individually. However, this increases the CME's internal complexity and also comes with the risk of lowering a CME's psychological validity if design-time decisions create conflicting assumptions and/or models (Lisetti and Hudlicka, 2015, p. 99). A CME's tolerance for this risk depends on its intended purpose and application domain (see Chapter 4.1 for discussion).

Using the Decision-Making Process for EMgine

Referring to the theory scores in Tables 7.4, 7.5, 7.6, and 7.7 and the information that drove their derivation (i.e. design scope (Chapter 6.2), analysis of broad perspectives (Chapter 6.3), and notes about how theories could satisfy requirements (Appendix C)), EMgine choose three theories for EMgine—Oatley & Johnson-Laird, Plutchik, and PAD Space:

1. *Prioritize High-Level Requirements* (Step A.)

   EMgine prioritizes RF1, RF6, RF7, RF8, RE1, RE2, and RE4 because it is unlikely that developers will adopt EMgine without them. The remaining requirements offer more options to tailor it to different game designs (RF2, RF3, RE5) and/or could be satisfied as an extension later on (RF4, RF5, RE6, RE7).

2. *Choose an Initial Theory or Model* (Step B.)

   The first chosen theory must support as many requirements as possible for both the system-level and component-level (Section 7.1) to maximize coverage. For EMgine, this means choosing an *appraisal theory* because discrete and dimensional theories cannot support the prioritized component-level requirements RE1, RE2 (Input), and RE4.

There are three appraisal theories that have *Disqualified* scores (Table 7.8): Lazarus, Scherer, and Roseman. Both Lazarus and Scherer are *Disqualified* for a priority requirement (RE2 (Input) and RF1 respectively), so EMgine should not choose them. Neither should it choose Roseman because it has a *Weak* score for a priority requirement. Roseman also has an ill-defined emotion elicitation process compared to the others (e.g. Appendix C.3.2) which makes it a weak initial choice for EMgine, an emotion generation-focused CME.

Of the remaining theories, Oatley & Johnson-Laird is the most promising: it has *Strong* scores for all but one priority requirement (RE1) and only *Good* and *Strong* scores for non-prioritized ones. Compared to the remaining appraisal theories—Frijda, OCC, and Smith & Kirby—Oatley & Johnson-Laird has the same score as the next strongest candidate for all requirements except for RF3 (Frijda), RF7 (Smith & Kirby), and RE1 (Frijda). While two of these are priority requirements, it is a reasonable trade-off for achieving a minimum score of *Good* for *all* requirements. Therefore, EMgine's initial theory is Oatley & Johnson-Laird.

3. *Can EMgine use more than one theory?* YES (Step C.b.)

   EMgine could use one theory but would be difficult for it to have all of the required emotion components (Chapter 6.2.3), as none of the discrete, dimensional, or appraisal perspectives provides them all. There is no reason to limit EMgine to one theory because the added complexity would be internal to EMgine (otherwise it would conflict with RE1, a priority requirement), so it should consider a combination of them.

4. *Can EMgine use theories from different perspectives?* YES (Step D.b.)

   From the analysis of broad perspectives (Chapter 6.3), the discrete and dimensional theories cannot satisfy the need for *cognitively generated/slow, secondary emotions* in EMgine's design scope (Chapter 6.2.3). This means that it must use at least one appraisal theory. It also knows that the discrete theories can best address the need for *fast, primary emotions*. Therefore, EMgine should choose at least one appraisal and one discrete theory. This approach is sufficient because EMgine is a domain-specific model (see Chapter 4.1 for discussion)—it does not need to faithfully replicate affective processes (Hudlicka, 2019, p. 131).

5. *Can EMgine use multiple theories from the same perspective?* NO (Step D.b.i.)

   There does not appear to be a need for more appraisal theories because the motivation for using multiple theories is to address different aspects of EMgine's design scope that only one type of theory cannot satisfy. Since Oatley & Johnson-Laird already satisfy every high-level requirement with a minimum score of *Good*, EMgine removes the remaining appraisal theories from the candidate pool.

6. *Are there any unsatisfied or weakly satisfied requirements?* NO (Step E.a.)

   Every requirement is currently satisfied with a minimum score of *Good*.

7. *Should EMgine continue to choose theories?* YES (Step F.b.)

   The motivation for using theories from different perspectives is to address different aspects of EMgine's design scope (see step 4). Therefore, the decision-making process continues because there are other theories to choose from.

Table 7.8: Summary of Support for High-Level Requirements by Appraisal Theories

			Frj.	**OCC**	**S&K**	**O&JL**	**Laz.**	**Sch.**	**Ros.**
❄	RF1	*Independence from an Agent Architecture*	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆	–	☆☆
❄	RF6	*Allowing Developers to Specify How to Use CME Outputs*	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
❄	RF7	*Ability to Operate on Different Levels of NPC Complexity*	☆	☆☆	☆☆☆	☆☆	☆☆☆	☆☆☆	☆☆
❄	RF8	*Be Efficient and Scalable*	☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆	☆
❄	RE1	*Hiding the Complexity of Emotion Generation*	☆☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆☆	☆☆
❄	RE2	*Having a Clear API (Input)*	☆☆	☆	☆☆	☆☆☆	–	☆☆	☆☆
❄	RE2	*Having a Clear API (Output)*	☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆	☆	☆☆☆
❄	RE4	*Traceable CME Outputs*	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆	☆☆☆
	RF2	*Choosing Which Tasks to Use*	☆	☆☆	☆☆	☆☆	☆	☆☆☆	–
	RF3	*Customization of Existing Task Parameters*	☆☆☆	☆☆	☆☆	☆☆	–	☆☆	–
	RF4	*Allowing the Integration of Components*	☆☆☆	☆☆☆	☆	☆☆☆	☆	☆	☆
	RF5	*Choosing NPC Emotions*	☆	☆☆	☆	☆☆☆	☆	☆☆	☆☆
	RE3	*Minimizing Authorial Burden*	Excluded from analysis						
	RE5	*Allowing the Automatic Storage and Decay of the Emotion State*	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	–
	RE6	*Showing that Emotions Improve the Player Experience*	☆☆	☆	☆☆	☆☆	☆☆	☆☆☆	☆☆
	RE7	*Providing Examples of Novel Game Experiences*	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆

❄ *Priority requirement*

8. *Are there still emotion theories and/or models for EMgine to choose from?* YES (Step G.b.)

   The other appraisal theories are no longer in the candidate pool (see step 5), leaving the discrete and dimensional ones. Of these, EMgine likely needs a discrete theory (see step 4), so it examines these next. Since Oatley & Johnson-Laird satisfy all requirements, EMgine is looking for a theory to either more strongly satisfy an already satisfied requirement or a theory to disqualify.

   Table 7.9 shows that the discrete theories' scores vary for only three requirements: RF4, RF5, and RE2 (Output). Izard is *Disqualified* for one requirement that the others are not (RF5) and has no *Strong* scores. Therefore, it cannot satisfy any requirement more strongly than Oatley & Johnson-Laird—which has a *minimum* score of *Good* for all requirements—and EMgine should not use it. Therefore, it disqualifies Izard from the candidate pool.

9. *Can EMgine use multiple theories from the same perspective?* NO (Step D.b.i.)

   EMgine has only chosen one theory so far, an appraisal theory, and removed all other appraisal theories from the candidate pool. Therefore, it continues to the next step.

10. *Are there any unsatisfied or weakly satisfied requirements?* NO (Step E.a.)

    Every requirement remains satisfied with a minimum score of *Good*.

Table 7.9: Summary of Support for High-Level Requirements by Discrete Theories

			Ek.	Plu.	Iz.
❋	RF1	*Independence from an Agent Architecture*	☆☆	☆☆	☆☆
❋	RF6	*Allowing Developers to Specify How to Use CME Outputs*	☆☆	☆☆	☆☆
❋	RF7	*Ability to Operate on Different Levels of NPC Complexity*	☆☆	☆☆	☆☆
❋	RF8	*Be Efficient and Scalable*	☆☆	☆☆	☆☆
❋	RE1	*Hiding the Complexity of Emotion Generation*	–	–	–
❋	RE2	*Having a Clear API (Input)*	–	–	–
❋	RE2	*Having a Clear API (Output)*	☆☆☆	☆☆	☆
❋	RE4	*Traceable CME Outputs*	–	–	–
	RF2	*Choosing Which Tasks to Use*	–	–	–
	RF3	*Customization of Existing Task Parameters*	–	–	–
	RF4	*Allowing the Integration of Components*	☆	☆☆	☆
	RF5	*Choosing NPC Emotions*	☆	☆☆☆	–
	RE3	*Minimizing Authorial Burden*	Excluded from analysis		
	RE5	*Allowing the Automatic Storage and Decay of the Emotion State*	–	–	–
	RE6	*Showing that Emotions Improve the Player Experience*	☆☆	☆☆	☆☆
	RE7	*Providing Examples of Novel Game Experiences*	☆	☆	☆

❋ *Priority requirement*

11. *Should we continue to choose theories for EMgine?* YES (Step F.b.)

    The reasoning is the same as step 7.

12. *Are there still emotion theories and/or models for EMgine to choose from?* YES (Step G.b.)

    EMgine has not yet considered all discrete theory candidates, so it continues its examination to find one that better satisfies a requirement than Oatley & Johnson-Laird or that it can disqualify.

    Ekman & Friesen and Plutchik have different scores for three requirements (Table 7.9): RE2 (Output) (Ekman & Friesen *Strong*, Plutchik *Good*), RF4 (Ekman & Friesen *Weak*, Plutchik *Good*), and RF5 (Ekman & Friesen *Weak*, Plutchik *Strong*). By scores alone, neither of these theories satisfy any requirement better than Oatley & Johnson-Laird. Certainly not for RF4 which Oatley & Johnson-Laird have a *Strong* score for. However, scrutinizing Ekman & Friesen for RE2 (Output) and Plutchik for RF5 shows small but significant differences in their support of those requirements.

    For RE2 (Output), EMgine notes that Ekman & Friesen wrote their publication on facial expressions for the general public (Appendix C.1.3). However, Oatley & Johnson-Laird's identification of basic emotions are partially based on and "[are] consistent with" Ekman & Friesen's findings (Oatley and Johnson-Laird, 1987, p. 33, 47). This implies that EMgine's overall design would not benefit from using Ekman & Friesen explicitly because it can leverage these strengths implicitly through Oatley & Johnson-Laird.

    Concerning Plutchik and RF5 (Appendix C.1.2), EMgine sees that it uses a colour wheel analogy to describe the creation of "new" emotions based on how a layperson understands "emotion combinations". This does not require additional processes/data sources like Oatley & Johnson-Laird do, which create "new/complex" emotions by adding semantic content to "basic" emotions (Appendix C.3.5). This implies that EMgine would benefit from Plutchik as it could support RF5 in entities with low complexity as required by RF7. Happily, Plutchik also has a better score distribution than Ekman & Friesen (Seven to five *Good* scores and equal counts of *Disqualified* and *Strong* scores). Therefore, EMgine chooses Plutchik to address *fast, primary emotions* in its design scope while also improving coverage of RF5.

13. *Can EMgine use multiple theories from the same perspective?* NO (Step D.b.i.)

    EMgine does not appear to need multiple discrete theories for (see step 4 for rationale) and Ekman & Friesen's benefits are implicitly captured by Oatley & Johnson-Laird (see Step 12 for rationale). Therefore, EMgine removes all remaining discrete theories from the candidate pool.

14. *Are there any unsatisfied or weakly satisfied requirements?* NO (Step E.a.)

    Every requirement remains satisfied with a minimum score of *Good*.

15. *Should EMgine continue to choose theories?* YES (Step F.b.)

    One could stop here, ignoring the dimensional theories. The coverage of Oatley & Johnson-Laird and Plutchik satisfies all requirements with a minimum score of *Good*. However, from the perspective-level analysis (Chapter 6.3), EMgine knows that dimensional theories are especially suitable for representing different types of affect and their interactions in a common space—which is promising for RF4—and afford more control over what emotions could "do" in an NPC, which is promising for RF6. The additional design freedom afforded to game developers for believable NPC behaviours suggests that including a dimensional theory could increase EMgine's overall flexibility. Therefore, EMgine continues the decision-making process.

16. *Are there still emotion theories and/or models for EMgine to choose from?* YES (Step G.b.)

    The dimensional theories remain, so EMgine examines these now. V-A and PAD Space have identical scores except for one—RF5—which PAD Space scores higher on (Table 7.10). Therefore, EMgine considers this model first.

    The scores for PAD Space do not make it obvious if it better satisfies any requirement than the coverage achieved with Oatley & Johnson-Laird and Plutchik. However, the rationale in step 15 suggests that PAD Space could add new ways to address RF4 and RF6. Therefore, EMgine chooses to include it to improve its coverage of these requirements.

17. *Can EMgine use multiple theories from the same perspective?* NO (Step D.b.i.)

    There does not appear to be a benefit in including a second dimensional theory in EMgine. Additionally, EMgine could construct V-A in PAD Space due to their overlapping dimensions (Table 7.11), so there is no need to explicitly include it. Therefore, EMgine removes all remaining dimensional theories from the candidate pool.

18. *Are there any unsatisfied or weakly satisfied requirements?* NO (Step E.a.)

    Every requirement remains satisfied with a minimum score of *Good*.

19. *Should EMgine continue to choose theories?* YES (Step F.b.)

    Answering this question with NO here does not change the outcome. For illustrative purposes, EMgine chooses YES to show that this process terminates when every candidate theory/model has been chosen or disqualified.

Table 7.10: Summary of Support for High-Level Requirements by Dimensional Theories

			V-A	PAD
❋	RF1	*Independence from an Agent Architecture*	☆☆	☆☆
❋	RF6	*Allowing Developers to Specify How to Use CME Outputs*	☆☆☆	☆☆☆
❋	RF7	*Ability to Operate on Different Levels of NPC Complexity*	☆	☆
❋	RF8	*Be Efficient and Scalable*	☆	☆
❋	RE1	*Hiding the Complexity of Emotion Generation*	–	–
❋	RE2	*Having a Clear API (Input)*	–	–
❋	RE2	*Having a Clear API (Output)*	☆	☆
❋	RE4	*Traceable CME Outputs*	–	–
	RF2	*Choosing Which Tasks to Use*	–	–
	RF3	*Customization of Existing Task Parameters*	–	–
	RF4	*Allowing the Integration of Components*	☆☆☆	☆☆☆
	RF5	*Choosing NPC Emotions*	☆	☆☆
	RE3	*Minimizing Authorial Burden*	Excluded from analysis	
	RE5	*Allowing the Automatic Storage and Decay of the Emotion State*	–	–
	RE6	*Showing that Emotions Improve the Player Experience*	☆☆	☆☆
	RE7	*Providing Examples of Novel Game Experiences*	☆☆	☆☆

❋ *Priority requirement*

20. *Are there still emotion theories and/or models for EMgine to choose from?* NO (Step G.a.)

    Since EMgine chose not to use multiple theories from the *same* perspective, it disqualified all theories/models except for the chosen three: Oatley & Johnson-Laird, Plutchik, and PAD Space. The decision-making process ends.

This execution of the process for EMgine produced three theories that fully cover all its high-level requirements: Oatley & Johnson-Laird because it has only *Strong* or *Good* scores for *all* requirements; Plutchik because it provides additional, complementary support for RF5; and PAD Space to afford more flexibility for RF4 and RF6 without detracting from Oatley & Johnson-Laird and Plutchik.

7.3 Summary

Although somewhat subjective, examining each theory in the discrete, dimensional, and appraisal perspectives and assigning them a categorical score reveals which high-level requirements they could

Table 7.11: Comparison of Dimensions in Dimensional Theories

Dimension	**Valence-Arousal (V-A)**	**PAD (Mehrabian, 1996b)**
Pleasure/Valence	✓	✓
Arousal	✓	✓
Dominance		✓

satisfy and how well. It is clear that EMgine needs at least one appraisal theory because they are the only ones that can satisfy component-level requirements. The next question is which and how many appraisal theories EMgine should use, and if it also needs theories from the discrete and/or dimensional perspectives.

EMgine must have an appraisal theory to specify *cognitively generated/slow, secondary emotions* and a discrete theory for *fast, primary emotions* to satisfy EMgine's design scope. Using a systematic decision-making process, EMgine chose three theories to fully cover all its high-level requirements (Table 7.12): Oatley & Johnson-Laird as its appraisal theory because it has the best requirements score distribution with only *Strong* or *Good* scores; Plutchik as its discrete theory because it provides additional, complementary support for RF5; and PAD Space, a dimensional theory, because it affords more flexibility for RF4 and RF6 without detracting from Oatley & Johnson-Laird and Plutchik. EMgine does not necessarily need to use PAD Space, so it can be safely removed from the design if it proves difficult to integrate.

Table 7.12: Coverage of EMgine High-Level Requirements by Chosen Theories

			O&JL	**Plu.**	**PAD**
❄	RF1	*Independence from an Agent Architecture*	☆☆☆ 🙌	☆☆	☆☆
❄	RF6	*Allowing Developers to Specify How to Use CME Outputs*	☆☆☆	☆☆	☆☆☆ 🙌
❄	RF7	*Ability to Operate on Different Levels of NPC Complexity*	☆☆ 🙌	☆☆	☆
❄	RF8	*Be Efficient and Scalable*	☆☆☆ 🙌	☆☆	☆
❄	RE1	*Hiding the Complexity of Emotion Generation*	☆☆ 🙌	–	–
❄	RE2	*Having a Clear API (Input)*	☆☆☆ 🙌	–	–
❄	RE2	*Having a Clear API (Output)*	☆☆☆ 🙌	☆☆	☆
❄	RE4	*Traceable CME Outputs*	☆☆☆ 🙌	–	–
	RF2	*Choosing Which Tasks to Use*	☆☆ 🙌	–	–
	RF3	*Customization of Existing Task Parameters*	☆☆ 🙌	–	–
	RF4	*Allowing the Integration of Components*	☆☆☆	☆☆	☆☆☆ 🙌
	RF5	*Choosing NPC Emotions*	☆☆☆	☆☆☆ 🙌	☆☆
	RE3	*Minimizing Authorial Burden*	Excluded from analysis		
	RE5	*Allowing the Automatic Storage and Decay of the Emotion State*	☆☆ 🙌	–	–
	RE6	*Showing that Emotions Improve the Player Experience*	☆☆	☆☆	☆☆
	RE7	*Providing Examples of Novel Game Experiences*	☆☆	☆	☆☆

❄ *Priority requirement*
🙌 *Best satisfies requirement*

Key Points

- EMgine's high-level requirements are the evaluation perspective that it views theories from the discrete, dimensional, and appraisal perspectives from
- For each requirement and theory, notes record information from the Affective Science literature relevant to their evaluation
- After reviewing those notes, categorical scores show a theory's "suitability" for satisfying a requirement
- Assigned scores are at least partially subjective, which could change based on how requirements and theories are understood and developments in affective science
- Scores form the basis for selecting theories to based EMgine's design on
- A combination of theories is best for EMgine as there are no strict restrictions on its design complexity and it takes advantage of each perspective's strengths while mitigating their weaknesses
- After examining their scores in Tables 7.4, 7.5, 7.6, and 7.7, EMgine uses Oatley & Johnson-Laird (appraisal), Plutchik (discrete), and PAD Space (dimensional)

Chapter 8

Interlude: Choosing Theories for Other CMEs

Come with me if you want to live.

The Terminator, *Terminator 2: Judgment Day*

The vision for EMgine is to afford game developers a way to integrate emotion in their Non-Player Characters (NPCs) such that they enhance player engagement. It also aims to give game developers complete freedom to specify how to use its outputs (RF6) because they know how to best engage players with "emotional" NPCs.

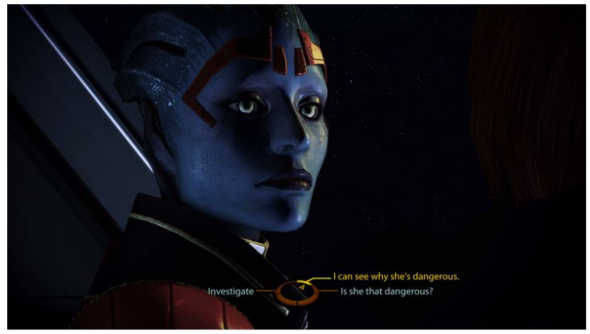
Due to the choice of theories, EMgine can provide both categorical (e.g. emotion types) and dimensional (e.g. variables) data, which offers a wider range of mechanisms for expressing NPC emotions. This is important because these mechanisms vary with the game—a text-based game does not have the same ways to express NPC emotions as one with graphics, which itself varies with resolution (e.g. 2D sprites versus 3D models). This also allows developers to specify how EMgine synchronizes with other game elements (e.g. camera, story manager) that might have their own concept of "emotion" to create a cohesive, contextually-relevant player experience (PX). The methodology and decision-making process led to three theories—Oatley & Johnson-Laird, Plutchik, and PAD Space—that support the vision for EMgine (Section 7.2.2). This begs the question: is the methodology useful for choosing theories for Computational Models of Emotion (CMEs) with different requirements and/or scope?

8.1 Sketch of Choosing Theories for a CME that Expresses Emotion

Another kind of CME that is beneficial for games—and complementary to one that generates emotion—is one that selects an NPC's facial expression based on its current emotion. During player-NPC dialogue interactions, the NPC's facial expression often conveys more information that influences a player's response because "the face is one of the most powerful channels of nonverbal communication" (De la Torre and Cohn, 2011, p. 377). For example, Orgnar's expression helps convey how he feels about different conversation topics to add "flavor" to the interaction, while Samara's expression shows us her grief for her estranged daughter which could interest a player in other conversation options that could lead to new tasks or missions (Figure 8.1).

It is common for Ekman & Friesen to appear in CMEs that model facial expressions (Hudlicka,

(a) Orgnar from *The Elder Scrolls V: Skyrim* (Bethesda Game Studios, 2011)



(b) Samara from *Mass Effect 2* (BioWare, 2010)

Figure 8.1: Character dialogue screens where their facial expressions are a prominent aspect of the interface and contribute to the interaction

2014b, p. 4). This is an expected outcome for this short example of a facial expression-oriented CME—EMgine/Express—aimed at character dialogue screens where the character's face is prominently visible:

1. Reviewing the high-level requirements (Chapter 6.1) with respect to generating facial expressions from emotion labels or dimensions/appraisal variables, RF6 and RE7 no longer apply because EMgine/Express targets a specific output method with a specific purpose (facial expressions in NPC dialogue screens)—there is no need to account for emotion expression mechanisms or their influence on CME processes. RE1 is also no longer applicable because EMgine/Express gives the designer control over how and when a character shows their emotion, which requires some level of understanding of those mechanisms/rules. RE5 might still apply if game designers want to treat the "decay" of facial expressions separately from the emotions themselves. The remaining requirements are still applicable to EMgine/Express.

2. For the design scope (Chapter 6.2), EMgine/Express focuses on *Emotion Effects on Behaviour* because facial expressions are an observable (i.e. external) behaviour of an internal emotion state. Since it is targeting NPC dialogue screens where their face is visible, EMgine/Express scopes the NPC's embodiment to those that include a face. Finally, EMgine/Express chooses to focus on the *emergent emotions* emotion component because it is not eliciting emotions (primary and secondary emotion components), reasoning about them in connection with other aspects of the NPC (emotional experience), nor connecting facial expressions into the NPC's internal systems (mind-body interactions). Including these components requires assumptions about the NPC's other elements and additional aspects of its embodiment that EMgine/Express does not want to make.

3. From the examination of the perspectives of emotion (Chapter 6.3), EMgine/Express chooses to delve into discrete theories because they categorize emotion types by their observable features that laypeople typically recognize. It also chooses to delve into dimensional theories because they can relate different types of affect. Their numerical representation might be also useful for generating "in-between" expressions for more fluid animation transitions. EMgine/Express will not examine the appraisal and neurophysiological theories because of their focus on internal processes and their relative complexity.

4. After analyzing each candidate theory in the discrete and dimensional perspectives with respect to the high-level requirements (Chapter 7.1), EMgine/Express derives the example scores shown in Table 8.1. Finally, it begins the decision-making process (Chapter 7.2):

   (a) EMgine/Express prioritizes requirements that enforce a game developer's ability to tailor an NPC's expressions (perhaps in collaboration with their character artist(s)) in their chosen development environment easily and to ensure that players can observe the results with minimal effort so that it does not interfere with the intended message. Therefore, it prioritizes RF1, RF3, RF5, RF7, RF8, RE2, RE3, RE4, and RE6.

   (b) For the initial theory, EMgine/Express sees that: V-A and PAD Space weakly satisfy priority requirements RF1, RE2, and RE6; Izard weakly satisfies RF5; and Plutchik weakly satisfies RE6. Since Ekman & Friesen have only *Strong* and *Good* scores for all priority requirements, it is the best option for an initial theory. Therefore, EMgine/Express chooses it.

   This makes sense because Ekman & Friesen focus on facial expressions as an indicator of emotion kinds (Ekman, 2007) and has a well-known system for identifying facial expressions from facial muscle movements (Ekman et al., 2002). This makes it ideal for guiding the design of a system that controls them. This example also illustrates that relying on counts of *Strong* alone is not reliable because Ekman & Friesen, V-A, and PAD Space have equal counts of *Strong* scores.

   (c) For argument's sake, EMgine/Express assumes that it can use multiple theories. They do not have to be from the same perspective, nor be the only one chosen from a perspective. Now EMgine/Express must decide if it should continue the decision-making process or

Table 8.1: Example Scores for EMgine/Express, a Facial Expression-Oriented CME

			Discrete			**Dimensional**	
			Ekman & Friesen	Izard	Plutchik	V-A	PAD Space
Flexibility	❋	RF1	☆☆	☆☆	☆☆	☆	☆
		RF2	☆☆	☆☆	☆☆	☆☆☆	☆☆☆
	❋	RF3	☆☆☆	☆☆	☆☆	☆☆☆	☆☆☆
		RF4	☆☆☆	☆☆	☆	☆☆☆	☆☆☆
	❋	RF5	☆☆☆	☆☆☆	☆☆	☆☆☆	☆☆☆
		RF6	Not applicable				
	❋	RF7	☆☆☆	☆☆	☆☆	☆☆☆	☆☆☆
	❋	RF8	☆☆	☆☆	☆☆	☆☆☆	☆☆☆
Ease-of-Use		RE1	Not applicable				
	❋	RE2	☆☆☆	☆☆☆	☆☆	☆	☆
	❋	RE3	☆☆☆	☆☆☆	☆☆	☆☆☆	☆☆☆
	❋	RE4	☆☆☆	☆☆☆	☆☆	☆☆	☆☆
		RE5	☆	☆	☆	☆☆☆	☆☆☆
	❋	RE6	☆☆☆	☆☆☆	☆	☆	☆
		RE7	Not applicable				

❋ = *Priority Requirement*
☆☆☆= *Strong*, ☆☆= *Good*, ☆= *Weak*, – = *Disqualified*

end it. Ekman & Friesen have only one weakly satisfied requirement and it is not a priority one (RE5). Although it could stop the process here, EMgine/Express chooses to continue because there are only four other options to examine and it will be easy to exhaust them.

(d) In this cycle, EMgine/Express compares the discrete theories and finds that Izard also uses facial expressions as an indicator of emotion kinds (Izard, 1977) and has a system for identifying facial expressions from facial muscle movements (Izard, 1995) like Ekman & Friesen. Izard also appears to identify more expressions than they do. However, Izard is unable to better satisfy any requirement than Ekman & Friesen, so EMgine/Express disqualifies it.

Later, EMgine/Express might use Izard to justify the configuration of expressions for emotion kinds that Ekman & Friesen do not specify (e.g. *Interest*, *Shame* (Izard, 1977, 1971)). Ekman & Friesen could implicitly support this due to their significant overlap and by specifying them as a "blend" of other expressions (Ekman, 2007, p. 3, 69).

(e) Continuing the selection process, EMgine/Express examines Plutchik. This theory identifies emotion kinds by their intended "effect" (e.g. *Fear* has the intended effect of "Protection") (Plutchik, 1984) and does not explicitly connect them to expression mechanisms. Since EMgine/Express is focusing on facial expressions specifically, it chooses to disqualify Plutchik from the candidate pool.

(f) EMgine/Express now considers V-A and PAD Space because they can satisfy RF2, RF8 (a prioritized requirement), and RE5 better than Ekman & Friesen. In this case, V-A and PAD Space have identical scores for all requirements so EMgine/Express must look more closely to see which, if either, one it chooses to use.

People tend to judge facial expressions in a circumplex structure along the V-A dimensions (Barrett and Bliss-Moreau, 2009) and researchers have connected these dimensions to individual facial muscle movements (Smith and Scott, 1997). PAD Space also makes some connections between its dimensions and facial expressions (Mehrabian, 1980, p. 186), although they are less defined than V-A. However, PAD Space offers an additional dimension that developers can manipulate to produce more variation in NPC expressions while retaining the benefits of the V-A dimensions (Bakker et al., 2014). Therefore, EMgine/Express chooses PAD Space over V-A.

(g) In the previous step EMgine/Express reasoned that PAD Space could adequately capture V-A within itself, so it disqualifies V-A. The decision-making process now stops because there are no more theories to choose from.

By following the methodology and decision-making process, EMgine/Express first chose Ekman & Friesen—an expected outcome—and found that PAD Space could also be useful. Existing facial expression-generating CMEs have combined these theories successfully (Bidarra et al., 2010; Breazeal, 2003)[1,2], implying that they are reasonable outcomes.

[1] The Soul (60) and Kismet (53), included in the CME survey (Chapter 5)

[2] Breazeal (2003) uses *stance* rather than *dominance* but it appears to serve a comparable purpose.

8.2 Sensitivity to Changes in High-Level Requirements and Scope

The sketch of EMgine/Express demonstrates that changing the relevance of three high-level requirements—RF6, RE1, and RE7—and the CME task from *Emotion Generation* to *Emotion Effects on Behaviour* causes cascading changes through other design scope elements, and the focus of the analysis of emotion perspectives and individual theories. This suggests that the methodology is sensitive to high-level requirements and design scope changes. Therefore, it is reasonable to expect that it culminates in any examined theory or group of theories given a relevant set of requirements and scope. For example, a CME:

- That uses experienced emotions to change its behaviours over time might use requirements like EMgine's—such as RF2, RF5, and RE4—but have an entirely different scope (i.e. *Emotion Effects on Internal Cognitive Processes*, *Mind-Body Interactions*) which could lead to Izard because it describes emotion-dependent personality development (Izard and Ackerman, 2000)

- That needs a simple emotion model which can relate to observable behaviours and account for influencing factors such as personality (e.g. Ball and Breese (2000)) with *valence* and *arousal* as internal reward signal for reinforcement learning (e.g. Laird and Marinier III (2012, p. 279–280)) might need requirements like *Must operate in real-time interactions* and *Must only use one affective theory/model*—which would likely change the scope as well (e.g. *Emotion Effects on Behaviour + Internal Cognitive Processes*, *Emergent Emotions + Mind-Body Interactions*) could culminate in V-A due to its dissociation from specific expressions and action tendencies (Broekens, 2021) and the numerical nature of dimensional theories

- That acts as/is part of an agent's behaviour control system (e.g. Martinho et al. (2000); Petta (2002)) and has similar requirements as EMgine has a different design scope—*Emotion Effects on Internal Cognitive Processes*, favours physical embodiment (e.g. toy robot), and *Mind-Body Interactions*—could result in Frijda because its continuous information processing nature incorporates control signals and a feedback loop (Frijda, 1986, p. 454)

- That uses emotion to plan social interactions (e.g. Marsella et al. (2000)) might have the same requirements and scope as the CME that chooses Frijda (perhaps with no constraints on agent embodiment), but instead culminate in Lazarus because of its focus on an individual's ability to change their emotion-eliciting appraisal of the causal environment and/or event (i.e. stress and coping in emotion processes) (Lazarus, 1991)

- For generating ambient agent crowd behaviour (i.e. individual agent behaviours (subsystem) have less impact than those of the group (system)) that prioritizes RE3 and does not need to explicitly label the behaviours (i.e. scoped to *Emotion Effects on Behaviour* and *Emergent Emotions*) might lead to Scherer because it views the emotion process as a continuously fluctuating pattern of change in several subsystems (Scherer, 2001, p. 108)

- Where actions selection depends on the current social context (e.g. Yacoubi and Sabouret (2018)) and mandates that the CME must *Allow designers to define the association between emotions and agent response goals* and *Allow designers to define the process(es) for choosing actions for goal achievement* might scope to *Emotion Effects on Internal Cognitive Processes* and *Mind-Body Interactions*, and subsequently lead to Roseman due to its definition of emotion-specific general responses that can manifest in different ways (i.e. emotion strategies) (Roseman, 2011)

- For an empathetic agent (e.g. Ochs et al. (2012)) that is similar to EMgine in both requirements and design scope—but disregards *Fast, Primary Emotions*—might choose OCC because of its "Fortunes-of-others" emotions (Ortony et al., 2022, p. 109)
- Which has multiple appraisal processes with distinct mechanisms that collectively produce a single emotion response (e.g. Broekens and DeGroot (2004)) and stresses the importance of RF3, RF4, RF7, and RF8 might culminate in Smith & Kirby due to its description of appraisal detectors that monitor for, collect, and combine information from disparate sources to determine the overall emotion response (Smith and Kirby, 2001)
- That learns about and responds to stimuli based on an underlying emotion elicitation mechanism (e.g. Becker-Asano (2008)) might examine the neurophysiological perspective more closely and find that one or more of Damasio (1995), LeDoux (1998), and/or Sloman et al. (2005) satisfies their needs

The nature of this methodology makes different outcomes possible because it provides focus and structure for the theory-choosing process rather than imposing constraints on it. Again, it depends on one's understanding of the high-level requirements and design scope that one applies to their interpretations of static affective theory/model academic texts to choose a CME's foundation. However, following this process justifies *why* a CME uses a theory/model in a reproducible way. This lends credibility to the choices and to the CME built on those choices.

8.3 Summary

The proposed theory-selection methodology has many potential outcomes due to differences in one's understanding of the high-level requirements, their relative priorities, and one's understanding of the Affective Science literature. For game development, and domain-specific CMEs in general, this variation is of little concern because the goal is *interesting* behaviours rather than strictly *realistic* ones. This encourages variation because the process leads to different designs which might be better suited for some games and not others. Ultimately, this gives game developers more tools to choose from so that they can continue to create a cornucopia of games to play.

Key Points

- The proposed methodology for choosing affective theories and/or models has many potential outcomes and is sensitive to changes in high-level requirements and design scope

Chapter 9

Spec Your EMgine: Defining the Pieces

Isn't it strange, to create something that hates you?

Ava, *Ex Machina*

At this point, EMgine has only specified its high-level design goals (Chapter 6.1) and systematically chosen emotion theories and models that appear to best support those goals. On their own, these theories/models are inadequate specifications and cannot be directly translated into software. Therefore, specifications for EMgine's models develop progressively from representations of the environment (Section 9.2) and emotions (Section 9.3) to task-specific models that depend on them (Sections 9.4, 9.5, 9.6, and 9.7). Although this process looks straightforward, there were many instances of backtracking to and concurrent work between the models.

Other CMEs have documented their models (e.g. Reilly (1996); El-Nasr et al. (2000); Becker-Asano (2008); Jain and Asawa (2019); Alfonso et al. (2017); Yacoubi and Sabouret (2018), and Bourgais et al. (2017)[1]), although they do not appear to do so with the same depth or thoroughness as EMgine. There is also a set-based formalism for representing appraisal theories (Broekens et al., 2008) whereas EMgine relies on formal types instead.

9.1 Interfacing EMgine's Underlying Affective Theories

An inevitable challenge that occurs when combining emotion theories and/or models into a formal model is bridging the gap in their underlying assumptions. For example, a common conflict is how many—if any—emotions are "basic" (Ortony, 2022, p. 57). Luckily, these issues have little effect on EMgine because each of the chosen theories interact somewhat superficially:

- Plutchik models the internal structure of emotion, its storage and organization,
- Oatley & Johnson-Laird generate emotions for storage in the internal structure, and
- PAD Space provides an alternate representation of the internal emotion structure.

This implies that it is sufficient for EMgine, a Computational Model of Emotion (CME) designed for entertainment rather than research, to find comparable definitions of the emotions represented

[1] Em/Oz (66), FLAME (4), WASABI (8), HybridC (17), GenIA[3] (14), TEATIME (46), and GAMA-E (27), included in the CME survey (Chapter 5)

by each theory. While the resulting mappings between definitions might not be strictly correct or precise, they do rely on an English-speaking North American understanding of emotion terms in everyday language (Oatley, 1992, p. 75; Plutchik, 1980, p. 93, 152; Mehrabian, 1980, p. 39–40) suggesting that the same word represents an identical or comparable concept. Since Plutchik's emotion kind definitions serve as the baseline (Section 9.3), guiding EMgine's development and subsequent testing (Broekens, 2021, p. 367), it acts like an "interface" between Oatley & Johnson-Laird (Section 9.4) and PAD Space (Section 9.7).

9.2 Data Types for Communicating with the Environment

Some non-affective data types, chiefly focused on the entity's environment, are necessary if EMgine is to generate any emotions at all. EMgine assumes that variables represent the environment and that events are changes in those variables.

9.2.1 User-Implemented Data Types

EMgine defines some data types as Application Programming Interface (API) specifications because it expects their implementation to change with each game/application. Users must provide the minimum functionality described in the APIs, expanding it with any additional functionality they need. This improves EMgine's portability and minimizes authorial effort by only requiring users to provide implementations for predesigned modules. Since this is EMgine's point-of-contact with an external system, defining these APIs allows EMgine to assume that certain behaviours are available for its use without constraining users to specific implementations of them.

Time and Delta Time Data Types

Emotion is time-dependent (Chapter 3.1), so EMgine requires representations of time—assumed to be linearly ordered—and a difference or "change" between two points in time (i.e. delta Δ):

$$\mathbb{T}, \mathbb{T}_{\Delta} \tag{9.2.1}$$

These are essential for defining the Attention Data Type (Equation 9.2.9), defining emotion as a set of states over time (Equation 9.3.6), and Emotion Decay (Equations 9.6.5, 9.6.7, and 9.6.8).

World State View (WSV) Data Type

EMgine requires a representation of the world that an entity exists in because emotion is a response to it. In games, "the world" $\mathbb{W}$ is an imaginary universe where game events occur and are typically two or three dimensional spaces containing characters and objects (Adams, 2009, p. 640). EMgine needs to know about the configuration of characters, objects, and variables in "the world" in order to evaluate an entity's relation to it. However, it does not necessarily need to know *everything* about "the world"—only those aspects that are relevant to the entity. For example, if $\mathbb{W}$ contained variables `health` and `wealth` but the entity only cares about `health`, then EMgine does not care about the `wealth` variable. EMgine requires a type that describes this world state "view":

$$\mathbb{S} \subseteq \mathbb{W} \tag{9.2.2}$$

This is essential for: defining the Goal and Plan Data Types (Equations 9.2.6 and 9.2.7); eliciting *Joy* (Equation 9.4.1), *Sadness* (Equation 9.4.2), *Fear* (Equation 9.4.3), *Anger* (Equation 9.4.4), *Disgust* (Equation 9.4.5), *Acceptance* (Equation 9.4.6), and *Surprise* (Equation 9.4.8); and calculating the intensity of *Sadness* (Equation 9.5.3).

World Event Data Type

EMgine also requires a representation of changes (i.e. events) in an entity's "world" to know when to trigger emotion processes. Games can understand an event as a game action that changes a game world's configuration of characters, objects, and variables. EMgine takes this to mean that it is a "change" (i.e. delta Δ) in the game world. As with WSV, EMgine only needs to know about "changing" aspects relevant to the entity. Therefore, the World Event Data Type represents a "change" in a WSV $\mathbb{S}$:

$$\mathbb{S}_\Delta \subseteq \mathbb{S} \tag{9.2.3}$$

Applying the event to the current WSV gives the next WSV (i.e. $s \oplus s_\Delta : \mathbb{S} \times \mathbb{S}_\Delta \rightarrow \mathbb{S}$).

This is essential for: defining the Goal and Plan Data Types (Equations 9.2.6 and 9.2.7); and eliciting *Joy* (Equation 9.4.1), *Sadness* (Equation 9.4.2), *Fear* (Equation 9.4.3), *Anger* (Equation 9.4.4), *Disgust* (Equation 9.4.5), *Acceptance* (Equation 9.4.6), and *Surprise* (Equation 9.4.8).

Distance Between WSVs Data Type

EMgine needs a way to compare two WSVs $\mathbb{S}_1, \mathbb{S}_2$ to evaluate their relative desirability for some target (e.g. goals). It takes this as a "distance" between them, describing the differences between each element in the compared WSVs:

$$\mathbb{D} \tag{9.2.4}$$

This is essential for: defining the Goal Data Type (Equation 9.2.6); eliciting *Joy* (Equation 9.4.1), *Sadness* (Equation 9.4.2), *Fear* (Equation 9.4.3), and *Disgust* (Equation 9.4.5); and calculating the intensity of *Sadness* (Equation 9.5.3) and *Disgust* (Equation 9.5.6).

Change in Distance Between WSVs Data Type

EMgine also needs some way to measure how much a game event $\mathbb{S}_\Delta$ changes a WSV $\mathbb{S}$. EMgine assumes this to be equivalent to the magnitude of "change" (i.e. delta Δ) that the event causes in the WSV configuration, describing the differences between each "changed" element in the WSV:

$$\mathbb{D}_\Delta \tag{9.2.5}$$

This is essential for defining the Goal Data Type (Equation 9.2.6); eliciting *Joy* (Equation 9.4.1), *Fear* (Equation 9.4.3), *Disgust* (Equation 9.4.5), and *Acceptance* (Equation 9.4.6); and calculating the intensity of *Joy* (Equation 9.5.2), *Fear* (Equation 9.5.4), and *Acceptance* (Equation 9.5.7).

9.2.2 EMgine-Implemented Data Types

When given with information about the "world", EMgine forms structures about an entity's relation to it: goals, plans, what they pay attention to, and their social attachments to other entities. Users can opt to provide information for goals alone, which is enough for EMgine to generate five of eight emotions—*Joy*, *Fear*, *Disgust*, *Surprise*, and a limited evaluation of *Sadness*. If users require the other three emotion kinds, they must provide information for one or more of the other data types to enable their evaluation.

Goal Data Type

Unless they are lucky, an entity will not always exist in a game world state that satisfies them. They will need a way to represent the WSV that they want so that they know when events impact them and by how much (Ortony, 2002, p. 208). They need goals, which are essential to emotion elicitation. Typically, all Non-Player Character (NPC) entities already have some (Broekens et al., 2016, p. 223). EMgine represents a goal as a record containing a predicate on a WSV `goalState`, two functions `goal` and `goal′`, a non-negative, real-valued `importance` value, and a `type` set:

$$\begin{aligned}&\mathbb{G} : \{\texttt{goalState} : \mathbb{S} \to \mathbb{B}, \texttt{goal} : \mathbb{S} \to \mathbb{D}, \texttt{goal}' : \mathbb{S} \times \mathbb{S}_\Delta \to \mathbb{D}_\Delta,\\ &\texttt{importance} : \mathbb{R}_{\geq 0}, \texttt{type} \subseteq \{\texttt{SelfPreservation}, \texttt{Gustatory}\}\}\end{aligned} \tag{9.2.6}$$

- The `goalState` predicate represents the entity's desired WSV $\mathbb{S}$ (Equation 9.2.2). If they are not already in `goalState` and striving to maintain it, they are in another state and want to move towards or away from `goalState`.
- The function `goal` maps a WSV $\mathbb{S}$ to a distance $\mathbb{D}$ (Equation 9.2.4) between it and `goalState` to measure the difference between the current WSV and the desired one.
- The function `goal′` is the derivative of `goal`, measuring a change in the distance $\mathbb{D}_\Delta$ (Equation 9.2.5) to `goalState` when a game event $s_\Delta : \mathbb{S}_\Delta$ changes a WSV $s : \mathbb{S}$ (Equation 9.2.3). EMgine evaluates $\mathbb{S} \times \mathbb{S}_\Delta$ as $s \oplus s_\Delta$, shorthand for $\texttt{apply}(x, y)$, which is a function that changes x by y.
- The goal's perceived relative `importance` to the entity such that higher values reflect a higher importance, mimicking the tendency for higher importance goals to motivate an individual more than lower importance ones (Izard, 1977, p. 204). If this is set to zero, EMgine assumes that the goal has no importance to the entity and does not trigger emotion processes when affected by world events.
- Oatley & Johnson-Laird's descriptions of emotion-elicitation conditions imply that goals can have the types of *Self-Preservation* and/or *Gustatory* (Table 9.1). Goal `type` stores this information, allowing a goal to have none, one, or both of these types.

Plan Data Type

According to Oatley & Johnson-Laird, a plan is necessary to elicit *Anger* and offers another way to elicit *Sadness* (Oatley and Johnson-Laird, 1987, p. 36). EMgine represents a plan as:

$$\begin{gathered}\mathbb{P} : \{\texttt{actions} : (\mathbb{S}_{\Delta 1}, ..., \mathbb{S}_{\Delta n}), \texttt{toProgress} : ((\mathbb{S} \to \mathbb{B})_0, ..., (\mathbb{S} \to \mathbb{B})_n),\\ \texttt{nextStep} : \mathbb{S} \times \mathbb{N} \to \mathbb{S}, \texttt{isFeasible} : \mathbb{S} \to \mathbb{B}\}\\ \text{where } n : \mathbb{N}_{>0},\\ \texttt{nextStep}(s : \mathbb{S}, i : \mathbb{N}) = \begin{cases} s, & i = 0 \\ \texttt{nextStep}(s, i) \oplus \texttt{planActions}(i), & \textit{Otherwise} \end{cases},\\ \text{and } \texttt{isFeasible}(s : \mathbb{S}) = \bigwedge_{i=0}^{n} \texttt{toProgress}(i, \texttt{nextStep}(s, i))\end{gathered} \tag{9.2.7}$$

- A sequence of `actions` such that applying them to an initial WSV generates a series of "good" WSVs that satisfy a sequence of predicates on them representing plan progression (`toProgress`), where each element in `actions` is something the entity can do (i.e. there are no elements in `actions` that the entity believes are impossible)
- At some step $i : \mathbb{N}$, the function `nextStep` evaluates the next WSV in the plan by applying the *ith* plan action to the *ith* `nextStep` where $\texttt{nextStep}(s, 0)$ is the initial state $s : \mathbb{S}$

- A constant `isFeasible` generated by checking that, for each step $i : \mathbb{N}$ starting from $i = 0$ and a WSV $s : \mathbb{S}$, each evaluation of $\texttt{nextStep}(s, i)$ satisfies the *ith* condition in `toProgress`

The Plan Data Type is not explicitly connected to the Goal type so that users can apply it to entity plans that do not target an EMgine-specific goal $\mathbb{G}$.

Social Attachment[2] Data Type

Modelling *Acceptance* as a social emotion (Section 9.4.2) implies the need for relations between entities (Broekens, 2021, p. 360). Therefore, EMgine provides a Social Attachment Data Type, defined as a discrete "degree" or "level" of attachment to some entity where "degree" can be negative to represent disliking that entity:

$$\mathbb{SA} : \mathbb{Z} \tag{9.2.8}$$

The Social Attachment Data Type is linearly ordered such that higher "degrees" or "levels" represents a stronger attachment to another entity that can reflect a "history" with it. Users can extend this type with additional information about an entity's attachment to another as needed. Since Social Attachment is just an association between two entities (Broekens, 2021, p. 359–360), users do not have to limit the "other" entity to characters—it could refer to objects, actions, or other game elements.

Attention Data Type

Oatley & Johnson-Laird hypothesize that attention is foundational to *Interest* (Oatley and Johnson-Laird, 1987, p. 33). Researchers view attention as a set of mechanisms that allow a limited-capacity system to select salient or goal-relevant information (Vuilleumier, 2009, p. 54). This leads EMgine to define the Attention Data Type as the consecutive elapsed time $\mathbb{T}_\Delta$ (Equation 9.2.1) spent focusing on some x:

$$\mathbb{AT}_x : \mathbb{T}_\Delta \tag{9.2.9}$$

Users can extend this type with additional information about an entity's focus on x and the resources available for attention as needed.

9.3 Emotion Representation

EMgine represents emotions with data types. The most basic type is Emotion Intensity, a non-negative real value:

$$\mathbb{I} : \mathbb{R}_{\geq 0} \tag{9.3.1}$$

The domain of real numbers allows EMgine to represent intensity as a continuous value while affording users the ability to define emotion as a discrete value if they wish. Emotion Intensity is strictly non-negative because EMgine assumes that Plutchik's concept of a "deep sleep" state refers to an absence of emotion. "Deep sleep" implies that the entity is not experiencing emotion at all because this is when it loses consciousness (Mondino et al., 2021, p. 1–2). However, this is unlikely to be unique to Plutchik due to the responsive nature of emotion (Chapter 3.1) and a common sense understanding assumes that an entity is either experiencing emotion or not (i.e. feeling some intensity or none).

[2] EMgine uses the term "Social Attachment" instead of "Social Relationship" because it appears to represent a simpler concept (Rempel et al., 1985).

EMgine combines an Emotion Intensity with an Emotion Intensity Change ($\mathbb{I}_\Delta$, see Section 9.5) using a logarithmic function:

$$\texttt{UpdateIntensity}(i : \mathbb{I}, i_\Delta : \mathbb{I}_\Delta) : \mathbb{I} \mathrel{\hat{=}} \begin{cases} 0.1 \cdot \log_2\left(2^{10 \cdot i} + 2^{10 \cdot i_\Delta}\right), & i_\Delta > 0 \\ 0.1 \cdot \log_2\left(2^{10 \cdot i} - 2^{10 \cdot |i_\Delta|}\right), & i_\Delta < 0 \\ i, & \textit{Otherwise} \end{cases} \tag{9.3.2}$$

EMgine bases this function on one from Em/Oz (Reilly, 2006) and a reinforcement learning agent (Broekens, 2021, p. 370). It relies on a logarithm so that it is not strictly additive and both values contribute to the output such that its magnitude is at least as much as the highest input. Although not experimentally verified, it emulates these desired behaviours and reportedly works well.

Emotion Kinds

The Emotion Kinds enumeration encodes Plutchik's eight emotion types as labels, ensuring that the "primary" emotions that EMgine supports are finite and consistently ordered:

$$\mathbb{K} : \langle \texttt{Fear}, \texttt{Anger}, \texttt{Sadness}, \texttt{Joy}, \texttt{Interest}, \texttt{Surprise}, \texttt{Disgust}, \texttt{Acceptance} \rangle \tag{9.3.3}$$

An invariant on $\mathbb{K}$ requires that labels be uniquely "paired" with exactly one other emotion type label. While there are no data types or functions that need this information, it embeds a fundamental characteristic of Plutchik's emotion Circumplex into the type. EMgine assumes that functionally coupling "paired" emotion kinds such that the experience of one reduces the experience of the other would make a state of "deep sleep" impossible, so it does not do so.

Defining Emotion Kinds independently of Emotion Intensity (Equation 9.3.1) allows them to be theory-agnostic (i.e. not strictly tied to Plutchik). This means that EMgine can still be functional if there is *some* definition for Emotion Kinds, which could have differing types and number of labels than Plutchik.

Emotion State

Emotion State Data Type composes the Emotion Intensity and Kinds Data Types into a new structure. EMgine represents an emotion state as a record containing functions `intensities` and `max`:

$$\mathbb{ES} : \{\texttt{intensities} : \mathbb{K} \to \mathbb{I}, \texttt{max} : \mathbb{K} \to \mathbb{I}\} \tag{9.3.4}$$

- The function `intensities` maps Emotion Kinds to Emotion Intensities ($\mathbb{K} \to \mathbb{I}$) to represent the current intensity of each emotion kind in the state. This is similar to a vector of intensity values, which CMEs commonly use to represent affective states (Broekens, 2021, p. 358). The function must satisfy the invariant:

$$\forall k : \mathbb{K} \to \texttt{intensities}(k) \leq \texttt{max}(k)$$

- EMgine assumes that emotion intensity is a finite quantity, so the function `max` maps Emotion Kinds to Emotion Intensities ($\mathbb{K} \to \mathbb{I}$). This encodes a maximum intensity for each emotion kind individually, allowing users to vary this value between emotion kinds in a state. Storing maximum intensities in the Emotion State Data Type localizes these constraints to a specific state, allowing the maximum intensities of other states to vary. This also makes it easy to ensure that updates to `intensities` satisfies its constraints. The `max` function must satisfy the invariant:

$$\exists k : \mathbb{K} \to \texttt{max}(k) > 0$$

This prevents situations where every value in `max` is zero (i.e. constantly zero). Due to the association between zero and "deep sleep" in Emotion Intensity (Equation 9.3.1), at least one emotion type in the state must be non-zero for the entity to be "awake".

Users might need to simultaneously update multiple emotion intensities in one state. For this task, EMgine provides a helper function that uses the function for combining an emotion intensity with an emotion intensity change (Equation 9.3.2):

$$\begin{aligned} &\texttt{NewStateByIntensityChanges}(es : \mathbb{ES}, i_\Delta : \mathbb{K} \to \mathbb{I}_\Delta) : \mathbb{ES} \\ &\mathrel{\mathring{=}} es' \text{ with } (\forall k : \mathbb{K} \to es'.\texttt{intensities}\,(k) = \texttt{clamp}\,(I_k, 0, es.\texttt{max}(k))\,, \\ &\qquad es'.\texttt{max}(k) = es.\texttt{max}(k)) \\ &\text{where } I_k = \texttt{UpdateIntensity}(es.\texttt{intensities}\,(k)\,, i_\Delta\,(k)) \end{aligned} \tag{9.3.5}$$

A logarithm is an unbounded function and EMgine assumes that emotion intensities are finite (i.e. have a maximum value), so it is necessary to clamp the updated intensity.

User-Defined Emotion Types

An advantage of defining emotion kinds and intensities as data types is the ability to combine them into new structures. Effectively, this allows users to define custom emotion types (RF5). User-defined emotion types do not have to be scientifically correct as long as it has the desired behaviour.

Both Plutchik and Oatley & Johnson-Laird acknowledge the concept of "complex" emotions, which EMgine uses as guidelines for the data types a user could create:

- Combinations of Emotion Kinds, e.g. *Fear* + *Surprise* is *Awe* (Plutchik, 1980, p. 162–165)
- A partition of an Emotion Kind's maximum intensity in an Emotion State, e.g. an entity experiences *Rage* if the intensity of *Anger* is $\geq 90\%$ of the maximum intensity (Plutchik, 1980, p. 159–160)
- An Emotion Kind with additional propositional meaning, e.g. *Disgust* directed at a person is *Contempt* (Oatley, 1992, p. 60) (see Equation 9.4.6 for an example)

Rather than encoding these in models, EMgine simply recognizes these as functional requirements so that users can apply these guidelines as they see fit.

Emotion as States Over Time

EMgine represents the temporal nature of emotion by assigning Emotion States to instances in time (Equation 9.2.1):

$$\mathbb{E} : \mathbb{T} \to \mathbb{ES} \tag{9.3.6}$$

As time progresses and users create new emotion states, they can update the contents of and retrieve emotion states from Emotion at a time $t : \mathbb{T}$:

$$\texttt{UpdateEmotion}(e : \mathbb{E}, t : \mathbb{T}, es : \mathbb{ES}) : \mathbb{E} \mathrel{\mathring{=}} \{e \text{ with } e\,(t) = es\} \tag{9.3.7}$$

$$\texttt{GetStateFromEmotion}(e : \mathbb{E}, t : \mathbb{T}) : \mathbb{ES} \mathrel{\mathring{=}} e(t) \tag{9.3.8}$$

9.4 Emotion Elicitation

EMgine draws chiefly from Oatley & Johnson-Laird to define its emotion elicitation models. Several assumptions about emotion elicitation narrow the models' scope to afford more flexibility to choose when and where EMgine's tasks operate (RF2):

- Emotion elicitation and emotion intensity evaluation does not have to be done simultaneously, so EMgine models emotion intensity separately (Section 9.5)
- An entity can experience multiple emotions simultaneously but can only be in one state at any given time, so users can select and combine the results into a single emotion state with Equation 9.3.5 after intensity evaluations

Before developing a model for emotion elicitation from Oatley & Johnson-Laird's work, EMgine must determine how to map its outputs to the Plutchik-based Emotion State. This is a non-trivial issue because Plutchik accounts for more emotions than Oatley & Johnson-Laird (Equation 9.3.4). Ignoring this will render part of the state unusable. EMgine examines both theories for commonalities that it can exploit to address this issue.

A core hypothesis in Oatley & Johnson-Laird—that emotions signal a change has happened which changes a goal-oriented plan's likely outcome—follows Plutchik (Oatley, 1992, p. 55–56, 422 Note 27). Although they differ significantly in other aspects, this comparison is enough for EMgine to assume that an emotion kind shared by both theories refers to the same or nearly the same concept. Therefore, EMgine maps Oatley & Johnson-Laird's five emotions directly to those on Plutchik's Circumplex: *Joy* (*Happiness*), *Sadness*, *Fear* (*Anxiety*), *Anger*, and *Disgust*. EMgine must connect the remaining Plutchik emotions—*Acceptance*, *Surprise*, and *Interest*—to Oatley & Johnson-Laird indirectly. Oatley & Johnson-Laird do not dismiss the potential for these three to be "basic" emotions[3] (Oatley, 1992, p. 59–61). However, EMgine does not need Oatley & Johnson-Laird and Plutchik to agree if an emotion is "basic" or not—it only needs them to agree on their definition for modelling. Therefore, the models for *Acceptance*, *Surprise*, and *Interest* draw from additional research in their specification.

9.4.1 Eliciting *Joy*, *Sadness*, *Fear*, *Anger*, and *Disgust*

Oatley & Johnson-Laird's theory connects five "basic" emotions to plan junctures where the likelihood of a plan's success might change (Table 9.1). EMgine defines separate models for each of these emotions so that users can choose which ones to use (RF5). This also allows entities to experience multiple emotions simultaneously depending on how the user calls and provides information to the models.

At first glance, the descriptions appear to have a clear translation to formal models with respect to goals and plans. A closer inspection reveals aspects that people could interpret differently (e.g. what is a "sub-goal"?). Therefore, EMgine rephrases Oatley & Johnson-Laird's descriptions to remove potential ambiguities before translating them into mathematical models.

Each model for *Joy*, *Sadness*, *Fear*, *Anger*, and *Disgust* outputs an Option Type ($A^?$) containing a tuple of processed goal and/or plan data as WSV $\mathbb{S}$, event $\mathbb{S}_\Delta$, distance $\mathbb{D}$ (Equation 9.2.4), and/or change in distance $\mathbb{D}_\Delta$ (Equation 9.2.5) information. If the entity is not experiencing an emotion, the corresponding Option type is empty. Using Option Types improves EMgine's efficiency (RF8), because it avoids reevaluations of potentially expensive functions that users might want to use as inputs to others such as emotion intensity (Section 9.5).

[3]Their confidence in the inclusion of *Disgust* as a "basic" emotion is also shaky.

Table 9.1: Oatley & Johnson-Laird's Connection of Goals and Plans to Five Emotions (Adapted from Oatley (1992, p. 55))

Emotion	**Juncture of Current Plan**	**Next State**
Happiness	Sub-goals being achieved	Continue with plan, modifying if needed
Sadness	Failure of a major plan or loss of an active goal	Do nothing/Search for a new plan
Anxiety	Self-preservation goal threatened or goal conflict	Stop, Attend to Environment/Escape
Anger	Active plan frustrated	Try harder/Aggress
Disgust	Gustatory goal violated	Reject substance/Withdraw

Global Functions on Goals

These functions simplify the models of *Joy*, *Sadness*, *Fear*, *Anger*, and *Disgust* by collecting common evaluations and assigning them meaningful names:

- An event progresses an entity *towards* goal achievement iff the distance to the goal state is larger in the WSV unchanged by the event compared to the WSV changed by the event:

$$\texttt{IsCloserAfterEvent}(g : \mathbb{G}, s : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta) : \mathbb{B} \mathrel{\hat{=}} g.\texttt{goal}(s) > g.\texttt{goal}\left(s \oplus s_\Delta\right)$$

- An event moves an entity from a WSV into another where a goal is unachievable iff the distance to the goal state is infinitely large in WSV changed by the event:

$$\texttt{IsUnachievableAfterEvent}(g : \mathbb{G}, s : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta) : \mathbb{B} \mathrel{\hat{=}} \left| g.\texttt{goal}\left(s \oplus s_\Delta\right) \right| = +\infty$$

- An event causes a noticeable change in distance to a goal from a WSV iff its magnitude exceeds a minimum "threshold":

$$\texttt{IsNoticeable}(g : \mathbb{G}, s : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon : \mathbb{D}_\Delta) : \mathbb{B} \mathrel{\hat{=}} \left| g.\texttt{goal}'\left(s, s_\Delta\right) \right| > \epsilon$$

Joy (*Happiness*)[4]

This emotion occurs when an action moves an entity closer to a goal's achievement, assuming that each intermittent WSV is a goal state itself (i.e. a "sub-goal" of the goal). EMgine conceives this as an evaluation where:

> *An event transitions the previous WSV to the current WSV such that there is a change in the distance to a goal state where there is less distance between it and the current WSV compared to the distance between it and the previous WSV*

For its model, EMgine uses an entity goal (Equation 9.2.6), a WSV (Equation 9.2.2), an event (Equation 9.2.3), and a "tolerance" threshold for distance changes between WSVs:

$$J(g : \mathbb{G}, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_J : \mathbb{D}_\Delta) : (dist_{prev} : \mathbb{D}, dist_{now} : \mathbb{D}, dist_\Delta : \mathbb{D}_\Delta)^?$$
$$\mathrel{\hat{=}} \begin{cases} (g.\texttt{goal}(s_{prev}), \\ g.\texttt{goal}(s_{prev} \oplus s_\Delta), & \texttt{IsCloserAfterEvent}(g, s_{prev}, s_\Delta) \\ g.\texttt{goal}'(s_{prev}, s_\Delta)), & \land\, \texttt{IsNoticeable}(g, s_{prev}, s_\Delta, \epsilon_J) \\ \text{None}, & \textit{Otherwise} \end{cases} \tag{9.4.1}$$

[4]See Chapter 12.2.1 for a partial test of Equation 9.4.1

If the distance to the goal state was larger in *the previous WSV* compared to the current WSV (i.e. *decreases* the distance, $\texttt{IsCloserAfterEvent}(g, s_{prev}, s_{\Delta})$) and the change in distance exceeds a minimum threshold ($\texttt{IsNoticeable}(g, s_{prev}, s_{\Delta}, \epsilon_J)$), then the entity is achieving its "sub-goals" and it experiences *Joy*. The threshold ϵ_J controls the entity's "sensitivity" to changes such it experiences *Joy* more easily with lower threshold values compared to high ones.

Sadness[5]

Sadness occurs when an entity has a plan that becomes impossible to carry out (i.e. "failure of a plan") or a goal becomes impossible to achieve (i.e. "loss of a goal"). EMgine conceives this as an evaluation where:

> *An event transitions the previous WSV to the current WSV such that there is an unreachable plan state, implying that the plan is no longer viable, or when the distance from the current WSV to a goal state is insurmountably large, implying that it is not possible to reach that goal state (i.e. "lost")*

For its model, EMgine uses one or both of an entity goal and plan (Equation 9.2.7), a WSV, and an event:

$$S(g : \mathbb{G}^?, p : \mathbb{P}^?, s_{prev} : \mathbb{S}, s_{\Delta} : \mathbb{S}_{\Delta}) : (g_{sadness} : \mathbb{G}^?, p_{sadness} : \mathbb{P}^?, s_{now} : \mathbb{S}, dist_{now} : \mathbb{D}^?)^?$$

$$\mathrel{\hat{=}} \begin{cases} (\text{None}, p, s_{prev} \oplus s_{\Delta}, \text{None}), & p \neq \text{None} \wedge p.\texttt{isFeasible}(s_{prev}) \\ & \wedge \neg p.\texttt{isFeasible}(s_{prev} \oplus s_{\Delta}) \\ (g, \text{None}, s_{prev} \oplus s_{\Delta}, & \\ g.\texttt{goal}\,(s_{prev} \oplus s_{\Delta})), & g \neq \text{None} \wedge \texttt{IsUnachievableAfterEvent}(g, s_{prev}, s_{\Delta}) \\ \text{None}, & \mathit{Otherwise} \end{cases} \tag{9.4.2}$$

It is not necessary to provide both a goal and plan because the predicates on them are mutually exclusive. If the plan was feasible in *the previous WSV* ($p.\texttt{isFeasible}(s_{prev})$) and the world event transitions to a WSV where the plan is no longer feasible ($\neg p.\texttt{isFeasible}(s_{prev} \oplus s_{\Delta})$), or the distance to g becomes impossible to travel after the event ($\texttt{IsUnachievableAfterEvent}(g, s_{prev}, s_{\Delta})$), then the entity experiences *Sadness*. Including $g_{sadness} : \mathbb{G}^?$ and $p_{sadness} : \mathbb{P}^?$ in the output makes it easy to determine which of an entity's goal or plan elicited *Sadness* at s_{prev}.

Fear (Anxiety)[6]

This emotion occurs when there is a threat to self-preservation (i.e. "self-preservation goal threatened"), which requires a prediction about a future WSV based on the current world state and an action that could change it, or there are at least two goals that are mutually exclusive (i.e. "goal conflict", the entity cannot satisfy both). EMgine conceives this as an evaluation where:

> *A potential event transitions the current WSV to a future WSV where the distance between the future WSV and a goal state is larger than the distance from the current WSV and a goal state for a goal of type "Self-Preservation" OR it is impossible to satisfy the desired states of two different goals*

[5]See Chapter 12.1.1 for a partial test of Equation 9.4.2
[6]Equation 9.4.3 not yet tested

For its model, EMgine uses a WSV, event, two entity goals where one of them might be empty, and a "tolerance" threshold for distance changes between WSVs:

$$\begin{aligned}&F(g:\mathbb{G}, g':\mathbb{G}^?, s_{now}:\mathbb{S}, s_\Delta:\mathbb{S}_\Delta, \epsilon_F:\mathbb{D}_\Delta)\\&:(g_{fear}:\mathbb{G}, dist_{now}:\mathbb{D}, dist_{next}:\mathbb{D}, dist_\Delta:\mathbb{D}_\Delta, g_{lost}:\mathbb{G}^?)^?\end{aligned}$$

$$\mathrel{\hat{=}}\begin{cases}\begin{array}{l}(g, g.\mathtt{goal}(s_{now}),\\ g.\mathtt{goal}(s_{now}\oplus s_\Delta),\\ g.\mathtt{goal}'(s_{now}, s_\Delta),\\ \text{None}),\end{array} & \begin{array}{l}\mathtt{SelfPreservation}\in g.\mathtt{type}\\ \wedge\neg\mathtt{IsCloserAfterEvent}(g, s_{now}, s_\Delta)\\ \wedge\ \mathtt{IsNoticeable}(g, s_{now}, s_\Delta, \epsilon_F)\end{array}\\ \begin{array}{l}(g, g.\mathtt{goal}(s_{now}),\\ g.\mathtt{goal}(s_{now}\oplus s_\Delta), g'),\end{array} & g'\neq\text{None}\wedge\mathtt{WillConflict}(g, g', s_{now}, s_\Delta)\\ \begin{array}{l}(g', g'.\mathtt{goal}(s_{now}),\\ g'.\mathtt{goal}(s_{now}\oplus s_\Delta), g),\end{array} & g'\neq\text{None}\wedge\mathtt{WillConflict}(g', g, s_{now}, s_\Delta)\\ \text{None}, & \textit{Otherwise}\end{cases} \tag{9.4.3}$$

$$\begin{aligned}&\text{where }\mathtt{WillConflict}(g_1, g_2, s_{now}, s_\Delta)\\&=\mathtt{IsCloserAfterEvent}(g_1, s_{now}, s_\Delta)\wedge\mathtt{IsUnachievableAfterEvent}(g_2, s_{now}, s_\Delta)\end{aligned}$$

If the goal concerns self-preservation ($\mathtt{SelfPreservation}\in g.\mathtt{type}$) and there is a potential event that would make the distance to the goal state larger in the next WSV compared to *the current WSV* (i.e. would *increase* the distance, $\neg\mathtt{IsCloserAfterEvent}(g, s_{now}, s_\Delta)$), and the change in distance exceeds a minimum threshold ($\mathtt{IsNoticeable}(g, s_{now}, s_\Delta, \epsilon_F)$), then the entity perceives a threat to g and it experiences *Fear*. The threshold ϵ_F controls the entity's "sensitivity" to changes such it experiences *Fear* more easily with lower threshold values compared to high ones.

Alternatively, if $g':\mathbb{G}^?$ contains a goal ($g'\neq$ None) and there is a potential event that would reduce the distance to the goal state of either g or g' ($\mathtt{IsCloserAfterEvent}(g, s_{now}, s_\Delta)$ or $\mathtt{IsCloserAfterEvent}\ (g', s_{now}, s_\Delta)$) that also makes it impossible to reach the other ($\mathtt{IsUnachie-vableAfterEvent}(g', s_{now}, s_\Delta)$ and $\mathtt{IsUnachievableAfterEvent}(g, s_{now}, s_\Delta)$, respectively), then the goals `WillConflict` and the entity experiences *Fear*. In this case, neither goal g or g' have to concern self-preservation.

Including $g_{fear}:\mathbb{G}$ and $g_{lost}:\mathbb{G}^?$ in the output makes it easy to determine if two conflicting goals elicited *Fear* and which one will become lost if the event occurs.

Anger[7]

Anger occurs when an entity has a plan where the next step cannot be reached after an intentional action to achieve it, but there are one or more other actions that can (i.e. the plan is "frustrated" because it is still feasible, but it had to change to remain so). EMgine conceives this as an evaluation where:

> *An event transitions the previous WSV into the current WSV that is not part of the entity's plan, but there is a series of events that transitions the current WSV to another state that makes progress in the entity's plan*

[7] Equation 9.4.4 not yet tested

For its model, EMgine uses a WSV, event, and a set of plans targeting the same end-state:

$$A(s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, ps : \{\mathbb{P}\}) : (s_{now} : \mathbb{S}, p_{fail} : \mathbb{P}, ps_{alt} : \{\mathbb{P}\})^?$$

$$\triangleq \begin{cases} (s_{prev} \oplus s_\Delta, p_\alpha, \forall p \in \{\mathbb{P}\} & \exists p_\alpha \in ps \rightarrow (\forall p \in ps \\ \quad \rightarrow p.\texttt{isFeasible}(s_{prev} \oplus s_\Delta), & \quad \rightarrow p \neq p_\alpha \wedge \texttt{Cost}(p_\alpha) \leq \texttt{Cost}(p)) \\ & \wedge \neg p_\alpha.\texttt{isFeasible}(s_{prev} \oplus s_\Delta) \\ & \wedge \exists p \in ps \rightarrow p.\texttt{isFeasible}(s_{prev} \oplus s_\Delta) \\ \text{None}, & \textit{Otherwise} \end{cases} \tag{9.4.4}$$

The world event transitioned *the previous WSV* into the current WSV which makes the entity's lowest effort plan ($\exists p_\alpha \in ps \rightarrow (\forall p \in ps \rightarrow p \neq p_\alpha \wedge \texttt{Cost}(p_\alpha) \leq \texttt{Cost}(p))$ impossible to progress ($\neg p_\alpha.\texttt{isFeasible}(s_{prev} \oplus s_\Delta)$), but there is at least one other plan for achieving the same end-state ($\exists p \in ps \rightarrow p.\texttt{isFeasible}(s_{prev} \oplus s_\Delta)$). Therefore, the entity can continue working towards a desired end-state but must use a plan that requires more effort ("frustrated") and the entity experiences *Anger*. The function $\texttt{Cost} : \mathbb{P} \rightarrow \mathbb{R}$ evaluates the "cost" of the plan such that low costs are desirable.

Including $p_{fail} : \mathbb{P}$ in the output makes it easy to determine which plan "failed" and caused the elicitation of *Anger*. Note that the set of plans that the model returns is a strict subset of the provided set of plans $ps_f \subset ps$ because it has at least one plan fewer due to the infeasibility of p_α.

Disgust[8]

Disgust occurs when an entity has been "contaminated" or encounters "contaminated" substances that it wants to avoid (i.e. "gustatory goal violated"). EMgine conceives this as an evaluation where:

> *An event transitions the previous WSV, where the entity's gustatory goal was satisfied, to the current WSV that dissatisfies the goal such that the distance between the goal state and the current WSV is larger than the distance to the previous WSV*

For its model, EMgine uses an entity goal, WSV, event, and two "tolerance" thresholds for distance changes between WSVs:

$$D(g : \mathbb{G}, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_{DS} : \mathbb{D}_\Delta, \epsilon_{DN} : \mathbb{D}_\Delta) : (dist_{prev} : \mathbb{D}, dist_{now} : \mathbb{D}, dist_\Delta : \mathbb{D}_\Delta)^?$$

$$\triangleq \begin{cases} (g.\texttt{goal}(s_{prev}), & \texttt{Gustatory} \in g.\texttt{type} \\ g.\texttt{goal}(s_{prev} \oplus s_\Delta), & \wedge g.\texttt{goal}(s_{prev}) \leq \epsilon_{DS} \\ g.\texttt{goal}'(s_{prev}, s_\Delta)), & \wedge g.\texttt{goal}(s_{prev} \oplus s_\Delta) > \epsilon_{DS} \\ & \wedge \texttt{IsNoticeable}(g, s_{prev}, s_\Delta, \epsilon_{DN}) \\ \text{None}, & \textit{Otherwise} \end{cases} \tag{9.4.5}$$

If the goal is gustatory-related ($\texttt{Gustatory} \in g.\texttt{type}$), *the previous WSV* satisfied that goal within some "satisfaction threshold" ($g.\texttt{goal}(s_{prev}) \leq \epsilon_{DS}$), but the event transitioned into the current WSV where the goal is unsatisfied ($g.\texttt{goal}(s_{prev} \oplus s_\Delta) > \epsilon_{DS}$) and the difference is noticeable ($\texttt{IsNoticeable}(g, s_{prev}, s_\Delta, \epsilon_{DN})$), then the entity experiences *Disgust*.

The threshold ϵ_{DS} defines an entity's "tolerance" for goal dissatisfaction such that higher values means that the entity allows larger distances between the current WSV and its goal state before experiencing *Disgust*. The threshold ϵ_{DN} controls the entity's "sensitivity" to changes such it experiences *Disgust* more easily with lower threshold values compared to high ones.

[8]Equation 9.4.5 not yet tested

9.4.2 Eliciting *Acceptance*[9]

There is no explicit reference to an emotion like *Acceptance* in Oatley & Johnson-Laird. It is difficult to find information about it in the literature, so EMgine uses *Trust* as its conceptual reference because Plutchik's Circumplex associates it with *Acceptance* via the intensity dimension.

"Affective trust" builds on past experiences with, feelings of security, confidence, and satisfaction towards, and the perceived level of selfless concern demonstrated by a partner regardless of what the future holds (Rempel et al., 1985, p. 96). The idea of a "partner" seems to align with the concept of joint planning in Oatley & Johnson-Laird, where joint plans are only possible if each member believes that they can rely on all other members (Oatley, 1992, p. 178–179, 192). From Oatley & Johnson-Laird's description of "complex" emotions as "basic" emotions with additional propositional meaning, *Trust* might be a "basic" emotion elaborated with relationship-focused information.

The role of oxytocin in social attachments and affiliation is one biological basis of affective trust (Fehr and Zehnder, 2009, p. 393), supporting *Trust*'s reliance on relationships. This is another potential connection between *Trust* and Oatley & Johnson-Laird: they use "emotions of attachment" as an example of infant-level social emotions, linking them to the "basic" emotion *Happiness* (Oatley, 1992, p. 192). Therefore, EMgine takes the proposal that *Trust* is *Happiness* elaborated with information about social attachment as the basis for the *Acceptance* evaluation model.

Due to Plutchik's differentiation of *Trust* and *Acceptance* through emotion intensity and Oatley & Johnson-Laird's concept of "complex emotions", EMgine conceives *Acceptance* as an evaluation of *Joy* elaborated with social attachments such that:

> *An event transitions the previous WSV to the current WSV such that there is a change in the distance to a goal state where there is less distance between it and the current WSV compared to the distance between it and the previous WSV AND a socially-relevant entity caused the event*

For its model, EMgine uses an Option type that might contain a social attachment (Equation 9.2.8), entity goal, WSV, event, and two "tolerance" thresholds for distance changes between WSVs, and the model for *Joy* elicitation (Equation 9.4.1):

$$
\begin{aligned}
&Acc(r_A : \mathbb{SA}^?, g : \mathbb{G}, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_{A1} : \mathbb{S}_\Delta, \epsilon_{A2} : \mathbb{S}_\Delta) : (r_A : \mathbb{SA}, distAttribToA_\Delta : \mathbb{D}_\Delta)^? \\
&\quad \triangleq \begin{cases} (r_A, dist_\Delta - \epsilon_{A2}), & r_A \neq \text{None} \wedge |J(g, s_{prev}, s_\Delta, \epsilon_{A1}).dist_\Delta| > \epsilon_{A2} \\ & \wedge\, \texttt{CausedBy}(s_\Delta, A) \\ \text{None}, & Otherwise \end{cases}
\end{aligned} \tag{9.4.6}
$$

If an event elicits *Joy* ($J(g, s_{prev}, s_\Delta, \epsilon_{A1})$), the change in distance between *the previous WSV* and the current WSV exceeds a minimum threshold ($dist_\Delta > \epsilon_{A2}$), and the entity attributes the event to another entity A ($\texttt{CausedBy}(s_\Delta, A)$) that it has a social attachment to ($r_A \neq$ None), then the entity experiences *Acceptance* towards the other. The threshold ϵ_{A2} controls the entity's "sensitivity" to changes such it experiences *Acceptance* more easily with lower threshold values compared to high ones. This threshold also moderates the elicitation "magnitude" by returning the change in distance between WSVs that exceeds it ($dist_\Delta - \epsilon_{A2}$) so that the "magnitude" is relative to how easily "impressed" the entity is. The function $\texttt{CausedBy} : \mathbb{S}_\Delta \times A \rightarrow \mathbb{B}$ evaluates event causality, returning *True* if the entity believes that A is responsible for causing an event.

[9]See Chapter 12.2.1 for a partial test of Equation 9.4.6

If an entity has no social attachment yet, users could use this as a mechanism for establishing one:

1. Create a new social attachment $r'_A : \mathbb{SA}$
2. Use it to evaluate the presence of *Acceptance*:
   (a) If *Acceptance* is present, store r'_A
   (b) Otherwise discard it

9.4.3 Eliciting *Interest*[10]

Oatley & Johnson-Laird state that *Interest* "...implies sustained attention to certain external events" (Oatley and Johnson-Laird, 1987, p. 33). This seems to align with the "starting" behaviour tendencies that Plutchik's theory associates with *Interest* (Plutchik, 1984, p. 202). From this connection, and ignoring the implied limitation to events, EMgine conceives *Interest* as an evaluation where:

A significant amount of attention is paid to something

For its model, EMgine uses the amount of attention spent on some x (Equation 9.2.9) and a "tolerance" threshold on it such that:

$$\begin{aligned} &Inr(at_x : \mathbb{AT}_x, \epsilon_{Inr} : \mathbb{AT}_x) : \mathbb{AT}_x^? \\ &\mathrel{\hat{=}} \begin{cases} at_x - \epsilon_{Inr}, & at > \epsilon_{Inr} \\ \text{None}, & Otherwise \end{cases} \end{aligned} \tag{9.4.7}$$

If the amount of attention paid to x exceeds the threshold ($at > \epsilon_{Inr}$), then the entity experiences *Interest* towards x. This threshold also moderates the elicitation "magnitude" by returning the amount of attention that exceeds it ($at_x - \epsilon_{Inr}$) so that the "magnitude" is relative to how much x "fascinates" the entity.

9.4.4 Eliciting *Surprise*[11]

Oatley & Johnson-Laird state that *Surprise* "...is elicited by a sudden unexpected event..." (Oatley and Johnson-Laird, 1987, p. 33). This seems to align with the "stopping" behaviour tendencies that Plutchik's theory associates with *Surprise* (Plutchik, 1984, p. 202). However, what is meant by a "sudden unexpected" event needs clarification.

Researchers have proposed that events appraised to be a contradiction of explicitly or implicitly held expectations and beliefs elicit *Surprise*, which lab-based experiments found convincing supporting evidence (Reisenzein et al., 2019). Quantitative models of *Surprise* intensity rely on event probabilities such that an "unexpected" event is an improbable one, and assume that intensity increases monotonically with the degree of unexpectedness. This has no obvious conflicts with Oatley & Johnson-Laird's concept of emotions as system-wide non-propositional communication signals, so EMgine conceives *Surprise* as an evaluation where:

A significantly-improbable event happens

[10] Equation 9.4.7 not yet tested
[11] Equation 9.4.8 not yet tested

For its model, EMgine uses a WSV, an event, and a "tolerance" threshold such that:

$$Sur(s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_P : [0,1]) : [0,1]^? \\ \stackrel{\circ}{=} \begin{cases} \epsilon_P - P(s_\Delta | s_{prev}), & P(s_\Delta | s_{prev}) < \epsilon_P \\ \text{None}, & Otherwise \end{cases} \tag{9.4.8}$$

If the improbability of the event in *the previous WSV* is below the threshold ($P(s_\Delta|s_{prev}) < \epsilon_P$), then the entity experiences *Surprise*. This threshold also moderates the elicitation "magnitude" by returning how much the event's improbability falls below it ($\epsilon_P - P(s_\Delta|s_{prev})$) so that the "magnitude" is relative to how "impossible" the entity believes the event is. The probability of the event *depends on* the previous WSV because what is "expected" and "unexpected" depends on its preconditions (e.g. water falling on someone is unexpected on a sunny day bt not on a rainy one). This model assumes that there are exactly two outcomes for any given event—either it happens or it does not. This is for simplicity (Reisenzein et al., 2019, p. 56) and an assumption that users will want more control over entity reactions in complex scenarios.

9.4.5 A Word About NPCs' World Knowledge and Perception

Definitions for the functions `Cost` : $\mathbb{P} \to \mathbb{R}$ in Equations 9.4.4 and 9.5.5, `CausedBy` : $\mathbb{S}_\Delta \times A \to \mathbb{B}$ in Equation 9.4.6, $P(s_\Delta|s)$ in Equation 9.4.8, and `Dist` : $\mathbb{S} \times \mathbb{S} \to \mathbb{D}$ in Equation 9.5.3 are not part of EMgine's models by design because they are not emotion-specific evaluations—they are evaluations about an NPC's perception of their "world" and their relation to elements in it. This implies that there is additional "world knowledge" that NPCs need to access to evaluate how desirable the "world" is with respect to their internal goals and plans. The dependence of EMgine's elicitation models on "external" functions is unsurprising given the role that cognition plays in the emotion system (Chapter 3.1) and suggests that linking EMgine with other NPC systems such as decision-making and planning would improve the cohesiveness and consistency of NPC behaviours overall.

9.5 Emotion Intensity

Compared to other aspects of emotion, intensity is an understudied topic (Frijda et al., 1992, p. 60) so EMgine must draw from informal accounts and a general understanding of it to define models of it. EMgine's definition of Emotion Intensity (Equation 9.3.1) implicitly assumes that this value can change such that an entity can experience more or less of any given emotion kind—implying that changes can be both "positive" and "negative". Therefore, EMgine defines Emotion Intensity Change separately from, and unconstrained by, Emotion Intensity while maintaining the conceptual relation between them:

$$\mathbb{I}_\Delta : \mathbb{R} \tag{9.5.1}$$

When evaluating the value of an intensity change, there appear to be four determinant categories (Frijda et al., 1992, p. 71):

- How much the entity "values" affected internal conditions (e.g. goals),
- The "seriousness" or "value" of the event that affected those internal conditions,
- Contextual considerations of elements such as coping, support, and unexpectedness, and
- The entity's personality attributes that affect factors such as emotion response thresholds and dispositions towards different emotions.

Of these factors, only the value of the internal condition and the event are within EMgine's scope. Users can extend EMgine's intensity evaluations by integrating contextual considerations and/or personality attributes to the evaluation after getting the initial Emotion Intensity Change.

9.5.1 Evaluating the Intensity of *Joy*, *Sadness*, *Fear*, *Anger*, and *Disgust*

Oatley & Johnson-Laird propose that an emotion's intensity is proportional to the force causing an emotion ("entrained in an emotion mode") and how fixed or non-adjustable that force is ("degree it is locked into that mode") (Oatley and Johnson-Laird, 1987, p. 34). From this, EMgine assumes that emotion intensity directly relates to the degree that something impacts a goal or plan such that an entity would want to maintain the momentum caused by an emotion "mode" as long as that "something" affects that goal and/or plan. This aligns with the concept of an affected "internal condition".

Joy[12]

From the model of *Joy* elicitation (Equation 9.4.1), the affected "internal condition" is the entity goal (Equation 9.2.6) causing the elicitation and its "value" is its `importance`. The magnitude of change in distance caused by the event is its "seriousness" or "value" because it measures how much the event moved the entity towards the desired goal state. To evaluate the intensity of *Joy*, EMgine treats the event's "value" as an objective measure that it scales with the entity's goal's subjective (i.e. personal) "value":

$$J_\Delta(g : \mathbb{G}, d_\Delta : \mathbb{D}_\Delta) : \mathbb{I}_\Delta \mathrel{\hat{=}} |d_\Delta| \cdot g.\texttt{importance} \tag{9.5.2}$$

Using goal `importance` as a scaling factor moderates intensity changes such that its magnitude varies for entities observing the same d_Δ whose goals only differ in their `importance`. Note that the *Joy* elicitation model outputs a tuple with element $dist_\Delta$, which users can provide as the input d_Δ.

Sadness[13]

From the model of *Sadness* elicitation (Equation 9.4.2), there are two possible "internal conditions" affected by the event that determines the eliciting event's "value" or "seriousness":

- An entity plan (Equation 9.2.7) with a "value" equal to the distance to the desired end-state before it became infeasible, such that the event's "value" or "seriousness" is inversely proportional to the distance between the plan's end-state and the previous WSV where the plan was feasible. This means that plans the entity was close to completing elicit more intense *Sadness* compared to ones that were farther from completion.

- An entity goal with a "value" equal to its `importance`, but the event's "value" or "seriousness" is not necessarily tied to the event—an entity can experience intense *Sadness* if they were significantly far from the goal state (e.g. if there is a goal to see a loved one before they pass, losing them feels equally painful if one just began saving money for a plane ticket or if they have already spent a week with them). This means that goals with higher `importance` elicit more intense *Sadness* compared to less important ones relative to some maximum *Sadness* an entity can experience.

[12] See Chapter 12.2.1 for a partial test of Equation 9.5.2
[13] See Chapter 12.1.2 for a partial test of Equation 9.5.3

To evaluate the intensity of *Sadness*, EMgine treats the event's or maximum intensity's "value" as an objective measure that it scales with the entity's goal's or plan's subjective (i.e. personal) "value":

$$S_\Delta(g : \mathbb{G}^?, p : \mathbb{P}^?, s_{prev} : \mathbb{S}, i_{max\Delta} : \mathbb{I}_\Delta) : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} \dfrac{1}{|dist_p|}, & p \neq \text{None} \\ \dfrac{g.\texttt{importance}}{m_G} \cdot i_{max\Delta}, & g \neq \text{None} \end{cases} \tag{9.5.3}$$
$$\text{where } dist_p : \mathbb{D} = \texttt{Dist}(s_{prev}, p.\texttt{nextStep}(s_{prev}, |p.\texttt{actions}|))$$

For evaluating the "seriousness" of a plan becoming infeasible, the function generates the plan's end-state from the previous WSV by applying every plan action to it ($p.\texttt{nextSteps}(s_{prev}, |p.\texttt{actions}|)$), then calculates the distance between the generated plan end-state and the previous WSV (s_{prev}) using the function $\texttt{Dist} : \mathbb{S} \times \mathbb{S} \to \mathbb{D}$ (similar to the function `goal` in $\mathbb{G}$, see Section 9.4.5). This emulates an evaluation of "how close" the entity was to plan completion.

For evaluating the "seriousness" of a goal being "lost", the goal's `importance` relative to m_G is a scaling factor that moderates a maximum intensity change $i_{max\Delta}$ such that its magnitude varies for entities with different `importance` valuations in otherwise identical goals. The value m_G is a user-defined maximum for goal `importance`, effectively normalizing it to $[0, 1]$. The function can access m_G itself so that the user does not have to provide it. Users also provide the value of $i_{max\Delta}$ so that they have more control over how much an entity experiences emotion changes (i.e. the model does not have to be relative to the maximum possible *Sadness* intensity).

Note that the *Sadness* elicitation model outputs a tuple with elements $g_{sadness} : \mathbb{G}^?$ and $p_{sadness} : \mathbb{P}^?$, which users can supply as the inputs g and p.

Fear[14]

From the model of *Fear* elicitation (Equation 9.4.3), the affected "internal conditions" are entity goals causing the elicitation and their "value" is their `importance`. The change in distance caused by the event is its "seriousness" or "value" because it measures how much the event will move the entity away from the desired goal state or, when there are two goals, move the entity towards one while making the other unachievable. To evaluate the intensity of *Fear*, EMgine treats the event's "value" as an objective measure that it scales with the entity's goal's subjective (i.e. personal) "value":

$$F_\Delta(g : \mathbb{G}, g_{lost} : \mathbb{G}^?, d_\Delta : \mathbb{D}_\Delta) : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} d_\Delta \cdot g.\texttt{importance}, & g_{lost} = \text{None} \\ d_\Delta \cdot \dfrac{g_{lost}.\texttt{importance}}{g.\texttt{importance}}, & g_{lost} \neq \text{None} \end{cases} \tag{9.5.4}$$

Using goal `importance` as a scaling factor moderates intensity changes such that its magnitude varies for entities with different `importance` valuations in otherwise identical goals that observe the same d_Δ. In the case where conflicting goals elicit *Fear*, the scaling factor is a ratio between their `importance` values such that the "value" of the progressed goal tempers that of the "lost" goal—the intensity of *Fear* is higher when the `importance` of the "lost" goal is larger than the `importance` of the other goal.

Note that the *Fear* elicitation model outputs a tuple with elements $g_{fear} : \mathbb{G}$, $g_{lost} : \mathbb{G}^?$, and $dist_\Delta$, which users can use as the inputs g, g_{lost}, and d_Δ.

[14] Equation 9.5.4 not yet tested

Anger[15]

From the model of *Anger* elicitation (Equation 9.4.4), the affected "internal condition" is the change in entity plan availability and their "value" is the amount of effort the entity needs to execute them (i.e. plan "cost"). The difference in "cost" between the infeasible plan and the next lowest "cost" plan is its "seriousness" or "value" because it measures how much additional effort the entity needs to achieve the same result. Both of these values are subjective because the entity assigns them. Therefore, EMgine evaluates *Anger* intensity as the difference between the subjective "cost" of the "frustrated" plan and the next lowest "cost" plan:

$$\begin{aligned} &A_\Delta(p : \mathbb{P}, ps : \{\mathbb{P}\}) : \mathbb{I}_\Delta \\ &\mathrel{\mathring{=}} \exists p_\beta \in ps \to (\forall p \in ps \to p \neq p_\beta \land \texttt{Cost}(p_\beta) \leq \texttt{Cost}(p)) \to \texttt{Cost}(p_\beta) - \texttt{Cost}(p) \end{aligned} \tag{9.5.5}$$

Taking the difference between plan "costs" ensures that *Anger* is more intense if the "cost" of the next most desirable plan increases compared to the original one. The model calculates plan "cost" using the function $\texttt{Cost} : \mathbb{P} \to \mathbb{R}$ such that low "costs" are desirable (*Anger* elicitation also uses this function, see Section 9.4.5). If these plans are for achieving a goal, users can choose to scale the resulting *Anger* intensity with the goal's importance manually.

Note that the *Anger* elicitation model outputs a tuple with elements $p_{fail} : \mathbb{P}$ and $ps_{alt} : \{\mathbb{P}\}$, which users can use as the inputs p and ps.

Disgust[16]

From the model of *Disgust* elicitation (Equation 9.4.5), the affected "internal condition" is the entity goal causing the elicitation and its "value" is its `importance`. The distance between the current state and the desired goal state is the event's "seriousness" or "value" because it measures how much the event moved the entity out of it. To evaluate the intensity of *Disgust*, EMgine treats the distance's "value" as an objective measure that it scales with the entity's goal's subjective (i.e. personal) "value":

$$D_\Delta(g : \mathbb{G}, d : \mathbb{D}) : \mathbb{I}_\Delta \mathrel{\mathring{=}} d \cdot g.\texttt{importance} \tag{9.5.6}$$

Using goal `importance` as a scaling factor moderates intensity changes such that its magnitude varies for entities observing the same d_Δ whose goals only differ in their `importance`. Note that the *Disgust* elicitation model outputs a tuple with element $dist_{now}$, which users can supply as the input d.

Although this model looks similar to the one for *Joy* intensity (Equation 9.5.2), there is a key difference between them. *Joy* is a response to events that move an entity *towards* an unsatisfied goal state, whereas *Disgust* is a response to events that move an entity *away* from a satisfied goal state. This means that in *Joy*, intensity is inversely proportional to the distance from a goal state ($|d|$), but in *Disgust* the intensity grows proportionally with the distance from a goal state (d).

9.5.2 Evaluating the Intensity of *Acceptance*[17]

From the model of *Acceptance* elicitation (Equation 9.4.6), the affected "internal condition" is an entity goal. However, EMgine assumes that the entity's relation to A (Equation 9.2.8) is the relevant "internal condition" that an event's "value" relates to in *Acceptance*. The magnitude of

[15] Equation 9.5.5 not yet tested
[16] Equation 9.5.6 not yet tested
[17] See Chapter 12.2.1 for a partial test of Equation 9.5.7

change in distance caused by the event *attributed* to A is its "seriousness" or "value" because it measures how much A helped moved the entity towards the desired goal state. To evaluate the intensity of *Acceptance*, EMgine treats the event's "value" as an objective measure and it scales with the entity's attachment to A as the subjective (i.e. personal) "value":

$$Acc_{\Delta}(r_A : \mathbb{SA}, r_{min} : \mathbb{SA}, d_{\Delta} : \mathbb{D}_{\Delta}) : \mathbb{I}_{\Delta} \circeq \begin{cases} |d_{\Delta}| \cdot \dfrac{r_A}{r_{min}}, & r_A < r_{min} \\ |d_{\Delta}|, & Otherwise \end{cases} \tag{9.5.7}$$

The value r_{min} represents the minimum social attachment that an entity must have with A to "fully" experience *Acceptance* towards it. Using r_{min} to "normalize" r_A creates a scaling factor that moderates intensity changes such that its magnitude varies with social attachment level. Tuning the minimum "level" changes the entity's resistance to the experience of *Acceptance* so that they appear more trustful or distrustful of other entities. Consequently, the entity's Emotion Intensity Change value depends on the entity's relationship to the other relative to their minimum "trust level".

Note that the *Acceptance* elicitation model outputs a tuple with element $distAttribToA_{\Delta}$, which users can use as the input d_{Δ}.

9.5.3 Evaluating the Intensity of ***Interest***[18]

From the model of *Interest* elicitation (Equation 9.4.7), the affected "internal condition" is an entity's attention (Equation 9.2.9). The "event" driving *Interest* elicitation is not necessarily the same as "world events", implying that the "value" or "seriousness" of increased attention is entity-specific. Therefore, to evaluate the intensity of *Interest*, EMgine uses a subjective attention "value" that it scales with the entity's attention paid to x:

$$Inr_{\Delta}(at : \mathbb{AT}_x, at_{min} : \mathbb{AT}_x, i_{\delta_x} : \mathbb{I}_{\Delta}) : \mathbb{I}_{\Delta} \circeq \begin{cases} i_{\delta_x} \cdot \dfrac{at}{at_{min}} & at < at_{min} \\ i_{\delta_x}, & Otherwise \end{cases} \tag{9.5.8}$$

The subjective attention "value" i_{δ_x} represents the entity's "fascination" with x such that higher values elicit more intense *Interest* with smaller changes in attention. Users can specify different values for i_{δ_x} so that entities are more "intrigued" by some x than others.

The value at_{min} represents the minimum attention that an entity must spend on x to "fully" experience *Interest* towards it. Using at_{min} to "normalize" at creates a scaling factor that moderates intensity changes such that its magnitude varies with uninterrupted, invested attention. Tuning the minimum "level" changes the entity's resistance to the experience of *Interest* so that they appear to be more or less "captivated" by x.

Note that the *Interest* elicitation model outputs a value with type $\mathbb{AT}_x$, which users can supply as the input at.

9.5.4 Evaluating the Intensity of ***Surprise***[19]

From the model of *Surprise* elicitation (Equation 9.4.8), the affected "internal condition" is an entity's prediction about an event's probability. Although the "event" driving *Surprise* is a "world event", its elicitation is driven by an entity's internal prediction about it rather than some event

[18] Equation 9.5.8 not yet tested

[19] Equation 9.5.9 not yet tested

"valuation" or "seriousness". Therefore, EMgine evaluates the intensity of *Surprise* using a subjective "unexpectedness value" that it scales with the "discrepancy" between the event and its improbability based on a common-sense hypotheses about the monotonically increasing relation between *Surprise* intensity and event unexpectedness (Reisenzein et al., 2019, p. 54, 56):

$$Sur_{\Delta}(discr_{s_{\Delta}} : [0,1], i_{max\Delta} : \mathbb{I}_{\Delta}) : \mathbb{I}_{\Delta} \mathrel{\hat{=}} i_{max} \cdot discr_{s_{\Delta}} \tag{9.5.9}$$

The subjective "unexpectedness value" $i_{max\Delta}$ measures how easily an entity is "startled" such that higher values elicit more intense *Surprise* with smaller event probability discrepancies. Users can specify different values for $i_{max\Delta}$ so that entities are more "startled" by some events than others.

Note that the *Surprise* elicitation model outputs a value with type $[0,1]^?$, which users can supply as the input $discr_{s_{\Delta}}$ if it is not None.

9.6 Emotion Decay

Emotions characteristically "fade" over time, implying that their dynamics include a decay function (Hudlicka, 2014a, p. 320; Hudlicka, 2014b, p. 16). The surveyed theories/models (Chapter 5, Table 5.1) do not discuss emotion decay. Like emotion intensity, emotion decay is relatively understudied (El-Nasr et al., 2000, p. 236). Therefore, EMgine approaches its modelling with instinctual knowledge of emotion dynamics. Other CMEs appear to have done the same, using a variety of solutions such as:

- Number of time steps (Ojha and Williams, 2017, p. 4; Loyall, 1997, p. 94; Reilly, 1996, p. 79),
- Linear functions of time (Bourgais et al., 2017, p. 98; Durupınar et al., 2016, p. 2149; Duy Bui, 2004, p. 125–126; Breazeal, 2003, p. 136; Gratch, 2000, p. 330),
- Exponential functions of time with (Kazemifard et al., 2011, p. 2646; Dang and Duhaut, 2009, p. 138) and without a probability distribution (Qi et al., 2019, p. 213; Shvo et al., 2019, p. 68; Zhang et al., 2016, p. 226; Moshkina et al., 2011, p. 212; Kasap et al., 2009, p. 26; Park et al., 2009, p. 260; van Dyke Parunak et al., 2006, p. 995; Dias and Paiva, 2005, p. 131; El-Nasr et al., 2000, p. 236),
- The "half-life" of emotions (Aydt et al., 2011, p. 75), and
- Multidimensional spring systems (Becker-Asano, 2008, p. 90).

A commonality between these solutions is time-dependence and baseline values. CMEs that do not combine emotion intensity and decay into a single function only decay values in the absence of emotion-eliciting events.

9.6.1 Base Model: Damped Harmonic Oscillator

EMgine assumes that entities have "equilibrium" intensities that emotion-eliciting events disrupt. Normalizing forces restore disrupted intensities to their "equilibrium" intensities over time. These normalizing forces are proportional to the "distance" that an intensity is from the "equilibrium" intensity. EMgine models this behaviour with a damped harmonic oscillator mass-spring system of the form:

$$x''(t) + c \cdot x'(t) + k_s \cdot x(t) = 0$$

where $x''(t)$, $x'(t)$, and $x(t)$ are the acceleration, speed, and position of a mass m at time t, c is a strictly positive and real-valued damping coefficient, and k_s is a spring constant. Emotion intensity is equivalent to the "position" of the mass in the system and the system's oscillation behaviour is a way for users to define an entity's "emotional stability".

The damping ratio ζ and natural angular frequency of the system ω_n govern its behaviour:

$$\zeta = \frac{c}{2 \cdot \sqrt{m \cdot k_s}}, \ \omega_n = \sqrt{\frac{k_s}{m}}$$

Closed-forms[20] of each case for ζ are necessary because the general solution allows for imaginary numbers which are not computationally tractable:

- If $0 < \zeta < 1$, the system is *underdamped* such that it oscillates as it returns to equilibrium. As ζ approaches 1, the oscillations decrease more quickly. This could represent an entity that is "emotionally unstable", alternating between high and low emotion intensities before returning to their "normal" state. Position x at time t is given by:

$$\begin{gathered} x(t) = e^{-r \cdot t} \cdot (A \cdot \cos(\omega \cdot t) + B \cdot \sin(\omega \cdot t)) \\ \text{where } A = x_0, \ B = \frac{v_0 + x_0 \cdot \omega_n \cdot \zeta}{\omega}, \ r = \omega_n \cdot \zeta \\ \text{and } \omega = \omega_n \cdot \sqrt{1 - \zeta^2} \end{gathered} \tag{9.6.1}$$

- If $\zeta = 1$, the system is *critically damped* such that it returns to equilibrium as quickly as possible without overshooting it. This could represent an entity that is the most "emotionally stable", recovering more quickly and directly than entities with other ζ values. Position x at time t is given by:

$$x(t) = e^{-\omega_n \cdot t} \cdot (x_0 + (v_0 + x_0 \cdot \omega_n) \cdot t) \tag{9.6.2}$$

- If $\zeta > 1$, the system is *overdamped* such that it does not oscillate as it returns to equilibrium. As ζ increases, the system reaches equilibrium more slowly. This could represent an entity that experiences their emotions longer than others. Position x at time t is given by:

$$\begin{gathered} x(t) = C \cdot e^{-r_1 \cdot t} + D \cdot e^{-r_2 \cdot t} \\ \text{where } C = \frac{1}{2} \cdot \left(x_0 + \frac{v_0 + x_0 \cdot \omega_n \cdot \zeta}{\omega} \right), \ D = \frac{1}{2} \cdot \left(x_0 - \frac{v_0 + x_0 \cdot \omega_n \cdot \zeta}{\omega} \right), \\ r_1 = \omega_n(\zeta - \sqrt{\zeta^2 - 1}), \ r_2 = \omega_n(\zeta + \sqrt{\zeta^2 - 1}) \\ \text{and } \omega = \omega_n \cdot \sqrt{\zeta^2 - 1} \end{gathered} \tag{9.6.3}$$

9.6.2 Decaying Emotion Intensity

EMgine encodes the spring constant k_s in a damped harmonic oscillator, a strictly positive and real-valued constant, in the Emotion Intensity Decay Rate Data Type:

$$\mathbb{I}_\lambda : \mathbb{R}_{>0} \tag{9.6.4}$$

Note that this tightly couples the emotion decay model with the data type such that changing the underlying model of one likely means changing the other as well.

[20] Closed forms from Alexiou (2013).

EMgine uses this data type to evaluate an intensity's "decayed" value. It substitutes $k_s = i_\lambda$, $m = 1$ such that $\omega_n = \sqrt{i_\lambda}$, $x_0 = x(t_0) = i_0 - i_{eq}$, $v_0 = 0$, and $t_0 = 0$ such that $t = 0 + \Delta t = \Delta t$ into each model of position, where $i_0 : \mathbb{I}$ is the "initial" intensity, $i_{eq} : \mathbb{I}$ is the "equilibrium" intensity, $\Delta t : \mathbb{T}_\Delta$ is the elapsed time since $t : \mathbb{T} = 0$, and $i_\lambda : \mathbb{I}_\lambda$ is the intensity's decay rate. After simplifying, Equations 9.6.1, 9.6.2, and 9.6.3 become:

$$\begin{aligned}
&\texttt{Decay}(i_0 : \mathbb{I}, i_{Eq} : \mathbb{I}, i_\lambda : \mathbb{I}_\lambda, \Delta t : \mathbb{T}_\Delta, \zeta : \mathbb{R}_{>0}) : \mathbb{I} \\
&\quad \mathrel{\mathring{=}} I_\lambda + i_{Eq} \\
&\text{where } I_\lambda = \begin{cases}
\begin{aligned} & e^{-\sqrt{i_\lambda}\cdot\zeta\cdot\Delta t}\cdot(i_0 - i_{Eq})\cdot\Bigg(\cos(\omega\cdot\Delta t) \\ &\quad + \left(\frac{\sqrt{i_\lambda}\cdot\zeta}{\omega}\right)\cdot\sin(\omega\cdot\Delta t)\Bigg) \\ &\quad \text{where } \omega = \sqrt{i_\lambda}\cdot\sqrt{1-\zeta^2} \end{aligned}, & 0 < \zeta < 1 \\[2ex]
e^{-\sqrt{i_\lambda}\cdot\Delta t}\cdot(i_0 - i_{Eq})\cdot\left(1 + \sqrt{i_\lambda}\cdot\Delta t\right), & \zeta = 1 \\[2ex]
\begin{aligned} & \frac{i_0 - i_{Eq}}{2}\cdot\Bigg(\left(1 + \frac{\zeta}{Q}\right)\cdot e^{-\sqrt{i_\lambda}\cdot(\zeta - Q)\cdot\Delta t} \\ &\quad + \left(1 - \frac{\zeta}{Q}\right)\cdot e^{-\sqrt{i_\lambda}\cdot(\zeta + Q)\cdot\Delta t}\Bigg) \\ &\quad \text{where } Q = \sqrt{\zeta^2 - 1} \end{aligned}, & \zeta > 1
\end{cases}
\end{aligned} \tag{9.6.5}$$

Adding i_{Eq} to I_λ shifts the position from 0 to the equilibrium point. The damping ratio $\zeta : \mathbb{R}_{>0}$ determines how much emotion intensity oscillates as an returns to equilibrium (Figure 9.1). Most entities will have a profile with $\zeta \geq 1$, but there might be a few whose personality is "emotionally unstable" that warrants the oscillating behaviour that $0 < \zeta < 1$ offers.

9.6.3 Decaying an Emotion State

EMgine assumes that each Emotion Kind $k : \mathbb{K}$ (Equation 9.3.3) can have a decay rate and "equilibrium" value defined independently of others in an Emotion State $es : \mathbb{ES}$ (Equation 9.3.4). This allows entities to vary how long it takes for them to return to "normal" for each emotion kind (e.g. if they experience *Joy* they might extend that state by prolonging the decay to "equilibrium"). To this end, EMgine defines the Emotion Decay State Data Type as a record tied to Emotion State via $\mathbb{K}$ that has two functions `equilibrium` and `decayRates`:

$$\mathbb{ES}_\lambda : \{\texttt{equilibrium} : \mathbb{K} \to \mathbb{I}, \texttt{decayRates} : \mathbb{K} \to \mathbb{I}_\lambda\} \tag{9.6.6}$$

- The function `equilibrium` maps Emotion Kinds to Emotion Intensities ($\mathbb{K} \to \mathbb{I}$), encoding the "equilibrium" intensity for each $k : \mathbb{K}$. It must satisfy the invariant:

  $$\exists k \in \mathbb{K} \to \texttt{equilibrium}(k) > 0$$

  This prevents situations where every value in `equilibrium` is zero (i.e. constantly zero). As with Emotion State (Equation 9.3.4), at least one emotion type in the equilibrium state must be non-zero for the entity to be "awake".

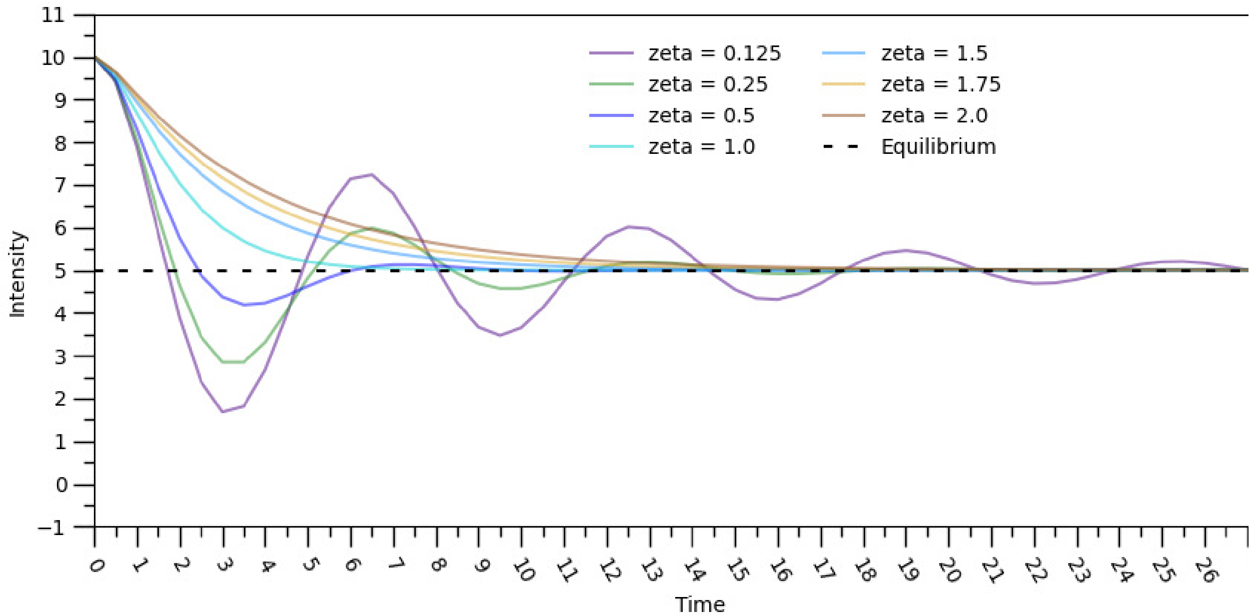


Figure 9.1: Examples of Emotion Decay Profiles with $i_0 = 10.0$, $i_{Eq} = 5.0$, $i_\lambda = 1.0$, and $\zeta =$ `zeta`

- The function `decayRates` maps Emotion Kinds to Emotion Intensity Decay Rates ($\mathbb{K} \to \mathbb{I}_\lambda$), encoding the decay rate for each emotion kind. This allows users to vary decay rates between kinds.

Collecting this information into Emotion Decay State makes it easier to maintain and access for decay process automation (RE5). While users might want to decay individual emotion types in a state, allowing them to decay some emotions while simultaneously exciting others, there might be situations where users want to decay *every* emotion type simultaneously. EMgine provides a helper function for this:

$$\begin{aligned}&\texttt{DecayState}(es_0 : \mathbb{ES}, es_\lambda : \mathbb{ES}_\lambda, \Delta t : \mathbb{T}_\Delta, \zeta : \mathbb{R}_{>0}) : \mathbb{ES}\\ &\quad \mathrel{\hat{=}} \{\, \forall k \to es \text{ with } es.\texttt{intensities}\,(k) = D \,\}\\ &\quad \text{where } D = \texttt{Decay}(\, es_0.\texttt{intensities}\,(k)\,, \Delta t, \zeta,\\ &\qquad es_\lambda.\texttt{decayRates}\,(k)\,, es_\lambda.\texttt{equilibrium}\,(k)\,)\end{aligned} \tag{9.6.7}$$

Users specify an Emotion State $es_0 : \mathbb{ES}$, a time difference $\Delta t : \mathbb{T}_\Delta$ (Equation 9.2.1), an Emotion Decay State $es_\lambda : \mathbb{ES}_\lambda$, and a single damping ratio $\zeta : \mathbb{R}_{>0}$. From this, EMgine decays the intensity of each Emotion Kind $k : \mathbb{K}$ in es_0 using the Emotion Intensity `Decay` function (Equation 9.6.5). The function returns a new Emotion State $es : \mathbb{ES}$ such that es_0 is unmodified.

If the user declared an Emotion $e : \mathbb{E}$ (Equation 9.3.6), EMgine can extract es_0 from e at a user-specified time t to generate a new state for some time $\{t' : \mathbb{T} \to t < t'\}$ using the `DecayState` function (Equation 9.6.7):

$$\begin{aligned}&\texttt{NextStateByDecay}(e : \mathbb{E}, es_\lambda : \mathbb{ES}_\lambda, \left\{t : \mathbb{T}, t' : \mathbb{T} \to t < t'\right\}, \zeta : \mathbb{R}_{>0}) : \mathbb{E}\\ &\quad \mathrel{\hat{=}} \left\{\, e \text{ with } e\left(t'\right) = \texttt{DecayState}\left(\, e\left(t\right), t' - t, \zeta, es_\lambda \,\right) \right\}\end{aligned} \tag{9.6.8}$$

9.7 Emotion States in PAD Space

EMgine distinguishes a PAD Space point from points in other dimensional spaces with a 3-tuple where each field's label is a PAD dimension:

$$P_{(P,A,D)} : (\texttt{pleasure} : [-1, 1] \subset \mathbb{R}, \texttt{arousal} : [-1, 1] \subset \mathbb{R}, \texttt{dominance} : [-1, 1] \subset \mathbb{R}) \quad (9.7.1)$$

The dimension ranges are mean ratings for emotion terms derived empirically by Mehrabian (1980, p. 40–41). There were 16 to 31 subjects per term whose ratings were linearly transformed to the -1 to 1 scale. Although not captured in EMgine's data type, mean ratings of each term differ in statistical significance—measured from a mean of 0 with ($p > 0.01$)—and standard deviation as shown in Table 9.3.

9.7.1 Mapping Emotion States to PAD Space

EMgine assumes that an entity can only be in one PAD Space location at any given time, so it must transform an eight-element Emotion State (Equation 9.3.4) into a three-dimensional coordinate. However, there is no direct mapping between these spaces. EMgine must define reference points in PAD Space for each emotion kind (Equation 9.3.3), effectively "mapping" Plutchik emotion kinds to PAD points. EMgine's approach for this heavily relies on the comparison of emotion terms in each model for equal or comparable semantic meaning, which is both subjective and error-prone. Unfortunately, there does not appear to be a more reliable alternative.

Assumptions Based on Plutchik's and Mehrabian's Empirical Studies

EMgine assumes that laypeople would judge the natural language meaning of the terms in Plutchik and PAD Space identically or nearly identically. It derives this assumption from published, independently run empirical studies by Plutchik and Mehrabian where they were evaluating their own affective models. For his study on emotion language, Plutchik created a list of 145 emotion terms and asked participants to judge how "similar" the terms are (Plutchik, 1980, p. 159, 168–170). They then assigned angular placements on a Circumplex to terms based on their relative "similarity" to each other. Mehrabian asked participants to judge the contribution of each dimension—*pleasure*, *arousal*, and *dominance*—in the experiences described by 151 terms from which it derived statistical mean and standard deviation values (Mehrabian, 1980, p. 39–45). Reports about the participants in these studies suggest that they were:

- Likely in the same age group (university undergraduates, college and graduate students), and
- Likely had an North American cultural perspective (studies done in the United States).

The publication dates (1980) further suggest that Plutchik and Mehrabian likely conducted their studies around the same time. Taken together, this implies that the laypeople in these studies shared common temporal and cultural experiences that would have influenced their interpretation of natural language terms.

Selection Process for PAD Space Reference Points of Plutchik Emotion Kinds

From Plutchik's list of emotion terms and angular placements, EMgine defined eight "boundaries" around Circumplex areas for each of its emotion kinds. "Boundary" terms are those where the perceived qualitative meaning changes between it and the next listed term (Figure 9.2, Table 9.2). For example, the change from "Attentive" to "Joyful" distinguishes a "boundary" between the

Interest and *Joy* areas because they do not "feel" like they have the same qualitative meaning (i.e. "Joyful" implies a higher degree of pleasantness than "Attentive", which does not imply either pleasantness or unpleasantness). This mimics the idea of discrete emotion "families" such that EMgine can use one affective term to specify a PAD Space reference point to serve as the emotion "family"'s dimensional representation (Figure 9.3). Gaps between "boundary" terms are inevitable due to the discrete nature of angular placements. However, they are relatively small (between 0.3° and 7.3°), so EMgine ignored them instead of trying to compensate for them to avoid introducing additional "translation errors".

EMgine compiled eight lists—one for each derived Circumplex "area"—of exact or nearly exact matches of emotion terms in Plutchik and PAD Space (Table 9.3). EMgine takes a single term from each list as its PAD Space reference point for that Plutchik emotion, giving preference to PAD terms that have statistically significant means for each dimension, then to semantically equivalent terms. If there was no term equivalence, EMgine took the term closest to the midpoint of the Plutchik Circumplex "area". EMgine ignores number of ratings and standard deviation of PAD terms for simplicity.

9.7.2 Converting EMgine Emotion States into PAD Space Coordinates

EMgine uses the chosen reference points to translate an emotion state (Equation 9.3.4) into a PAD point (Equation 9.7.1) by finding the PAD Space point for each individual emotion kind (Equation 9.3.3) in the state. The model evaluates these points such that an emotion kind with zero intensity has the coordinates $(0, 0, 0)$—the neutral PAD value (Mehrabian, 1980, p. 40)—and one at maximum intensity has the same value as the corresponding reference point. It then sums the individual points into an overall PAD point, clamping it to $[-1, 1]$, because EMgine assumes that an entity can only occupy one point in PAD Space at any given time:

$$\begin{gathered}
\texttt{ConvertStateToPADPnt}(es : \mathbb{ES}) : P_{(P,A,D)} \\
\stackrel{\circ}{=} \texttt{clamp}\left(0.1 \cdot \log_2\left(\sum_{k \in \mathbb{K}} 2^{10 \cdot v(k) \cdot I_k}\right), -1, 1\right) \\
\text{where } I_k = \frac{es.\texttt{intensities}(k)}{es.\texttt{max}(k)} \\
\text{and } v\,(k : \mathbb{K}) : P_{(P,A,D)} = \begin{cases} (-0.62, +0.82, -0.43), & k = \texttt{Fear} \\ (-0.51, +0.59, +0.25), & k = \texttt{Anger} \\ (-0.63, -0.27, -0.33), & k = \texttt{Sadness} \\ (+0.76, +0.48, +0.35), & k = \texttt{Joy} \\ (+0.64, +0.51, +0.17), & k = \texttt{Interest} \\ (+0.16, +0.88, -0.15), & k = \texttt{Surprise} \\ (-0.60, +0.35, +0.11), & k = \texttt{Disgust} \\ (+0.64, +0.35, +0.24), & k = \texttt{Acceptance} \end{cases}
\end{gathered} \tag{9.7.2}$$

EMgine bases the function inside `clamp` the one from Em/Oz (Reilly, 2006) and GAMYGDALA (Popescu et al., 2014, p. 38). It relies on a logarithm so that it is not strictly additive and all values contribute to the output such that its magnitude is at least as much as the highest input. Although not experimentally verified, it emulates these desired behaviours and reportedly works well.

This model does lose information about the converted emotion state because it is combining information from eight discrete categories into one point in a three-dimensional space (Schaap and

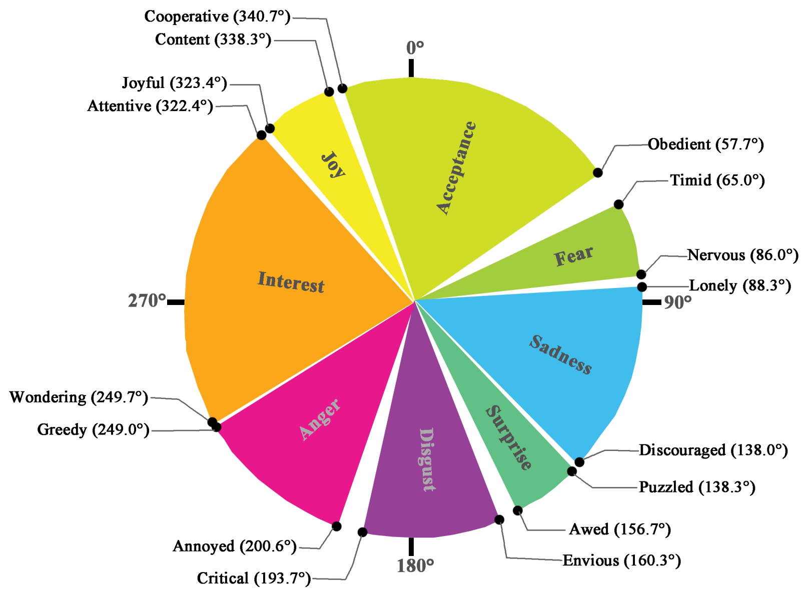


Figure 9.2: EMgine-Specific Emotion Kind Boundaries on Plutchik's Circumplex based on Plutchik's Empirical Data

Table 9.2: Summary of EMgine-defined Areas on the Plutchik Circumplex based on Plutchik's Empirical Data

Label	**Range (°)**	**Midpoint (°)**
Acceptance	[340.7, 57.7]	19.20
Fear	[65.0, 86.0]	75.50
Sadness	[88.3, 138.0]	113.15
Surprise	[138.3, 156.7]	147.50
Disgust	[160.3, 193.7]	177.00
Anger	[200.6, 262.0]	231.30
Interest	[249.7, 322.4]	286.05
Joy	[323.4, 338.3]	330.85

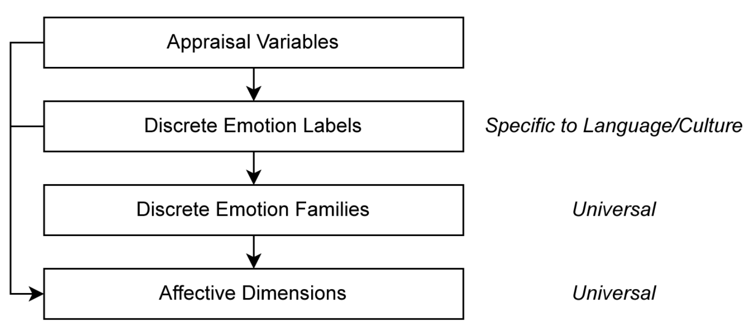


Figure 9.3: Mapping Data Between Perspectives, Adapted from Scherer (2010b, p. 15)

Table 9.3: Emotion Terms in Both Plutchik and PAD Space with their Associated Empirical Data from Each

Plutchik			PAD Space								
						P		**A**		**D**	
Area	**Term**	**Angle**	**Term**	**#**	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Acceptance	Affectionate	52.3°	Affectionate	34	29	0.64*	0.26	0.35*	0.34	0.24*	0.40
	Cooperative	340.7°	Cooperative	43	31	0.39*	0.32	0.13*	0.27	0.03	0.34
Fear	Anxious	78.3°	Anxious	50	28	0.01	0.45	0.59*	0.31	-0.15	0.32
	Humiliated	84.0°	Humiliated	99	27	-0.63*	0.18	0.43*	0.34	-0.38*	0.30
	Terrified	75.7°	Terrified	102	29	-0.62*	0.20	0.82*	0.25	-0.43*	0.34
	Helpless	80.0°	Helpless	104	29	-0.71*	0.18	0.42*	0.45	-0.51*	0.32
	Embarrassed	75.3°	Embarrassed	110	29	-0.46*	0.30	0.54*	0.26	-0.24*	0.40
	Shy	72.0°	Shy	117	29	-0.15	0.33	0.06	0.30	-0.34*	0.28
	Timid	65.0°	Timid	131	28	-0.15	0.41	-0.12	0.37	-0.47*	0.31
Sadness	Gloomy	132.7°	Solemn	72	29	0.03	0.39	-0.32*	0.26	-0.11	0.33
	Grief-Stricken	127.3°	Anguished	107	29	-0.50*	0.30	0.08	0.46	-0.20*	0.34
	Guilty	102.3°	Guilty	118	29	-0.57*	0.19	0.28*	0.38	-0.34*	0.28
	Remorseful	123.3°	Regretful	123	30	-0.52*	0.24	0.02	0.32	-0.21*	0.28
	Depressed	125.3°	Depressed	126	27	-0.72*	0.21	-0.29*	0.44	-0.41*	0.28
	Despairing	133.0°	Despairing	127	27	-0.72*	0.21	-0.16	0.34	-0.38*	0.25
	Lonely	88.3°	Lonely	128	29	-0.66*	0.35	-0.43*	0.36	-0.32*	0.30
	Meek	91.0°	Meek	129	29	-0.19	0.58	-0.25*	0.32	-0.41*	0.42
	Bored	136.0°	Bored	132	28	-0.65*	0.19	-0.62*	0.24	-0.33*	0.21
	Rejected	136.0°	Rejected	137	29	-0.62*	0.24	-0.01	0.38	-0.33*	0.27
	Discouraged	138.0°	Discouraged	150	30	-0.61*	0.25	-0.15	0.32	-0.29*	0.32
	Sad	108.5°	Sad	151	30	-0.63*	0.23	-0.27*	0.34	-0.33*	0.22
Surprise	Surprised	146.7°	Surprised	52	29	0.40*	0.30	0.67*	0.27	-0.13	0.38
	Awed	156.7°	Awed	56	30	0.18*	0.34	0.40*	0.30	-0.38*	0.21
	Astonished	148.0°	Astonished	74	30	0.16*	0.26	0.88*	0.19	-0.15*	0.26
	Confused	141.3°	Confused	121	30	-0.53*	0.20	0.27*	0.29	-0.32*	0.28
Disgust	Disgusted	161.3°	Disgusted	75	29	-0.60*	0.20	0.35*	0.41	0.11	0.34
	Contemptuous	192.0°	Contempt	85	29	-0.23*	0.39	0.31*	0.33	0.18*	0.29
	Suspicious	182.7°	Suspicious	90	29	-0.25*	0.23	0.42*	0.21	0.11	0.32
	Distrustful	185.0°	Skeptical	91	29	-0.22*	0.28	0.21*	0.25	0.03	0.33
	Displeased	181.5°	Displeased	109	29	-0.55*	0.21	0.16	0.34	-0.05	0.41
	Indignant	175.0°	Quietly Indignant	114	26	-0.28*	0.35	0.04	0.36	-0.16	0.40
	Dissatisfied	183.0°	Dissatisfied	122	30	-0.50*	0.22	0.05	0.28	0.13	0.32

Table 9.3: *(Continued)* Emotion Terms in Both Plutchik and PAD Space with their Associated Empirical Data from Each

	Plutchik		**PAD Space**								
						P		**A**		**D**	
Area	**Term**	**Angle**	**Term**	**#**	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
	Aggressive	232.0°	Aggressive	13	28	0.41*	0.30	0.63*	0.25	0.62*	0.24
	Irritated	202.3°	Irritated	78	29	-0.58*	0.16	0.40*	0.37	0.01	0.40
	Defiant	230.7°	Defiant	79	28	-0.16*	0.30	0.54*	0.37	0.32*	0.42
Anger	Hostile	222.0°	Hostile	81	29	-0.42*	0.31	0.53*	0.36	0.30*	0.32
	✎Angry	212.0°	Angry	82	29	-0.51*	0.20	0.59*	0.33	0.25*	0.39
	Annoyed	200.6°	Mildly Annoyed	83	29	-0.28*	0.16	0.17*	0.28	0.04	0.31
	Furious	221.3°	Enraged	84	29	-0.44*	0.25	0.72*	0.29	0.32*	0.44
	Scornful	227.0°	Scornful	89	28	-0.35*	0.21	0.35*	0.27	0.29*	0.32
	Adventurous	270.7°	Bold	1	27	0.44*	0.32	0.61*	0.24	0.66*	0.30
	Proud	262.0°	Proud	7	29	0.77*	0.21	0.38*	0.34	0.65*	0.33
	✎Interested	315.7°	Interested	8	29	0.64*	0.20	0.51*	0.21	0.17	0.40
Interest	Elated	311.0°	Elated	17	28	0.50*	0.47	0.42*	0.14	0.23*	0.36
	Hopeful	298.0°	Hopeful	18	29	0.51*	0.30	0.23*	0.33	0.14	0.41
	Wondering	249.7°	Wonder	54	30	0.27*	0.37	0.24*	0.35	-0.17*	0.26
	Curious	261.0°	Curious	58	28	0.22*	0.30	0.62*	0.20	-0.01	0.34
Joy	✎Joyful	323.4°	Joyful	20	29	0.76*	0.22	0.48*	0.26	0.35*	0.31
	Happy	323.7°	Happy	31	29	0.81*	0.21	0.51*	0.26	0.46*	0.38

N *Number of Ratings*
SD *Standard Deviation*
* *Statistically Significant* ($p > 0.01$)
✎ *Chosen term*

Bidarra, 2008, p. 172; Broekens, 2021, p. 353). After conversion, it is nearly impossible to determine which emotion kind-intensity combinations contributed to the point's generation. Should a user need this information, they must associate the state with the point manually.

9.8 Documenting EMgine's Models

EMgine adheres to Document Driven Design (DDD), progressively documenting requirements, design, implementation, and testing (Smith et al., 2016, p. 41–42). While it is an adaptation of the waterfall development model, this does not mean that the execution of the process follows it (Smith and Yu, 2009, p. 1157). It depends on traceability between the requirements and all other products of the design and testing process to account for changes at any point in the process, ensuring that the final documentation "will be rational and accurate" (Parnas and Clements, 1986, p. 256).

A Software Requirements Specification (SRS) documents the context of EMgine's design and acts as a benchmark to compare the final product against (Smith and Yu, 2009, p. 1157). EMgine uses a variation of the SRS template proposed by Smith and Lai (2005) and Smith et al. (2007)—demonstrated in Smith and Yu (2009)—because it accounts for formal models that designers can realize differently based on what assumptions they make. This is relevant to EMgine, which must translate informal emotion theories into formal models which necessarily requires assumptions. This template also encourages references to other CMEs, so that EMgine can use their solutions and avoid past mistakes (Parnas, 1996, p. 59). EMgine's SRS[21] documents four kinds of models:

1. *Conceptual Models*, which EMgine adds, describing the emotion theories as they are in the literature and how this designer understands them using natural language, offering transparency and maintaining a direct connection to the primary literature;

2. *Theoretical Models* begin to refine the Conceptual Models using natural language and explicit assumptions to improve their precision, reducing ambiguities about the connection between primary sources and the formal Data Types and Instance Models;

3. *Data Types* to define the formal structures that EMgine needs to realize Instance Models; and

4. *Instance Models* describe the formalization of Theoretical Models using type definitions and additional assumptions as needed.

The SRS also documents critical contextual information including constraints, functional and nonfunctional requirements, and anticipated changes.

9.9 Summary

EMgine's design relies heavily on data types, allowing it to represent abstract concepts such as "the world" and "emotion intensity". While EMgine defines most data types, it leaves some as API specifications so that it does not constrain users to implementations that might not be ideal for their game. These data types allow the definition of "interfaces" between models of different theories (i.e. Plutchik, Oatley & Johnson-Laird, and PAD Space) and models derived from other domains to represent underdeveloped concepts such as emotion decay. The contents of each model and EMgine's high-level requirements, documented in an SRS, then guide its design and implementation stages.

[21] See EMgine's SRS at https://github.com/GenevaS/EMgine/blob/main/docs/SRS/EMgine_SRS.pdf.

Key Points

- Plutchik's emotion kind definitions serve as the baseline for finding "interfaces" between Oatley & Johnson-Laird and PAD Space when specifying EMgine's models
- EMgine primarily represents conceptual information embedded in affective theories, such as goals and emotion intensity, with data types
- The translation of affective theory and model concepts into EMgine's models move through an intermediary stage where the natural language descriptions are "rewritten" with more formal natural language to clarify their relationship and necessary assumptions
- EMgine has separate elicitation and intensity evaluations for each emotion kind to afford more control over when and where emotion generation happens
- EMgine bases its model of emotion decay on the behaviour of damped harmonic oscillators from an intuitive understanding of how emotions "fade over time", which affords the creation of different decay "behaviours" by varying the damping ration ζ
- To "map" discrete Plutchik emotions into the PAD dimensional space, EMgine defined reference points by comparing lists of affective terms used in empirical studies of that theory and model to select representative terms from each that have comparable semantic meanings
- EMgine derives the PAD point "equivalent" of an emotion state by summing the "equivalent" PAD points for each emotion kind in the state, where emotion intensity in the state "scales" the associated reference PAD point
- EMgine bases its software requirements documentation on templates proposed by Smith and Lai (2005) and Smith et al. (2007) due to its focus on documenting assumptions that progressively refine mathematical models

Chapter 10

Build Your EMgine: Some Assembly Required

Hmm. Art?

Giant, *The Iron Giant*

It is easier to integrate EMgine's high-level design goals into its architecture design (Section 10.1) and subsequent implementation efforts (Section 10.2) after specifying its models (Chapter 9) because they describe how many and what types of components EMgine might need. Although its development looks like it followed the waterfall method, EMgine treated this development model more like guidelines than strict rules—there were many instances of backtracking to and concurrent work between stages.

10.1 Specifying EMgine's Architecture

EMgine cannot just provide a list of data types and functions—it must also describe how it groups them into units and how they communicate. A software's *architecture* describes these aspects. Generally, nonfunctional requirements guide the architecture style[1] selection because each style promotes different sets of competing software qualities (Qian et al., 2010, p. 9). EMgine included the user needs (Chapter 6.1) in its nonfunctional requirements, which it uses to inform its architecture style. In turn, the style aids module decomposition and the definition of their relationships. This process lead EMgine to a *library of components* design that comes packaged with a default *"engine"* that is itself a system of components. A library-based approach also alleviates some of EMgine's design pressure, as it no longer has to "...be generic enough to encompass all possible forms of a perception-action cycle in an agent" (Mascarenhas et al., 2022, p. 8:12).

10.1.1 Requirements to Architecture Style

The *Independence from an agent architecture* (RF1), *Hiding the complexity of emotion generation* (RE1), and *Providing a clear API* (RE2) requirements suggest that EMgine's processes should be a black-box. However, it would be difficult to support *Allowing EMgine's outputs to be traceable and understandable* (RE4) if one could not see how EMgine's parts passed information to each other so that its overall behaviour can be explained (Guimarães et al., 2022, p. 20). Users do not

[1] They are also called software architecture patterns.

need to know *how* EMgine decays emotion but they do need to know where the inputs are from and where the outputs are going. Therefore, EMgine's components should be black-boxes, but not their connections. This suggests that a component-based software architecture (Qian et al., 2010, p. 248–261) is best, where each of EMgine's "tasks" is a discrete component that users can include, exclude, and change as needed. A component-based design approach is common in CME development (Osuna et al., 2021, p. 141). For EMgine, this approach would:

- Increase its portability by specifying what each component is guaranteed to provide so that designers can use existing validated systems and integrate new components more easily and quickly (Rodríguez and Ramos, 2015, p. 443), supporting RF1 for both agent architectures and game engines
- Mandate well-defined interfaces to show what each component requires and provides, including its configuration parameters, supporting *Allowing the customization or redefinition of EMgine's preexisting configuration parameters* (RF3), *Allowing developers to choose which kinds of emotion EMgine produces* (RF5), *Allowing developers to specify how to use EMgine's outputs* (RF6), *Providing a clear API* (RE2), *Allowing EMgine's outputs to be traceable and understandable* (RE4), and *Allowing designers the option to automate the storing and decaying of EMgine's emotion state* (RE5)
- Allow designers to call EMgine's components as needed, supporting *Allowing the game designer to choose which of EMgine's tasks to use* (RF2) and—potentially—*Showing that EMgine improves the player experience* (RE6) and *Providing examples as to how EMgine can create novel game experiences* (RE7) if done in a unique way
- Allow designers to add or swap EMgine's components, supporting *Allow the integration of new components* (RF4), *Allowing developers to choose which kinds of emotion EMgine produces* (RF5), *Ability to operate on different levels of NPC complexity* (RF7), and *Be efficient and scalable* (RF8) (Carbone et al., 2020, p. 466)
- Have the potential for developing authoring tools that interface with and manage EMgine components, supporting *Minimizing authorial burden* (RE3)

Ongoing work on the FAtiMA architecture and its descendants, the FAtiMA Modular framework and FAtiMA Toolkit, found this approach successful (Mascarenhas et al., 2022, p. 8:2, 8:12–8:13). After gaining feedback from members of the games industry[2], the FAtiMA Toolkit's designers realized it as a library of components so that its parts can work autonomously. This also increased the Toolkit's chances of adoption, as it allows game designers to use it in their existing systems and/or frameworks while avoiding the complexity and accessibility issues of other agent architectures (Guimarães et al., 2022, p. 3). This also lets users focus on what emotion processing sequence works for their needs rather than constraining them to "EMgine's process" since no one really knows what order emotion processes truly run in (Moffat, 1997, p. 142).

While each of EMgine's components are black-boxes (Qian et al., 2010, p. 253), a game designer might not know when they should use a component or if it is necessary. This could jeopardize *Hiding the Complexity of Emotion Generation* (RE1). A component-based software architecture supports this need too by allowing the specification of a prebuilt component that is itself a "system" of components (Qian et al., 2010, p. 249) that minimizes the necessary decisions and inputs needed

[2]As part of the "Realising an Applied Gaming Eco-system" (RAGE) project (https://cordis.europa.eu/project/id/644187).

for emotion processing. It would accept data and return an emotion state without the designer knowing how it works (Rodríguez and Ramos, 2015, p. 443).

This prebuilt component or "engine" is similar to GAMYGDALA, which compares itself to a physics engine (Popescu et al., 2014, p. 32). Due to its plugin nature, designers have successfully applied GAMYGDALA to: arcade and puzzle games (Broekens, 2015); a narrative generation framework to drive character emotions (Kaptein and Broekens, 2015); and implement affective decision-making in fighting game characters (Yuda et al., 2019). A developer has also successfully integrated the fuzzy logic, classical conditioning, and learning from another CME[3] with GAMYGDALA (Code, 2015, p. 4). The breadth of games that developers have applied GAMYGDALA to and the potential for extensibility suggests that EMgine's inclusion of a large, prefabricated component could further increase its chances for success.

10.1.2 Turning Models into Modules

EMgine creates the building blocks for its architecture by decomposing its requirements specification into software elements or *modules* using the *information hiding* principle (Parnas, 1972). The goal is to isolate each of EMgine's parts that are likely to change into one module, supporting design for change, incremental development, and the separation of concerns. Defining a module's "likely change" also promotes highly cohesive internal elements because it often indicates the module's goal or concern that they work towards. Due to the *Allowing the game designer to choose which of EMgine's tasks to use* (RF2) and *Allowing the customization or redefinition of EMgine's preexisting configuration parameters* (RF3) requirements, EMgine conceptualizes a potential user task as a module's goal to work towards the seamless addition and removal of those tasks. The hidden "likely changes" describe the internal representations of data types, functions, and the relationships between them, which also moves EMgine towards satisfying *Hiding the complexity of emotion generation* (RE1). To this end, EMgine identifies seven logical units:

- Emotion Intensity, containing the $\mathbb{I}$ and $\mathbb{I}_\Delta$ data types (Equations 9.3.1 and 9.5.1), a function for "combining" an emotion intensity with an intensity change (Equation 9.3.2), and functions for evaluating emotion intensity (Chapters 9.5.1, 9.5.2, 9.5.3, and 9.5.4). EMgine subdivides the unit into Emotion Intensity Type and Emotion Intensity Function modules because at least five other units rely on $\mathbb{I}$ and the functions for evaluating emotion intensity are very likely to change.

- Emotion State, containing the $\mathbb{K}$ and $\mathbb{ES}$ data types (Equations 9.3.3 and 9.3.4), functions for manipulating an Emotion State (Equation 9.3.5), and emotion generation (Chapter 9.4). EMgine subdivides this unit into Emotion State Type and Emotion Generation modules to isolate the Plutchik-specified state from the Oatley & Johnson-Laird-specific generation functions.

- Emotion Decay, containing the $\mathbb{I}_\lambda$ and $\mathbb{ES}_\lambda$ data types (Equations 9.6.4 and 9.6.6) and functions for evaluating decayed emotion intensity and state (Equations 9.6.5 and 9.6.7). EMgine subdivides this unit into Emotion Intensity Decay and Emotion State Decay to separate the tasks of decaying a single emotion intensity and decaying all intensities in an emotion state.

- PAD, containing the $P_{(P,A,D)}$ data type (Equation 9.7.1) and function for converting and emotion state to a PAD point (Equation 9.7.2). EMgine subdivides the unit into PAD Type

[3]FLAME (4), included in the CME survey (Chapter 5)

and PAD Function modules because the definition of $P_{(P,A,D)}$ is highly unlikely to change whereas the conversion function is likely to change.

- Emotion, containing the $\mathbb{E}$ data type (Equation 9.3.6), functions for manipulating it (Equations 9.3.7 and 9.3.8), and the function for generating a decayed emotion state from a previous one stored in $\mathbb{E}$ (Equation 9.6.8). EMgine subdivides the unit into Emotion Type and Emotion Function modules because the functions are for ease-of-use, which a user might not need because they defined their own or they are not relevant to the task.

- Entity, containing the $\mathbb{G}$, $\mathbb{P}$, $\mathbb{SA}$, and $\mathbb{AT}_x$ data types (Equations 9.2.6, 9.2.7, 9.2.8, and 9.2.9). EMgine subdivides these into Goal, Plan, Social Attachment, and Attention modules. Only the Goal module is mandatory and there are no dependencies between the Plan, Attention and Social Attachment modules, so separating them into dedicated modules allows users to add and remove them as needed.

- World, containing the function signatures that users must implement for $\mathbb{T}$, $\mathbb{T}_\Delta$, $\mathbb{S}$, $\mathbb{S}_\Delta$, $\mathbb{D}$, and $\mathbb{D}_\Delta$ (Equations 9.2.1, 9.2.2, 9.2.3, 9.2.4, and 9.2.5). EMgine subdivides these into Time and World State modules because the World State is only necessary for emotion generation and evaluating emotion intensity, whereas Time is essential to modules that are independent of those components (e.g. Emotion Intensity Decay).

EMgine further organizes these units into two groups: behaviour-hiding modules, which EMgine specifies in its requirements and is responsible for implementing; and software decision modules, which EMgine does not specify in its requirements. EMgine recognizes the World logical unit and its modules—Time and World State—as software decision modules because, although it associates them with requirements, ultimately the user specifies these modules. This gives EMgine a total of three levels of decomposition and 16 modules to specify interfaces for and implement (Table 10.1) of which only Time, World State, Emotion Intensity Type, and Emotion State Type are highly coupled (Figure 10.1).

Module Decomposition Known Issues

Although this modularization makes it easy to add and remove EMgine's tasks, it does have points where it "leaks" information that should be hidden. These are a byproduct of modularization and it is worth noting that it is extremely difficult to remove them all. There are some situations where the "leak" is necessary because it supports other attributes of the modularization. Therefore, the goal is to reduce "leaks" as much as possible.

A non-exhaustive list of known information "leaks" highlights opportunities for future re-modularization efforts. Notably, there are no "leaks" in the World Module (**M15** and **M16**) because they lack implementation details by design.

Emotion Intensity Module The most concerning information leak is in the Emotion Intensity Type Module (**M1**), where it is apparent that it manipulates its internal values arithmetically. While other modules need to access those values to perform arithmetic operations, it implies that such operations are meaningful outside of this context (e.g. adding two *values* from the emotion intensity module is not equivalent to adding two *intensities*). Due to the number of modules that depend on $\mathbb{I}$ and $\mathbb{I}_\Delta$, there is no obvious module decomposition that seals the leak while retaining the ease of adding/removing EMgine tasks.

There are no significant information "leaks" in the Emotion Intensity Function Module (**M2**). While it is apparent that some functions depend on particular information (e.g. *Acceptance* requires

Level 1	**Level 2**	**Level 3**
Behaviour-Hiding Module	Emotion Intensity Module	**M1** Emotion Intensity Type Module
		M2 Emotion Intensity Function Module
	Emotion State Module	**M3** Emotion State Type Module
		M4 Emotion Generation Module
	Emotion Decay Module	**M5** Emotion Intensity Decay Module
		M6 Emotion State Decay Module
	PAD Module	**M7** PAD Type Module
		M8 PAD Function Module
	Emotion Module	**M9** Emotion Type Module
		M10 Emotion Function Module
	Entity Module	**M11** Goal Module
		M12 Plan Module
		M13 Attention Module
		M14 Social Attachment Module
Software Decision Module	World Module	**M15** Time Module
		M16 World State Module

Table 10.1: EMgine's Module Hierarchy (Implements numbered modules)

information about $\mathbb{SA}$), these follow the emotion kind's definitions. Since this matches the conceptual model of these kinds (e.g. an attachment to something must exist to experience *Acceptance* towards it), this is not an information "leak".

Emotion State Module There is potential for information "leakage" in the Emotion Generation Module (**M4**) because it uses its outputs in the internal evaluation. However, users cannot simply "generate" an emotion if they manually calculate each output because EMgine hides *how* it interprets them. Therefore, it is not a true information "leak".

There is a small "leak" in the Emotion State Type Module (**M3**) such that the PAD Function Module (**M8**) knows the structure of $\mathbb{K}$. An obvious solution is to include the PAD functions in **M3**, but this would no longer be a clear separation of tasks. After this, the riskiest operation in **M3** is combining an $\mathbb{I}_\Delta$ with an $\mathbb{I} \in \mathbb{ES}$. However, EMgine-defined data types handle this such that users cannot manipulate the state directly. This prevents external, "illegal" operations on an emotion state and only allows internal data manipulations.

Emotion Decay Module Revealing that the Emotion Intensity Decay Module (**M5**) models a damped harmonic oscillator is a potential information "leak". However, giving this information to users improves usability because they can leverage existing tools to create their desired emotion decay profile. Since this module isolates this information, it is not a true "leak".

There are no known information "leaks" in the Emotion State Decay Module (**M6**) because it is simply a container for decay objects so that users have a convenient way to simultaneously decay all intensities in an emotion state.

PAD Module An information "leak" in the PAD Type Module (**M7**) is the scaling function, which takes a $P_{(P,A,D)}$ and scales it by a real value $v \in \mathbb{R}$. The intended use is to "scale" a $P_{(P,A,D)}$

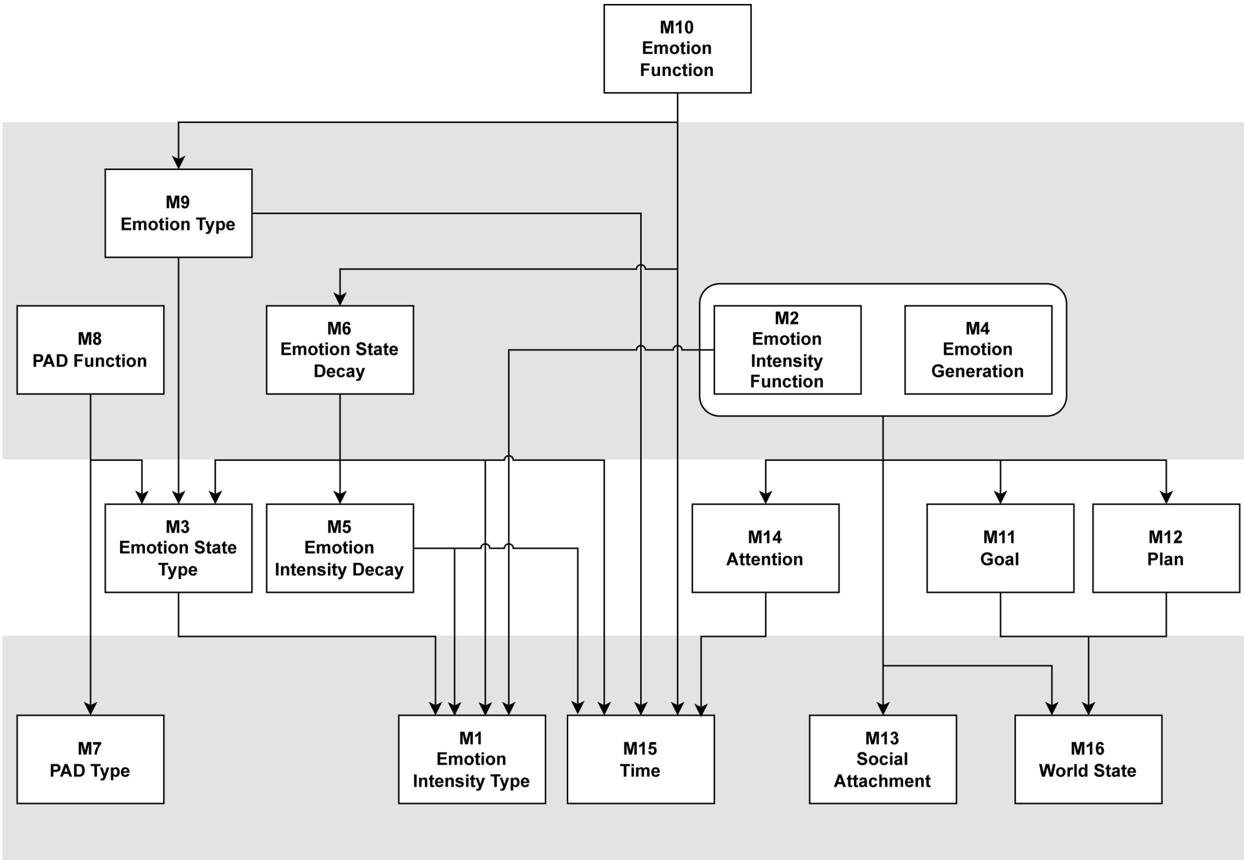


Figure 10.1: Module Dependency Hierarchy

with normalized values so that it stays in PAD Space. However, the "scaling" function implies that users can use it for other PAD Point scaling needs, such as animation parameters. As with the Emotion Intensity Type Module (**M1**), this operation is not meaningful outside of this context but its definition implies that it is. Sealing this "leak" might be a simple matter of renaming the function, but must be mentioned should it cascade into further issues.

There are no known information "leaks" in the PAD Function Module (**M8**).

Emotion Module There are no known information "leaks" in either the Emotion Type (**M9**) or Emotion Function (**M10**) modules, likely because they are mainly for tracking and automatically decaying emotion state data.

Entity Module Social Attachment Module (**M14**) has a potential information "leak" because it exposes its underlying representation of attachment levels. Since the representation is numeric, it implies that arithmetic operations on them are meaningful outside the module. As with the Emotion Intensity Type (**M1**) and PAD Type (**M7**) Modules, this is not the case and users might do so without realizing it. Sealing this "leak" might simply require a reconsideration of its interface, but alternative decomposition approaches should not discount it.

There are no known "leaks" in either the Goal (**M11**) or Plan (**M12**) modules, successfully hiding how they query and manipulate World Module data. There are no known "leaks" in the Attention Module (**M13**), which hides how it tracks discrete time steps.

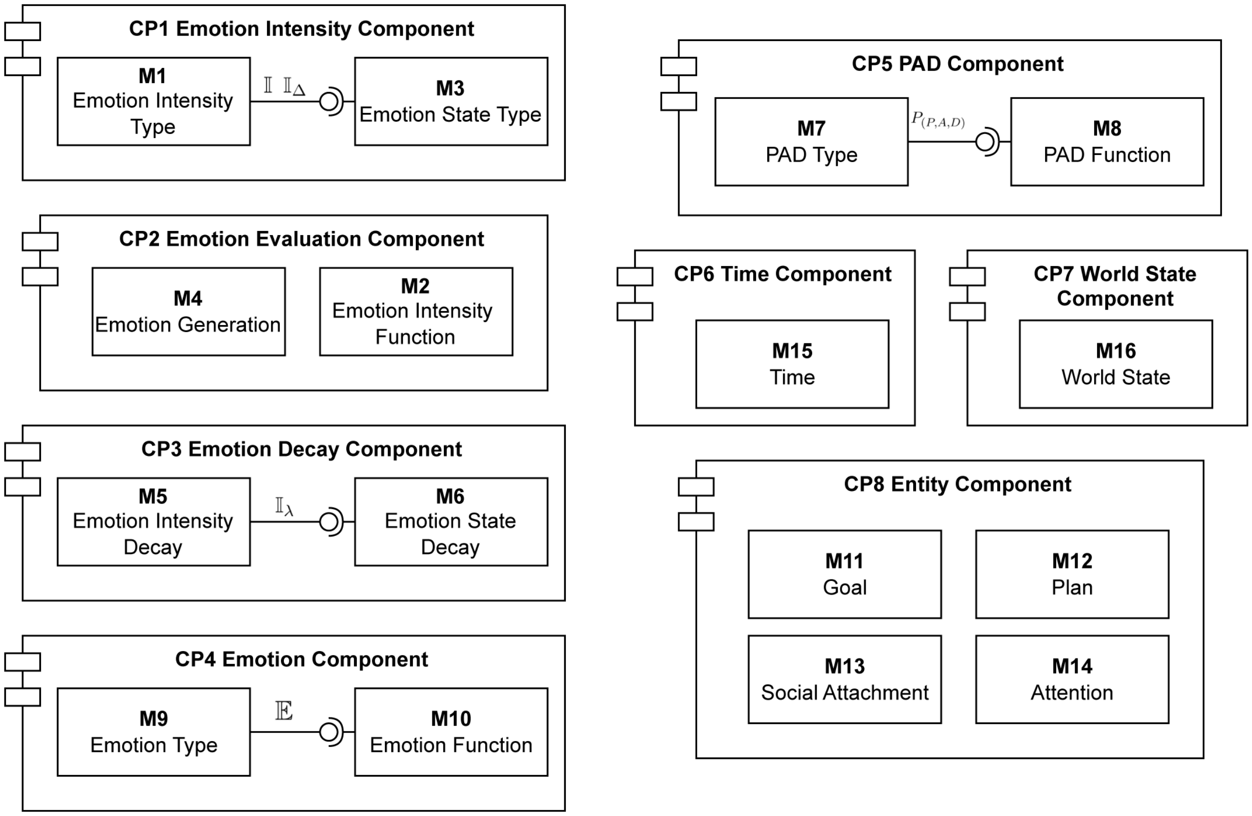


Figure 10.2: Organization of Modules in Components ("Ball" provides functionality that a "Cup" needs)

10.1.3 Turning Modules into Components

Module decomposition reduced EMgine's models into atomic units contained in unimplemented "virtual" modules (Levels 1 and 2 in Table 10.1) but this is not necessarily how a user would visualize their groupings. For example, the hierarchy does not group the Emotion Generation and Emotion Intensity Function modules together despite their common dependencies (Figure 10.1). A user might view them as a single unit because emotion intensity is only relevant if the associated emotion is present. Therefore, EMgine's assignment of the 16 modules to eight components aims to collect highly-related functionality into a comprehensive unit (Figure 10.2), exchangeable for another with comparable abilities while reducing inter-component connections (Figure 10.3):

C1 Emotion Intensity collects the Emotion Intensity Type (**M1**) and dependant Emotion State Type (**M3**) modules because they represent EMgine's core emotion types. This also collects all EMgine-specific models necessary for users to define custom emotion kinds (Chapter 9.3). Since Emotion Intensity Type does not depend on other modules, this only reduces visible dependencies by one as the component hides Emotion State Type's dependency on Emotion Intensity Type.

C2 Emotion Evaluation collects the Emotion Generation (**M4**) and Emotion Intensity Function (**M2**) modules due to the previously described interdependence of emotion generation and intensity evaluations. Since these two modules require all the same inputs, grouping them as one unit also halves the visible dependencies on other modules.

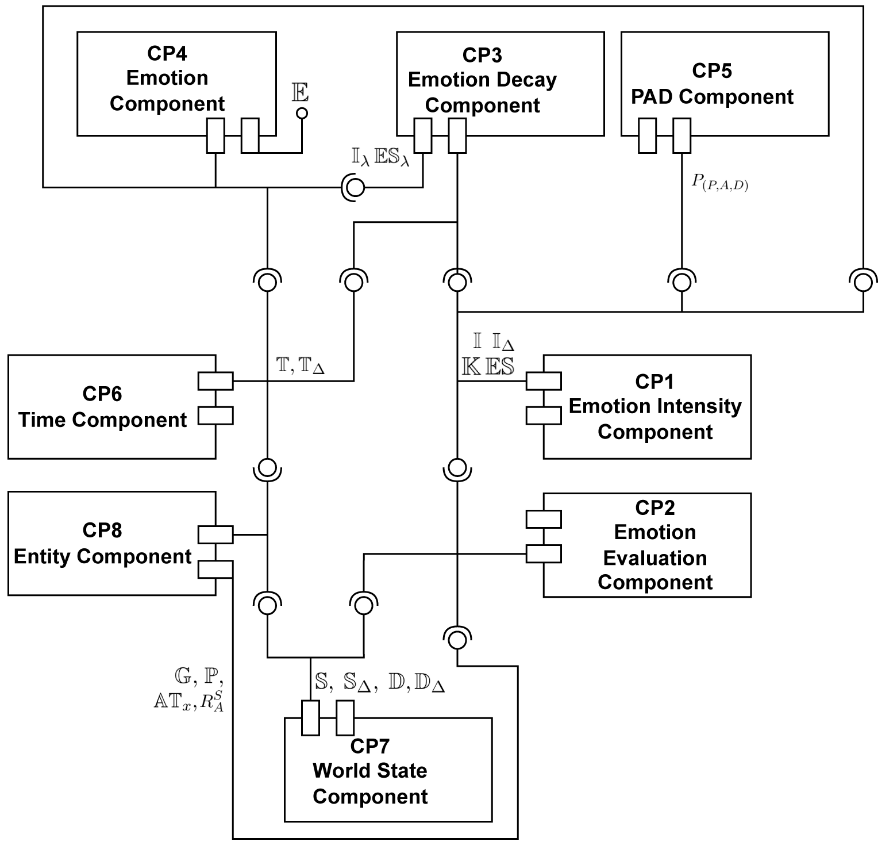


Figure 10.3: Relationships Between Modules ("Ball" provides functionality that a "Cup" needs)

C3 Emotion Decay collects the Emotion Intensity Decay (**M5**) and Emotion State Decay (**M6**) modules because they capture the "decay emotion" task. This hides Emotion State Decay's dependency on Emotion Intensity Decay while also halving the visible dependencies on other modules.

C4 Emotion collects the Emotion Type (**M9**) and Emotion Function (**M10**) modules because EMgine intends the latter to be helper functions that make Emotion Type easier to use, effectively making Emotion Function wholly dependant on Emotion Type. This hides Emotion Function's dependency on Emotion Type while also halving the visible dependencies on other modules.

C5 PAD collects the PAD Type (**M7**) and PAD Function (**M8**) modules because EMgine only requires a PAD data type to contain an emotion state that the PAD Function module has transformed into a PAD point. Since PAD Type does not depend on other modules, this only reduces visible dependencies by one as the component hides PAD Function's dependency on PAD Type.

C6 Time contains only the Time (**M15**) module. EMgine separated it from the World State module (**M16**) because there are significantly more dependencies on Time than World State, including ones that are otherwise independent of the world such as Emotion Decay (**M5** and **M6**). Time does not depend on other modules, so there are no visible dependency reductions.

C7 World State contains only the World State (**M16**) module due to the need for Time to be its own component. World State does not depend on other modules, so there are no visible dependency reductions.

C8 Entity contains the Goal (**M11**), Plan (**M12**), Attention (**M13**), and Social Attachment (**M14**) modules because of their common "entity representation" task. Unlike Time (**M15**) and World State (**M16**), there is no need to separate them into different components due to a higher number of dependencies on one module and not the others. The Emotion Evaluation component (**C2**) relies on all these modules, so collecting the Entity modules together is convenient. There are no dependencies between Goal, Plan, Attention, or Social Attachment, so the component does not hide visible dependencies within itself. However, Goal and Plan's mutual dependency on World State (**M16**) is visible as a single connection rather than two separate ones.

10.2 Implementing EMgine[4]

EMgine's implementation must use a non-proprietary programming language and environment is common in game development so that it is not limited to a specific development "style" and minimal work is necessary to prepare it for user studies. Therefore, it uses the C# programming language because it is one of the languages supported in Unity, a well-known game development platform (Unity Technologies, 2022b). Unity's default script editor for C# is the Microsoft Visual Studio (MVS) Integrated Development Environment (IDE), so EMgine's implementation relies on it (Table 10.2 summarizes relevant components/packages and their versions). This IDE also affords access to the following testing tools, which forwards verification and validation efforts:

- **NUnit Unit Testing Framework**
  This supports the bulk of the automated testing approach for unit, integration, system, and regression testing. The IDE configuration allows existing unit tests to run automatically when compiling the code base. Unity Testing Framework uses custom integration of NUnit 3.5 (Unity Technologies, 2022c).

- **Moq Library for .NET**
  This supports tests that rely on components that lack a concrete implementation, such as the user-implemented data types (Chapter 9.2). It allows the definition of type-safe, mocked interface calls in unit tests (Moq, 2022).

- **Performance Analysis**
  EMgine uses the performance tools built into MVS 2022, which includes CPU, memory, and time usage tools (Jones et al., 2022).

- **Code Style and Quality Analyzers**
  EMgine's development uses the official .NET Compiler Platform (Roslyn) (.NET Platform, 2021) and the third-party Roslynator (Pihrt, 2022) analyzers to help adhere to good code quality and style practices. The Unity documentation also references Roslyn analyzers for code style and quality (Unity Technologies, 2022a).

[4]See EMgine's implementation at https://github.com/GenevaS/EMgine/tree/main/src.

Table 10.2: Summary of EMgine's Implementation Environment

Name	**Version**
Operating System	
Windows 10 Pro	10.0.19044 Build 19044
IDE (Development), Project Target Framework: .NET Standard 2.0	
Microsoft Visual Studio 2022 Community Edition (64-bit)	17.4.3+33205.214
C# Tools	4.4.0-6.22580.4+d7a61210a88b584ca0827585ec6e871c6b1c5a14
Microsoft .NET Framework	4.8.04084
Microsoft .NET Standard Library	2.0.3
Microsoft .NET Core Platforms	1.1.0
NuGet Package Manager	6.4.0
IDE (Testing), Project Target Framework: .NET 6.0	
Microsoft .NET Test SDK	17.4.1
NUnit 3 Framework (Targeting .NET Standard 2.0 Framework, Microsoft .NET Core Platforms 1.1.0)	3.13.3
NUnit 3 Analyzers	3.5.0
NUnit 3 Test Adapter	4.3.1
Moq	4.18.3
Coding Support and Analysis	
MVS IntelliCode	2.2
Roslynator Analyzers	4.1.2
Coverlet	3.2.0

10.3 Documenting EMgine's Design

EMgine's design focuses on modularization to make it easier to change or swap EMgine's components without interfering with otherwise independent units. This depends on the principle of *information hiding* such that as few modules as possible contain likely changes and modules do not know how others work internally. Continuing with a Document Driven Design (DDD) approach (Chapter 9.8), EMgine uses two complementary templates from Smith and Yu (2009) to document these designs: a Module Guide (MG), summarizing EMgine's modules' intended tasks and their relationships (i.e. high-level architecture)[5]; and a Module Interface Specification (MIS), describing the syntax and semantics of each module's public interface (i.e. low-level module design)[6]. They also support DDD by documenting traceability information back to the Software Requirement Specification (SRS, Chapter 9.8), likely changes, and between modules; and help plan systematic testing of EMgine's implementation (Chapter 12.3) because modules can have independent evaluations and

[5]See EMgine's MG at https://github.com/GenevaS/EMgine/blob/main/docs/Design/MG/EMgine_MG.pdf.
[6]See EMgine's MIS at https://github.com/GenevaS/EMgine/blob/main/docs/Design/MIS/EMgine_MIS.pdf.

have clearly defined input and output interfaces.

10.4 Summary

EMgine moves towards a component-based software architecture because it can behave like a software library. This affords users maximum flexibility over how and when to use EMgine elements, aligning with many of its high-level requirements. However, this could be overwhelming for users if they are unsure when or if they need an EMgine component. To alleviate this issue, EMgine could include a prebuilt "component of components" that behaves like a software engine. This would alleviate user stress because they would not need to know how EMgine works—only what inputs to give it. EMgine's module decomposition supports this decision, but has several points where it "leaks" hidden information. Although removing all "leaks" is difficult, identifying them might help future modularization efforts to reduce them. EMgine's implementation relies on C# because it is a non-proprietary programming language supported by Unity, a well-known game development platform. This positions EMgine well for verification and validation efforts both in the target domain and for reuse elsewhere.

Key Points

- EMgine's architecture supports its decision to be a *library of components* that comes packaged with a default *"engine"* that is itself a system of components to maximize its overall flexibility and ease-of-use
- The module decomposition focuses on the ability to add and remove task components from EMgine, but other decomposition approaches might further reduce information "leaks"
- EMgine development used C# because it is a non-proprietary programming language that Unity, a well-known game development platform, supports
- EMgine uses the module guide and interface specification documentation templates proposed by Smith and Yu (2009) because it encourages modularization to accommodate predictable changes to different aspects of a design

Chapter 11

Gather Your Tools: Defining Acceptance Test Case Templates

> I taught the children what fear is. I felt they had to know so that they wouldn't run heedlessly into danger.
>
> Pascal, *Neir: Automata*

EMgine is successful if game developers can create Non-Player Characters (NPCs) that players find believable. Evaluating this requires at least two user studies: one to evaluate the usability of EMgine and another to evaluate the player experience (PX) with its NPCs. User studies are ideal for evaluating subjective judgments of believability. However, they can be expensive to plan, execute, and analyze. It is preferable to run some preliminary tests that do not include player agency to evaluate a Computational Model of Emotion (CME) on "obvious" scenarios with an expected output. Once these tests pass, then it might be time to run user studies because there are fewer erroneous results to confound them.

EMgine's models are psychologically valid because they are based on theories from affective science (i.e. hypotheses about human affective processes and behaviour) and tests can show that their implementation works as designed. It is unknown if EMgine's implementation creates plausible emotions that make sense to players (Broekens et al., 2016, p. 216–217). EMgine relies on acceptance test cases extended from templates built with the proposed development process (Chapter 4.2.4). It starts with generic templates that use "fuzzy" values to clearly separate them from EMgine's models to demonstrate that the process is not EMgine-specific and the templates could serve as a common nexus for building test cases to compare CMEs with similar functionality. Example acceptance test case templates based on Elsa from Disney's *Frozen* (Buck and Lee, 2013)—an in-depth one for *Grief* and a sketch for *Admiration*—illustrates this process, followed by their extension into implementable test cases specific to EMgine (Chapter 12).

11.1 Choosing a Test Case Source Medium

Choosing a test case source medium similar to video games, EMgine's intended domain, helps reduce the time, effort, and potential mistakes associated with translating a storyteller's tales into test cases. The obvious choice would be video games themselves, but they are not ideal for replicability due to their interactive nature. Since a player's role cannot be entirely scripted and their actions vary between sessions, their influence on the game state varies. This makes it more difficult to reproduce the scenario and, consequently, could make test case synthesis less reproducible. The only game aspects that do not change are cutscenes—non-interactive sequences that only make up a small fraction of most games' runtime. Character analysis can be intensive, so it is prudent to pick a data-rich source. Taking video game cutscenes as short films, film is the next medium to consider.

Broadly, films are great because they too are an audiovisual medium. A character's emotional responses are most evident because there are more and clearer cues to signal it than words alone (e.g. body language, facial expressions, vocal tone). Animated films, in particular, are likely best for believable emotion-focused CMEs because reality grounds them without limiting them:

> "In order to depart from reality, [animation] has to be based *on* reality."
>
> Williams (2001, p. 34)

Animators often use live action film as inspiration and reference for their work (Thomas and Johnston, 1995, p. 71–72, 319–320, Figure 11.1). Walt Disney famously brought performers and animals to the studio for his animators "...to try to capture a more realistic believable figure" (Korkis, 2022). When casting for live action references, staff were careful to "...select an actor whose natural voice and mannerisms are caricatures of a normal person's." (Thomas and Johnston, 1995, p. 550) likely because caricatures are the most unambiguous depictions of real behaviours (see Chapter 6.3.1 for a brief discussion). Animators then "...accentuate and suppress aspects of the model's character to make it more vivid" (Williams, 2001, p. 34) using their own knowledge and observations (Johnson-Laird and Oatley, 1992, p. 201, 217). These caricatures include emotion, making it easier to identify what a character is experiencing and deduce the eliciting factors. Film scene reenactment has proven useful for evaluating the influence of CME parameters on viewer perceptions of animated agents (Bidarra et al., 2010, p. 343–344)[1], so it is a reasonable hypothesis that they would also be good resources for building test cases. The audiovisual nature of film also eliminates the need to express emotion with specific words, making it easier to overcome language and cultural barriers. This is evident in successful translations to other languages (Thomas and Johnston, 1995, p. 315) and improves the potential to reproduce and/or localize test cases built on animated characters by itemizing observable "symptoms" of emotions (see Chapter 1.2 for a discussion).

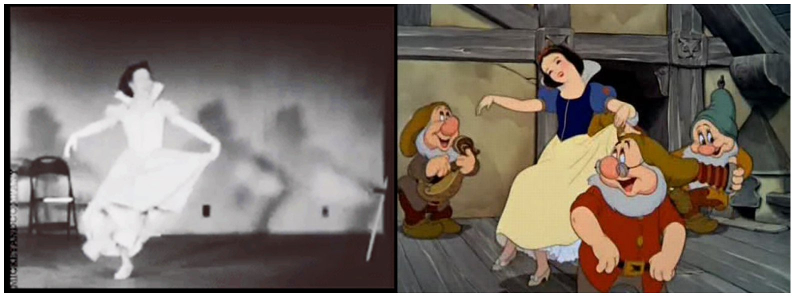
11.2 Emotion Profiles for Believable Characters

Building emotion profiles means describing the characteristics and observable signs of emotion that others can reference to recreate test cases. A core feature of the discrete perspective on emotion is distinct emotion kinds distinguishable with sets of observable features (see Chapter 6.3.1 for discussion). Many of these features are non-verbal, which often carry significantly more information than words alone (Mehrabian, 2008; Isbister et al., 2006, p. 1164). Therefore, it is the primary resource for building emotion profiles for believable characters. Each profile describes:

(a) The emotion's purpose, cognitive impact, and how it changes at different intensities. This provides a reference for deducing "transient" and "persistent" knowledge about a character.

(b) Action tendencies, physiological changes, and verbal and nonverbal signals. Together with facial expressions, this serves as a guide for identifying what emotion a character is experiencing.

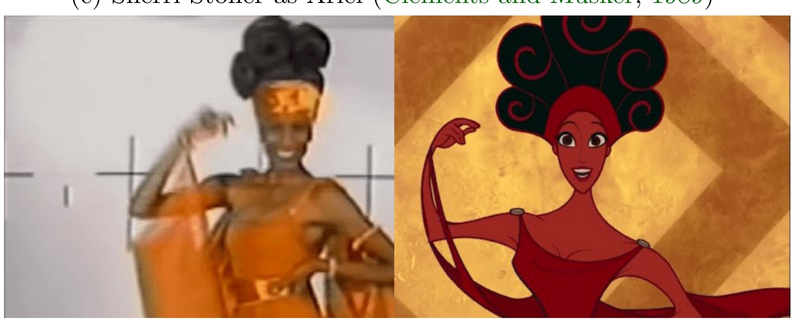
[1] The Soul (60), included in the CME survey (Chapter 5)



(a) Marge Belcher as Snow White (Hand et al., 1937)

(b) Kathyrn Beaumont as Alice (Geronimi et al., 1951)

(c) Sherri Stoner as Ariel (Clements and Musker, 1989)



(d) Kyausha Simpson as Calliope (Clements and Musker, 1997)

Figure 11.1: Comparison of live action reference and final animation in Disney's *Snow White and the Seven Dwarfs* (1937), *Alice in Wonderland* (1951), *The Little Mermaid* (1989) and *Hercules* (1997)

(c) Facial expressions associated with the emotion. Together with action tendencies, physiological changes, and verbal and nonverbal signals, facial expressions are a guide for identifying what emotion a character is experiencing. This is especially useful for identifying animated character emotions due to their caricaturisation.

(d) Examples from the source medium to demonstrate how different parts of the profile appear in the source medium.

The profile separates facial expressions from other observable signals like physiological changes and nonverbal utterances because they appear to convey the most information about an individual's affective state than any other channel (Vesterinen, 2001) and people tend to notice them more frequently (Scherer and Wallbott, 1994, p. 322). Although facial expressions are an imperfect indicator of emotion (Roseman, 2011, p. 440), the Facial Action Coding System (FACS) (Ekman et al., 2002) is encouraging for emotion specificity in facial movement (Barrett, 2006, p. 39). Previous work in Affective Computing successfully used combinations of individual FACS actions to recognize facial expressions in human users and videos (De la Torre and Cohn, 2011; Pantic and Rothkrantz, 2003, p. 1385–1386) and CMEs that express emotion in a face (e.g. Duy Bui (2004), Breazeal (2003), and Bidarra et al. (2010)[2]). Therefore, this system guides facial expression descriptions[3]. When an emotion is not explicitly represented as a complete facial expression in FACS, knowledge about individual facial changes, such as eyebrows, informs the creation of one (Smith and Scott, 1997, p. 241). A character's sleeping face is the baseline to compare changes in facial features to determine what, if any, facial expression they make.

The following profile for *Sadness* shows what it might look like. The remaining profiles for *Joy*, *Fear*, *Anger*, *Disgust*, *Acceptance*, *Interest*, and *Surprise* are in Appendix D.

Sadness Profile

Defined by loss, *Sadness* is a relatively intense and long-lasting emotion (Scherer and Wallbott, 1994, p. 324; Ekman, 2007, p. 84). It is a social emotion for signalling to the self and others that something is not well (Izard, 1977, p. 291)[a] or that a situation seems uncontrollable (Smith and Ellsworth, 1985, p. 834; Zammuner, 2009), acting as a cry for help and comfort. *Sadness* encourages problem solving by providing tolerable or less tense motivation to change the situation, while simultaneously supplying little energy to do anything about it (Izard, 1977, p. 326). The tendency to withdraw into oneself supports this by conserving energy while redirecting cognitive resources towards finding potential compensations or readjustments (Lazarus, 1991, p. 251). To exit the state of *Sadness* quickly, people often act on coping strategies without a reasonable evaluation of their future effects. This implies reduction in self-control, increasing the likelihood of accepting immediate over delayed gratification or discounting the safety of the self or bystanders. Subjectively, people tend to describe *Sadness* as an unpleasant feeling.

As the intensity of *Sadness* increases, the individual becomes less active, withdrawing into themselves and away from their surroundings. *Sadness* naturally cycles through periods of high[b] and low intensity (Ekman, 2007, p. 84–85), likely a result of the individual's continued appraisals of their ability to cope and the appraised value of compensations and adjustments made. This might also be why it is common for other emotions to manifest during periods of *Sadness* such as *Fear*, *Anger*, and *Joy*.

[2] ParleE (12), Kismet (53), and The Soul (60), included in the CME survey (Chapter 5)

[3] Although sufficient for these profiles, an individual untrained in FACS made these code assignments.

Signs of *Sadness* The action tendencies in *Sadness* are passive: withdrawal by the individual while unintentionally signalling for help. Others can perceive this as inaction (Lazarus, 1991, p. 252) with the assumed expectation that the individual is waiting for others to do something for them. Therefore, an individual experiencing *Sadness* might not do anything. A potential exception is to approach what has been lost to further evaluate its status or to approach something else that the individual perceives as comforting, such as a loved one. Although it is usually accompanied by strong nonverbal expressions to signal for help—notably crying—there are few vocal, verbal, or nonverbal expressions (Scherer and Wallbott, 1994, p. 322–324).

Vocally, the individual's voice becomes softer and lower (Ekman, 2007, p. 56). Physically, the body shuts down for energy conservation, signalled by a lowered body temperature (Scherer and Wallbott, 1994, p. 321–322, 326). However, there is also an increase in heart rate and muscle tension, in addition to a perceived constriction in the throat. The increased tension might serve as an additional social signal to convey the individual's stressful state and elicit soothing contact-based responses from others.

Characteristic Facial Expression *Sadness* registers on all facial areas (Tables 11.1, 11.2, and 11.3) and is difficult to mimic due to the inner eyebrow movement (Ekman and Friesen, 2003, p. 117, 121–122, 126; Izard, 1977, p. 287–288). Other facial movements are not reliable indicators of *Sadness* by themselves, so those expressions can be ambiguous.

The most reliable facial feature for detecting *Sadness* is the inner eyebrows because many people have difficulty moving them voluntarily. The inner corners of the eyebrows draw together and upwards in *Sadness*, which can cause creases to appear between them and on the forehead. As the eyebrows rise, these creases become exaggerated. Eyebrow movement also causes the inner corner of the upper eyelid to rise. The upper eyelid itself might lower, particularly if the eyes are cast downwards to avoid eye contact.

In the lower face, the outer corners of the mouth draw down and become more exaggerated as the intensity of the emotion increases. Tension in the cheek muscles increases with the intensity of *Sadness*, causing them to rise. This pushes the lower eyelids up, making the eyes look like they are closing.

Examples Elsa from Disney's *Frozen* (Buck and Lee, 2013) has built her life around her powers despite the unhappiness it brings her because she believes them to be dangerous and uncontrollable.

Elsa's facial expressions clearly convey *Sadness* via her raised inner eyebrows and subsequent rising of the inner eyelids (Figure 11.2). In all cases, Elsa is making eye contact with her conversation partner so her eyes are not downcast. As her *Sadness* intensifies, the tension in her cheeks increases and pushes her lower eyelids higher. The corners of her mouth also pull down as emotion intensity increases, eventually causing her mouth to open. Elsa only has the suggestion of creases between her eyebrows and running from her nose to mouth, likely due to artistic choice.

Sad01: Elsa wakes in the dungeons to find that her kingdom has entered a state of permanent winter. Wishing to avoid further harm, she is *pensive* because:

- Her powers have compromised the safety of her kingdom

- She believes that the damage is irreversible because she has little control over her powers
- Elsa believes her home is lost to her and needs to distance herself from it for its safety

Sad00 *Neutral*

Sad01 *Pensiveness*

Sad02 *Sadness*

Sad03 *Grief*

Figure 11.2: Examples of *Sadness* in Elsa's Facial Expressions

- Her sister forewarned of the situation, giving Elsa time to adjust to the idea that she had caused significant damage

Elsa's trembling voice and soft pleading to be released so that she can put distance between herself and the kingdom show her *pensiveness*. Her body language also implies it because she does not move and appears to be curling into herself.

Sad02: Elsa and her sister are arguing, which ends with her sister proclaiming that she cannot continue to live isolated from the outside. Elsa becomes *sad* because:

- She loves her sister dearly
- She has damaged her relationship with her sister by refusing her request and telling her to leave
- Elsa knows that distancing herself from her sister will not repair their relationship, but does not know how else to protect her

Elsa's unwillingness to speak to her sister further, apparent by a heavy sigh and turning away, as well as her crossed arms, drooping head, and curling shoulders, communicate her *Sadness*.

Sad03: Elsa's sister has been frozen solid, a fate equivalent to death, causing her *Grief*:

- Death cannot be reversed, so Elsa has no way to regain her sister and her safety
- The cause was Elsa's uncontrolled ice powers
- It has been a few minutes, at most, since her sister froze, so there has been no time to compensate or adjust

Elsa's *Grief* is apparent via her bodily collapse, hanging onto her sister's body, loud sobbing, and vocal denial of the situation.

[a] Izard refers to this as *Distress*, which this profile takes as a synonym for *Sadness* (Izard, 1977, p. 285).
[b] Ekman refers to this as *Agony*, which this profile takes a synonym for *Grief*.

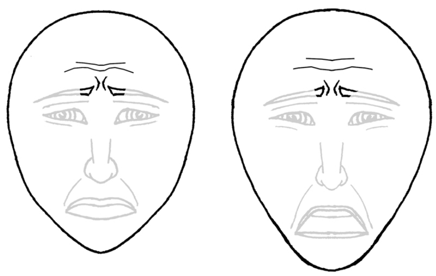
Table 11.1: Facial Sketches of *Pensiveness* with Suggested FACS Codes

Label Pensiveness
Intensity Low

Description	**FACS Codes**
Inner eyebrow corners raised and brought together	AU 1+4
A faint vertical wrinkle might appear between the inner eyebrows	AU 1*
Inner corner of the upper eyelid is pulled upwards by the raised eyebrows	AU 1*
Upper eyelids might be lowered	AU 43
Gaze might be cast downwards	64
Slightly raised cheeks	AU 6
Lower eyelids pushed up due to the raised cheek muscles which make the eyes look like they are closing	AU 6*
Corner of the lips are neutral OR pulled down slightly	– OR AU 15

* *Causes change indirectly*

Table 11.2: Facial Sketches of *Sadness* with Suggested FACS Codes



Label Sadness
Intensity Medium

Description	**FACS Codes**
Inner eyebrow corners raised and brought together	AU 1+4
A vertical wrinkle might appear between the inner eyebrows	AU 1*
Inner corner of the upper eyelid is pulled upwards by the raised eyebrows	AU 1*
Upper eyelids might be lowered	AU 43
Gaze might be cast downwards	64
Raised cheeks	AU 6
Lower eyelids pushed up due to the raised cheek muscles which make the eyes look like they are closing	AU 6*
Corner of the lips pulled down which might cause furrows on the cheeks	AU 15
Lips might be trembling	–
Lower lip might be pushed up	AU 17

* *Causes change indirectly*

Table 11.3: Facial Sketches of *Grief* with Suggested FACS Codes

Label	Grief
Intensity	High

Description	**FACS Codes**
Inner eyebrow corners raised and brought together	AU 1+4
Likely a vertical wrinkle between the inner eyebrows	AU 1*
Inner corner of the upper eyelid is pulled upwards by the raised eyebrows	AU 1*
Upper eyelids might be lowered	AU 43
Gaze might be cast downwards	64
High, raised cheeks	AU 6
Lower eyelids pushed up due to the raised cheek muscles which make the eyes look like they are closing	AU 6*
Corner of the lips pulled down causing furrows to appear on the cheeks	AU 15
Dropped jaw that might be trembling	AU 26

* *Causes change indirectly*

11.3 Character Analysis: Elsa from Disney's *Frozen* (2013)

To illustrate how the process transforms an animated film character analysis into an extendable test case template, this example expands the scenario of Elsa[4] expressing *Grief* from the *Sadness* profile (Example **Sad03**).

11.3.1 Collecting Local "Transient" Knowledge

Extending the description of **Sad03**, Elsa is primarily expressing *Sadness* with body language (Table 11.4). Anna's physical state (frozen solid) is most likely the cause because *Sadness* is defined by loss, such as the death of loved ones. Note that Elsa was already experiencing *Sadness* before this, reacting to news that Anna was dead because of Elsa's powers ("Your sister is dead...because of you.").

[4]Elements of Elsa's character analysis verified against her character page on Disney Wiki, a free, public, and collaborative encyclopedia on Walt Disney and the Disney corporation: https://disney.fandom.com/wiki/Elsa (Last Accessed 19 February 2023).

Table 11.4: Summary of "Transient" Knowledge About Elsa for Example **Sad03**

In Scene An Act of Love	**Approx. Time** 1:26:24–1:27:08
Character Elsa	**Emotion** *Grief* (Intense *Sadness*)
	
Actions	Loud sobbing; Hanging her head; Hugging Anna's shoulders (not supporting herself with her legs/feet) and slowly releasing her hold (kneeling at the end); Powers are not active (initially stopped when Hans told her that she killed Anna, mirrors their parents' funeral during "Do You Want to Build a Snowman?")
Dialogue	"Anna! Oh, Anna...no...no, please no." (pleading tone)
Physical State	Uninjured; Not in danger of injury
Character	Anna
Relation	Little Sister (Anna is 18 to Elsa's 21); Best Friend (from "Do You Want to Build a Snowman?", reunion at coronation party)
Actions	–
Dialogue	–
Physical State	Frozen solid ("dead")

11.3.2 Inferring Global "Persistent" Knowledge

Animated characters often have simple goals and personality (Peng et al., 2018, p. 2–3). This example focuses on two pieces of "persistent" knowledge about Elsa: her personality, to help contextualize her responses to the world; and her goal to `Protect Anna`. All NPCs have at least one goal of some form (Broekens et al., 2016, p. 223) (e.g. "watch the race", "generate income"), serving as a common nexus between the source medium and the aim to create believable NPCs with CMEs.

Summary of "Persistent" Knowledge About Elsa's Personality and `Protect Anna` Goal

Personality Elsa is a central character in Disney's 2013 film *Frozen* (Buck and Lee, 2013). She presents herself as a calm, reserved, and regal person, but also demonstrates a kind and generous nature (e.g. allowing young Anna to wake her during the night to play, creating a skating rink for the people of Arendelle in the summer). However, the danger posed by her powers make her insecure, depressed, and anxious.

Elsa was born with the power of ice and snow, which allows her to conjure, manipulate, and create sentient (e.g. Olaf, Marshmallow) and non-sentient (e.g. palace, skates) constructions from them. However Elsa's powers can cause harm if uncontrolled. Thus Elsa believes her powers make her monstrous. She wears gloves, believing that they help her control her powers ("Conceal it, don't feel it"), but falsified when she uses her powers to escape her jail cell by freezing manacles that completely cover her hands. Instead, Elsa manifests her powers unconsciously when she is severely distressed and/or frightened (e.g. after injuring Anna when they were children, at the overwhelming coronation party, discovering that Arendelle is frozen, escaping execution). In contrast, Elsa appears to have full control of her powers when not under stress (e.g. playing as children, "Let it Go", deicing Arendelle, making a skating rink in the castle courtyard).

Goal: `Protect Anna` Elsa does not want to harm anyone, especially those close to her (Distressed when she injures Anna as children; "No. Don't touch me. I don't want to hurt you." to her parents during "Do You Want to Build a Snowman?"). She is particularly concerned with keeping Anna safe, evident by Elsa's self-isolation after harming Anna with her powers when they were playing as children and after arriving at the North Mountain after the coronation party (in "Let it Go"). Elsa also demonstrates her desire to protect Anna by refusing to bless her engagement to Hans ("You can't marry a man you just met [Anna]...You asked for my blessing, but my answer is no."); by forcing Anna to leave the ice palace without her after coming for her ("I'm just trying to protect you [Anna]."); and by asking Hans to take care of Anna after her execution ("...Just take care of my sister."). This differs from her desire to protect her kingdom (experiences fear when Anna tells her Arendelle is frozen and distress when she sees it from her prison cell) and herself (asking for Anna to be cared for after Elsa's execution). Elsa also has no qualms with using her powers for defence (fighting thugs in her ice palace).

11.4 Translating Character Analyses into Acceptance Test Case Templates

The translation of character analyses into test cases should be implementation-agnostic for reusability. Therefore, the example test cases use "fuzzy" values like percentages, the set $\{\texttt{Low}, \texttt{Mid}, \texttt{High}\}$, and the constant `MIN` to avoid over-specification. These test cases are small for illustrative purposes, but extended versions for EMgine show their usefulness. The test cases use the following types:

- World State View (WSV) $\mathbb{S}$ (Equation 9.2.2);
- World Event $\mathbb{S}_\Delta$ (Equation 9.2.3);
- Goal $\mathbb{G}_{ATC}$, is a predicate on a WSV ($\texttt{goalState} : \mathbb{S} \rightarrow \mathbb{B}$) that a character wants to satisfy, and its relative importance in $\{\texttt{Low}, \texttt{Mid}, \texttt{High}\}$; and
- Emotion Intensity $\mathbb{I}_{ATC}$, in $\{\texttt{Low}, \texttt{Mid}, \texttt{High}\}$.

These are the minimum working data types necessary for defining these test cases. Although WSV and World Event are part of EMgine's data types, they are abstractions that do not assume anything about the underlying emotion theories and/or models. Therefore, they are suitable for defining theory-agnostic test cases. EMgine does have specifications for Goal $\mathbb{G}$ and Emotion Intensity $\mathbb{I}$, but their specification is likely to change with the underlying emotion theories and/or models. The types $\mathbb{G}_{ATC}$ and $\mathbb{I}_{ATC}$ represent their simplest form, capturing only essential information necessary for test case specification.

11.4.1 Acceptance Test Case Template of Elsa's *Grief*

Assuming that the characters have properties `Health` and `IsAlive` and using "persistent" character knowledge, the definition of Elsa's goal to `Protect Anna` is:

$$\begin{aligned}\texttt{ProtectAnna} : \mathbb{G}_{ATC} = \{&\texttt{goalState} = \{\texttt{Anna.Health} \geq 75\% \wedge \texttt{Anna.IsAlive}\},\\ &\texttt{importance} = \texttt{High}\}\end{aligned}$$

This model assumes that $\texttt{Health} = 0$ is unconsciousness (a changeable state) and $\texttt{IsAlive} = \textit{False}$ is a permanent death state, to reflect the ability to "revive" unconscious characters in video games.

Using `Health` in `ProtectAnna` reflects Elsa's fear of hurting others with her powers, which would be physical injuries. The arbitrary value of 75% reflects Anna's fearless and impulsive actions, which often leads to minor injuries like scrapes and bruises that Elsa would affectionately disapprove of. Goal importance is `High` because Elsa's responses in the story are strongest when Anna is involved.

From the "transient" knowledge about the scenario, Anna's health in the *current* world state $\texttt{S}_i : \mathbb{S}$ is below Elsa's goal ($h \in (\texttt{MIN}\%, 25\%]$) and Elsa's current *Sadness* intensity as `Mid`, reflecting that unmet, transient goal component:

$$\texttt{S}_i : \mathbb{S} = \{\texttt{Anna.Health} = h, \texttt{Anna.IsAlive} = \textit{True}\}; \qquad \texttt{Sadness}_i : \mathbb{I}_{ATC} = \texttt{Mid}$$

This WSV reflects Elsa's reaction to *hearing* that Anna is dead rather than *seeing* it, which she perceives as Anna being seriously injured rather than dead ($\texttt{MIN}\% < \texttt{Anna.Health} \leq 25\% \wedge \texttt{Anna.IsAlive}$). Elsa's *Sadness* is still elevated by the news because her goal, `ProtectAnna`, is currently unsatisfied.

The event of concern is Anna becoming solid ice, i.e. dying ("Anna, your life is in danger...to solid ice will you freeze, forever."):

$$\texttt{AnnaFreezes}_{\texttt{E}} : \mathbb{S}_{\Delta} = \{\texttt{Anna.IsAlive} = \mathit{False}\}$$

Applying this to $\texttt{S}_i$ produces:

$$\texttt{S}_{i+1} : \mathbb{S} = \{\texttt{Anna.Health} = h; \texttt{Anna.IsAlive} = \mathit{False}\}$$

Finally, the expected output is $\texttt{Sadness} : \mathbb{I}_{ATC} = \texttt{High}$ (completed test case in Table 11.5). If a CME's emotion intensity function rejects $\texttt{Sadness}_i$ as an input, a function $\texttt{Combine}(i_1 : \mathbb{I}_{ATC}, i_2 : \mathbb{I}_{ATC})$ should produce the expected output.

Although both world states $\texttt{S}_i$ and $\texttt{S}_{i+1}$ fail to satisfy `ProtectAnna`, there is a subtle difference between them: `Anna.Health` is a changeable quantity while `Anna.IsAlive` is not. This reflects *world knowledge* and *self knowledge* about one's goals that a CME needs to know, but the test cases do not need to embed that information. Nevertheless, it is the reason for the intensity of Elsa's *Sadness* (see Table 11.6 for the test case resulting in $\texttt{S}_i$).

Table 11.5: Test Case of Elsa's *Grief* When Anna Becomes Solid Ice

Setup	$\texttt{ProtectAnna} : \mathbb{G}_{ATC} = \{\texttt{goalState} = \{\texttt{Anna.Health} \geq 75\%$ $\wedge\ \texttt{Anna.IsAlive}\}, \texttt{importance} = \texttt{High}\}$, $\texttt{Sadness}_i : \mathbb{I}_{ATC} = \texttt{Mid}$, $\texttt{S}_i : \mathbb{S} = \{\texttt{Anna.Health} = h, \texttt{Anna.IsAlive} = \mathit{True}\}$ where $h \in (\texttt{MIN}\%, 25\%]$
Input	$\texttt{AnnaFreezes}_{\texttt{E}} : \mathbb{S}_{\Delta} = \{\texttt{Anna.IsAlive} = \mathit{False}\}$
Expected Output	$\texttt{Sadness}_{i+1} : \mathbb{I}_{ATC} = \texttt{High}$

Table 11.6: Test Case of Elsa's *Sadness* When Told That Anna is Dead

Setup	$\texttt{ProtectAnna} : \mathbb{G}_{ATC} = \{\texttt{goalState} = \{\texttt{Anna.Health} \geq 75\%$ $\wedge\ \texttt{Anna.IsAlive}\}, \texttt{importance} = \texttt{High}\}$, $\texttt{Fear}_i : \mathbb{I}_{ATC} = \texttt{Mid}, \texttt{Sadness}_i : \mathbb{I}_{ATC} = \emptyset$, $\texttt{S}_i : \mathbb{S} = \{\texttt{Anna.Health} = h_0, \texttt{Anna.IsAlive} = \mathit{True}\}$ where $h_0 \in [75\%, 100\%]$
Input	$\texttt{AnnaHurt}_{\texttt{E}} : \mathbb{S}_{\Delta} = \{\texttt{Anna.Health} = h_1\}$ where $h_1 \in (\texttt{MIN}\%, 25\%]$
Expected Output	$\texttt{Fear}_{i+1} : \mathbb{I}_{ATC} = \texttt{Low}, \texttt{Sadness}_{i+1} : \mathbb{I}_{ATC} = \texttt{Mid}$

11.4.2 Sketch of an Acceptance Test Case Template of Elsa's *Admiration* of Anna

Immediately following the *Grief* caused by Anna's transformation into ice, Elsa experiences intense *Acceptance* (i.e. *Admiration*) towards Anna when she thaws and appears otherwise unharmed (Figure 11.3). Elsa's *Admiration* is apparent via her facial expression, tight clasp on Anna's arm and move to stand closer to her, short utterance implying excitement ("Anna!"), and obvious concern for Anna (see *Acceptance* profile in Appendix D.5).

Based on the scenario, where the expected output is $\texttt{Acceptance}_{i+2} : \mathbb{I}_{ATC} = \texttt{High}$ and either no or very little $\texttt{Sadness}_{i+2} \in \{\emptyset, \texttt{Low}\}$, the *current* world state is where Elsa is experiencing *Grief* evaluated as $\texttt{S}_{i+1} = \texttt{S}_i \oplus \texttt{AnnaFreezes}_\texttt{E}$ from Table 12.1. The event of concern is Anna thawing, which also seems to restore her physical health:

$$\texttt{AnnaThaws}_\texttt{E} : \mathbb{S}_\Delta = \{\texttt{Anna.Health} = h_E, \texttt{Anna.IsAlive} = \mathit{True}\} \text{ where } h_E \in [75\%, 100\%]$$

Applying this to $\texttt{S}_{i+1}$ produces:

$$\texttt{S}_{i+2} : \mathbb{S} = \{\texttt{Anna.Health} = h_E, \texttt{Anna.IsAlive} = \mathit{True}\} \text{ where } h_E \in [75\%, 100\%]$$

A distinguishing feature of *Acceptance* is its reliance on social attachments describing an entity's degree of liking or disliking another entity. Representing this information requires another type, Social Attachment, describing the relative degree of "disliking" and "liking":

$$\mathbb{SA}_{ATC} \in \{\texttt{Despises}, \texttt{Dislikes}, \texttt{DoesNotCareFor}, \texttt{None}, \texttt{CaresFor}, \texttt{Likes}, \texttt{Loves}\}$$

From the "transient" knowledge about Elsa in Table 11.4, her reaction when Anna thaws, and supported by "persistent" knowledge about her goal (Section 11.3.2), it is clear that Elsa `Loves` Anna.

Adding Elsa's social attachment to Anna to the setup section of Table 11.5 and exchanging some of its other components is sufficient because it immediately follows that scenario in the story. The necessary exchanges for the remaining elements of the acceptance test case template are: $\texttt{Sadness}_i$ with $\texttt{Sadness}_{i+1}$ and $\texttt{S}_i$ with $\texttt{S}_{i+1}$ in the setup section; the input $\texttt{AnnaFreezes}_\texttt{E}$ with $\texttt{AnnaThaws}_\texttt{E}$; and the expected output $\texttt{Sadness}_{i+1}$ with $\texttt{Sadness}_{i+2}$ and $\texttt{Acceptance}_{i+2}$. Table 11.7 shows the resulting test case specification.

Figure 11.3: Elsa looks at Anna in *Admiration* After She Thaws

Table 11.7: Test Case of Elsa's *Admiration* When Anna Thaws

Setup	$\texttt{ProtectAnna} : \mathbb{G}_{ATC} = \{\texttt{goalState} = \{\texttt{Anna.Health} \geq 75\%$ $\wedge\ \texttt{Anna.IsAlive}\}, \texttt{importance} = \texttt{High}\}$, $\texttt{Anna} : \mathbb{SA}_{ATC} = \texttt{Loves}$, $\texttt{Sadness}_i : \mathbb{I}_{ATC} = \texttt{High}$, $\texttt{S}_{i+1} : \mathbb{S} = \{\texttt{Anna.Health} = h, \texttt{Anna.IsAlive} = \textit{False}\}$ where $h \in (\texttt{MIN}\%, 25\%]$
Input	$\texttt{AnnaThaws}_\texttt{E} : \mathbb{S}_\Delta = \{\texttt{Anna.Health} = h_E, \texttt{Anna.IsAlive} = \textit{True}\}$ where $h_E \in [75\%, 100\%]$
Expected Output	$\texttt{Sadness}_{i+2} : \mathbb{I}_{ATC} \in \{\emptyset, \texttt{Low}\}$, $\texttt{Acceptance}_{i+2} : \mathbb{I}_{ATC} = \texttt{High}$

A *Surprising* Test Case Although Elsa's reaction to Anna's miraculous thawing and recovery is *Admiration*, other characters—like Kristoff and Olaf (Figure 11.4)—would more likely experience an intense *Surprise* because it is probability-based (see *Surprise* profile in Appendix D.7). Elsa's *Admiration* might overwhelm any experience of *Surprise* because she feels responsible for Anna's "death" and her recovery absolves Elsa of that guilt. This suggests that there could be an additional mechanism that prioritizes emotion evaluations. This could be a simple ordering on the available emotion kinds or something more complex such as an ordering based on the external `CausedBy` function (Chapter 9.4.5).

11.5 Summary

Evaluating EMgine's success requires at least two user studies, which can be both time and resource intensive to run well. Therefore, to maximize the utility of these user studies, EMgine must pass preliminary acceptance test cases to ensure that it is behaving correctly with respect to its user requirements: that the emotions it generates are plausible.

Following the proposed methodology, animated films are the source medium because they are

Figure 11.4: Kristoff and Olaf look at Anna in *Amazement* After She Thaws

an audiovisual medium that are grounded in reality with significant freedom to convey a character's thoughts and emotions in "unrealistic" ways. This means that they afford more cues to communicate emotion with and makes it easier for audiences to agree on a character's emotion state. "Profiles" for each emotion kind based on the discrete perspective on emotion create a reference to aid in test case development and recreation. They describe the emotion's purpose, its observable signs such as action tendencies and facial expressions, and examples from animated films—the source medium.

Extending the example of *Grief* from the *Sadness* profile, a character study of Elsa from Disney's *Frozen* led to an acceptance test case template specification that uses "fuzzy" values like percentages to improve its relevance to different CME designs and implementations. The specification relies on a limited set of data types representing: a view of relevant aspects of the world state; a world event that changes that state; a goal describing the desired world state as a predicate, and the goal's relative importance to Elsa; and the expected emotion's intensity. However, the template's "fuzziness" means that testing efforts for specific CMEs—like EMgine—require extensions.

Key Points

- Animated films are likely the best source medium for CMEs like EMgine because they are an audiovisual medium and grounded in, yet not limited by, reality
- The emotion "profiles" describe the emotion's purpose, observable signs, and examples of the emotion from the source medium (animated films)
- An example character analysis of Elsa from Disney's *Frozen* demonstrates how both "persistent" and "transient" character knowledge contribute to implementation-agnostic acceptance test case template specifications
- Due to its "fuzziness", templates require extensions for use with specific CMEs

Chapter 12

Inspect Your EMgine: Extending Acceptance Test Case Templates

Only by accepting this can one discover what they truly want...

Aigis, *Shin Megami Tensei: Persona 3 FES*

The acceptance test case templates aim to describe an emotion eliciting scenario in the simplest and most generic form possible (Chapter 11.4): a World State View (WSV) and triggering event; a way for the entity to know if they have achieved their goal and its relative importance to them; and the expected emotion intensity as a relative quantity. Comparing their specifications, they share a small subset of type definitions with EMgine. However, they are sufficiently different it is necessary to extend them for EMgine evaluations. This is ideal, despite the additional effort, because each type of specification has its own concern. EMgine seeks to model particular theories with assumptions and design decisions that someone else might not, whereas an acceptance test case wants to represent a scenario with no expectations about the underlying processes, assumptions, or design decisions. This separation helps build confidence in both kinds of specification because it shows that one does not necessarily rely on the other, implying that the acceptance test cases move towards an unbiased evaluation of EMgine and can serve as one measure for comparing with other CMEs.

Extensions of the Elsa-focused templates of *Grief* and *Admiration* for EMgine's models demonstrates a way to translate them while remaining consistent with the original test case and character study. To build confidence in the EMgine-specific extensions, they serve as preliminary evaluations of some of EMgine's models "on paper". These evaluations also start building confidence in EMgine's models before making significant implementation efforts and separates modelling errors from implementation errors.

12.1 Extending the Acceptance Test Case Template of Elsa's *Grief*

EMgine cannot use the test case describing Elsa's *Grief* (Table 11.5) directly because it has different definitions for $\mathbb{G}_{ATC}$ and $\mathbb{I}_{ATC}$. Further translations must convert them to $\mathbb{G}$ (Equation 9.2.6) and $\mathbb{I}$ (Equation 9.3.1), respectively.

In both $\mathbb{G}_{ATC}$ and $\mathbb{G}$, the definition of `goalState` is identical so no changes are necessary. Both types also have `importance`, but use different specifications that are not directly compatible:

$\{\texttt{Low}, \texttt{Mid}, \texttt{High}\}$ and $\mathbb{R}_{\geq 0}$. To connect the specifications, a partition suitable for EMgine on $\mathbb{R}_{\geq 0}$ mapping to the "subsets" $\{\texttt{Low}, \texttt{Mid}, \texttt{High}\}$ is:

$$\texttt{importance} \in \left\{[0], \left(0, \frac{1}{3}\right], \left(\frac{1}{3}, \frac{2}{3}\right], \left(\frac{2}{3}, 1\right]\right\}$$

EMgine reserves 0 to represent an irrelevant goal (Equation 9.2.6), necessitating a separate partition for $0 : \mathbb{R}_{\geq 0}$. Other CMEs might decide to represent irrelevant goals differently, so the partition [0] is a EMgine-specific element.

The partitions divide the range $(0, 1]$ into three parts such that there is a linear relation between `importance` values. For example, a goal with $\texttt{importance} = 1.0$ has 0.2 more impact on an entity's evaluations than one with $\texttt{importance} = 0.8$. Users can define some maximum `importance` value m_G, then use it to normalize a goal's `importance` value to map it to a partition.

EMgine's definition of $\mathbb{G}$ has a function $\texttt{goal}(s)$ that evaluates the distance between a WSV and `goalState`, and its derivative $\texttt{goal}'(s, s_\Delta)$ evaluates a change in a WSV's distance to `goalState` caused by an event. The desirability a WSV relative to `goalState` defines these functions as:

$$\texttt{goal}(s) : \mathbb{S} \rightarrow \mathbb{D} = \begin{cases} +\infty, & \texttt{s.Anna.IsAlive} = \textit{False} \\ \dfrac{75\% - \texttt{s.Anna.Health}}{75\%}, & \texttt{s.Anna.Health} < 75\% \\ 0, & \textit{Otherwise} \end{cases}$$
$$\texttt{goal}'(s, s_\Delta) : \mathbb{S} \times \mathbb{S}_\Delta \rightarrow \mathbb{D}_\Delta = \texttt{goal}(s \oplus s_\Delta) - \texttt{goal}(s)$$

This model assumes that if $\texttt{goal}(s \oplus s_\Delta) = \texttt{goal}(s) = +\infty$, then $\texttt{goal}'(s, s_\Delta) = 0$.

The definition of $\mathbb{G}$ also has a `type` so that goals can be marked as *Self-Preservation* and/or *Gustatory* as needed. Elsa's character analysis implies that Elsa would be permanently changed if Anna died. Common sense suggests that people avoid this because it can be mentally and emotionally draining. Therefore, EMgine associates this goal as self-preservational, $\texttt{type} = \{\texttt{SelfPreservation}\}$, indicating that Elsa wants to "preserve" her mental state. There is nothing to suggest that `ProtectAnna` is gustatory.

Transforming emotion Intensity $\mathbb{I}_{ATC} \in \{\texttt{Low}, \texttt{Mid}, \texttt{High}\}$ to $\mathbb{I} \in \mathbb{R}_{\geq 0}$ uses the same approach as goal `importance`, becoming:

$$\mathbb{I} \in \left\{[0], \left(0, \frac{1}{3}\right], \left(\frac{1}{3}, \frac{2}{3}\right], \left(\frac{2}{3}, 1\right]\right\}$$

EMgine uses 0 to represent the absence of an emotion (Equation 9.3.1), necessitating a separate partition for $0 : \mathbb{I}$. Users can define some maximum $\mathbb{I}$ value m_I, then use it to normalize an intensity value to map it to a partition. Table 12.1 shows the final EMgine-specific test case.

12.1.1 Trying the Extended Test Case Specification on EMgine's *Sadness* Elicitation Model

The *Sadness* elicitation model (Equation 9.4.2) requires a goal or a plan (Equation 9.2.7), a WSV, and an event as inputs. The test case defines all of these except a plan for achieving `ProtectAnna`,

Table 12.1: Test Case of Elsa's *Grief* Extended for EMgine Type Definitions

Setup	$\texttt{ProtectAnna} : \mathbb{G} = \{\texttt{goalState} = \{\texttt{Anna.Health} \geq 75\% \land \texttt{Anna.IsAlive}\},$ $\texttt{goal}(s) : \mathbb{S} \to \mathbb{D} = \begin{cases} +\infty, & \texttt{s.Anna.IsAlive} = \mathit{False} \\ \frac{75\% - \texttt{s.Anna.Health}}{75\%}, & \texttt{s.Anna.Health} < 75\% \\ 0, & \mathit{Otherwise} \end{cases},$ $\texttt{goal}'(s, s_\Delta) : \mathbb{S} \times \mathbb{S}_\Delta \to \mathbb{D}_\Delta = \texttt{goal}(s \oplus s_\Delta) - \texttt{goal}(s),$ $\texttt{importance} = im \in \left(\frac{2}{3}, 1\right], \texttt{type} = \{\texttt{SelfPreservation}\}\},$ $\texttt{Sadness}_i : \mathbb{I} = I_i \in \left(\frac{1}{3}, \frac{2}{3}\right],$ $\texttt{S}_i : \mathbb{S} = \{\texttt{Anna.Health} = h, \texttt{Anna.IsAlive} = \mathit{True}\}$ where $h \in (\texttt{MIN}\%, 25\%]$
Input	$\texttt{AnnaFreezes}_\texttt{E} : \mathbb{S}_\Delta = \{\texttt{Anna.IsAlive} = \mathit{False}\}$
Expected Output	$\texttt{Sadness}_{i+1} : \mathbb{I} = I_{i+1} \in \left(\frac{2}{3}, 1\right]$

so its definition is None. Recalling the *Sadness* elicitation model:

$$S(g : \mathbb{G}^?, p : \mathbb{P}^?, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta) : (g_{sadness} : \mathbb{G}^?, p_{sadness} : \mathbb{P}^?, s_{now} : \mathbb{S}, dist_{now} : \mathbb{D}^?)^?$$
$$\mathrel{\hat=} \begin{cases} (\text{None}, p, s_{prev} \oplus s_\Delta, \text{None}), & p \neq \text{None} \land p.\texttt{isFeasible}(s_{prev}) \\ & \land \neg p.\texttt{isFeasible}(s_{prev} \oplus s_\Delta) \\ (g, \text{None}, s_{prev} \oplus s_\Delta, & g \neq \text{None} \land \texttt{IsUnachievableAfterEvent}(g, s_{prev}, s_\Delta) \\ g.\texttt{goal}\,(s_{prev} \oplus s_\Delta)), & \\ \emptyset, & \mathit{Otherwise} \end{cases}$$

Substituting ("$\rightsquigarrow$") data from Table 12.1 and $p = \text{None}$ into the *Sadness* elicitation model S then starting to solve leads to its goal-focused branch:

$$S(g = \texttt{ProtectAnna}, p = \text{None}, s_{prev} = \texttt{S}_i, s_\Delta = \texttt{AnnaFreezes}_\texttt{E})$$
$$\rightsquigarrow \begin{cases} (\texttt{ProtectAnna}, \text{None}, & \\ \texttt{S}_i \oplus \texttt{AnnaFreezes}_\texttt{E}, & \texttt{IsUnachievableAfterEvent}(\texttt{ProtectAnna}, \texttt{S}_i, \\ \texttt{ProtectAnna.goal} & \texttt{AnnaFreezes}_\texttt{E}) \\ (\texttt{S}_i \oplus \texttt{AnnaFreezes}_\texttt{E})), & \\ \emptyset, & \mathit{Otherwise} \end{cases}$$

Now, *Sadness* elicitation depends on the evaluation of `IsUnachievableAfterEvent` (Chapter 9.4.1).

Focusing on that piece gives:

$$\begin{gathered}\texttt{IsUnachievableAfterEvent}(\texttt{ProtectAnna}, \texttt{S}_i, \texttt{AnnaFreezes}_\texttt{E}) \\ \rightsquigarrow |\,\texttt{ProtectAnna.goal}\,(\texttt{S}_i \oplus \texttt{AnnaFreezes}_\texttt{E})\,| = +\infty \\ \rightsquigarrow |\,\texttt{ProtectAnna.goal}(\{\texttt{Anna.IsAlive} = \mathit{True}\} \oplus \{\texttt{Anna.IsAlive} = \mathit{False}\})| = +\infty \\ \rightsquigarrow |\,\texttt{ProtectAnna.goal}(\{\texttt{Anna.IsAlive} = \mathit{False}\})| = +\infty\end{gathered}$$

Looking up the value of $\texttt{ProtectAnna.goal}(\{\texttt{Anna.IsAlive} = \mathit{False}\})$ in the EMgine-specific test case specification (Table 12.1) gives:

$$\begin{gathered}\rightsquigarrow |+\infty| = +\infty \\ \rightsquigarrow \mathit{True}\end{gathered}$$

The WSV $\texttt{S}_i$ also has the field `Anna.Health`, but this example omits it for simplicity because it is not relevant to this evaluation.
Therefore, the model outputs a tuple indicating that the event $\texttt{AnnaFreezes}_\texttt{E}$ elicits *Sadness* from Elsa:

$$\begin{gathered}(g_{sadness} = \texttt{ProtectAnna}, \text{None}, s_{now} = \{\texttt{Anna.Health} = h, \texttt{Anna.IsAlive} = \mathit{False}\}, \\ dist_{now} = +\infty) \text{ where } h \in (\texttt{MIN}\%, 25\%]\end{gathered}$$

12.1.2 Trying the Extended Test Case Specification on EMgine's *Sadness* Intensity Model

Recalling the *Sadness* intensity model (Equation 9.5.3):

$$S_\Delta(g : \mathbb{G}^?, p : \mathbb{P}^?, s_{prev} : \mathbb{S}, i_{max\Delta} : \mathbb{I}_\Delta) : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} \dfrac{1}{|dist_p|}, & p \neq \text{None} \\ \dfrac{g.\texttt{importance}}{m_G} \cdot i_{max\Delta}, & g \neq \text{None} \end{cases}$$
$$\text{where } dist_p : \mathbb{D} = \texttt{Dist}(s_{prev}, p.\texttt{nextStep}(s_{prev}, |p.\texttt{actions}|))$$

Substituting ("$\rightsquigarrow$") data from the output of the *Sadness* elicitation evaluation into S_Δ and setting $m_G = 1$ and $i_{max\Delta} = m_I = 1$ to reflect the maximum values EMgine defines for goal `importance` and emotion intensity $\mathbb{I}$, then starting to solve leads to its goal-focused branch:

$$\begin{gathered}S_\Delta(g = \texttt{ProtectAnna}, p = \text{None}, s_{prev} = \texttt{S}_i, i_{max\Delta} = 1) \\ \rightsquigarrow \frac{\texttt{ProtectAnna.importance}}{1} \cdot 1\end{gathered}$$

Looking up the required values in Table 12.1 gives:

$$\rightsquigarrow im \text{ where } im \in \left(\frac{2}{3}, 1\right]$$

The intensity of Elsa's *Sadness* is directly proportional to the importance of `ProtectAnna` ($\mathbb{I} \propto im$), suggesting that it would be relatively high. This aligns with the expected outcome $\texttt{Sadness}_{i+1}$ (Table 12.1).

12.2 Extending the Acceptance Test Case Template of Elsa's *Admiration* of Anna

For extending the *Admiration* test case template (Table 11.7), it is sufficient to use the EMgine-specific test case in Table 12.1 and replace some data with that of the *Admiration* test case. This first requires a mapping between $\mathbb{SA}_{ATC}$ and EMgine's social attachment type $\mathbb{SA}$ (Equation 9.2.8). To connect the specifications, a partition suitable for EMgine on $\mathbb{Z}$ mapping to the "subsets" $\{\texttt{Despises}, \texttt{Dislikes}, \texttt{DoesNotCareFor}, \texttt{None}, \texttt{CaresFor}, \texttt{Likes}, \texttt{Loves}\}$ is:

$$\mathbb{SA} \in \{[-m_{SA}, -a_{Mid}), [-a_{Mid}, -a_{Low}), [-a_{Low}, 0), [0], (0, a_{Low}], (a_{Low}, a_{Mid}], (a_{Mid}, m_{SA}]\}$$
$$\text{where } a_{Low} = \left\lceil \frac{m_{SA}}{3} \right\rceil, a_{Mid} = \left\lceil \frac{2 \cdot m_{SA}}{3} \right\rceil \text{ and } m_{SA} \in \mathbb{N}_{\geq 3}$$

The partitions divide the range $[-m_{SA}, m_{SA}]$ into seven parts such that there is a linear relation between social attachment "degrees". A "degree" of zero represents no attachment ($0 = \texttt{None}$). The maximum attachment "degree" m_{SA} must be at least three to distinguish the three "degrees" of liking ($\texttt{CaresFor}, \texttt{Likes}, \texttt{Loves}$) and disliking ($\texttt{DoesNotCareFor}, \texttt{Dislikes}, \texttt{Despises}$). The ceiling function ensures that the partition boundaries are integers to satisfy the constraints on $\mathbb{SA}$. Table 12.2 shows the resulting test case specification.

Table 12.2: Test Case of Elsa's *Admiration* of Anna for EMgine Type Definitions

Setup	$\texttt{ProtectAnna} : \mathbb{G} = \{\texttt{goalState} = \{\texttt{Anna.Health} \geq 75\% \wedge \texttt{Anna.IsAlive}\},$ $\texttt{goal}(s) : \mathbb{S} \rightarrow \mathbb{D} = \begin{cases} +\infty, & \texttt{s.Anna.IsAlive} = \mathit{False} \\ \dfrac{75\% - \texttt{s.Anna.Health}}{75\%}, & \texttt{s.Anna.Health} < 75\% \\ 0, & \mathit{Otherwise} \end{cases},$ $\texttt{goal}'(s, s_\Delta) : \mathbb{S} \times \mathbb{S}_\Delta \rightarrow \mathbb{D}_\Delta = \texttt{goal}(s \oplus s_\Delta) - \texttt{goal}(s),$ $\texttt{importance} = im \in \left(\frac{2}{3}, 1\right], \texttt{type} = \{\texttt{SelfPreservation}\}\},$ $\texttt{Anna} : \mathbb{SA} = a \in \left(\left\lceil \frac{2 \cdot m_{SA}}{3} \right\rceil, m_{SA}\right],$ $\texttt{Sadness}_{i+1} : \mathbb{I} = I_{i+1} \in \left(\frac{2}{3}, 1\right],$ $S_{i+1} = \{\texttt{Anna.Health} = h_{i+1}, \texttt{Anna.IsAlive} = \mathit{False}\}$ where $h_{i+1} \in (\texttt{MIN}\%, 25\%]$
Input	$\texttt{AnnaThaws}_\texttt{E} : \mathbb{S}_\Delta = \{\texttt{Anna.Health} = h_E, \texttt{Anna.IsAlive} = \mathit{True}\}$ where $h_E \in [75\%, 100\%]$
Expected Output	$\texttt{Sadness}_{i+2} : \mathbb{I} = Is_{i+2} \in \left[0, \frac{1}{3}\right], \texttt{Acceptance}_{i+2} : \mathbb{I} = Ia_{i+2} \in \left(\frac{2}{3}, 1\right]$

12.2.1 Trying the Extended Test Case Specification with EMgine's *Joy* and *Acceptance* Models

EMgine treats *Acceptance* as a complex emotion based on *Joy*. Therefore, the acceptance test case in Table 12.2 is sufficient to evaluate EMgine's models of *Joy* and *Acceptance* elicitation and intensity (Equations 9.4.1, 9.4.6, 9.5.2, and 9.5.7) "on paper". This dependency means that the first evaluation must be of *Joy*.

Evaluating EMgine's *Joy* Elicitation and Intensity Models

The *Joy* elicitation model (Equation 9.4.1) requires a goal, WSV, event, and a "tolerance" value for distance changes between WSVs. The test case defines all of these except for a "tolerance" value, which relies on Elsa. Recalling the *Joy* elicitation model:

$$J(g : \mathbb{G}, s_{prev} : \mathbb{S}, s_{\Delta} : \mathbb{S}_{\Delta}, \epsilon_J : \mathbb{D}_{\Delta}) : (dist_{prev} : \mathbb{D}, dist_{now} : \mathbb{D}, dist_{\Delta} : \mathbb{D}_{\Delta})^{?}$$

$$\hat{=} \begin{cases} (g.\mathtt{goal}(s_{prev}), & \mathtt{IsCloserAfterEvent}(g, s_{prev}, s_{\Delta}) \\ g.\mathtt{goal}(s_{prev} \oplus s_{\Delta}), & \wedge\, \mathtt{IsNoticeable}(g, s_{prev}, s_{\Delta}, \epsilon_J) \\ g.\mathtt{goal}'(s_{prev}, s_{\Delta})), & \\ \emptyset, & \mathit{Otherwise} \end{cases}$$

Substituting ("$\rightsquigarrow$") data from Table 12.2 into the *Joy* elicitation model J gives:

$$J(g = \mathtt{ProtectAnna}, s_{prev} = \mathtt{S}_{i+1}, s_{\Delta} = \mathtt{AnnaThaws_E}, \epsilon_J)$$

$$\rightsquigarrow \begin{cases} (\mathtt{ProtectAnna.goal}(\mathtt{S}_{i+1}), & \mathtt{IsCloserAfterEvent}(\mathtt{ProtectAnna}, \mathtt{S}_{i+1}, \\ \mathtt{ProtectAnna.goal}(\mathtt{S}_{i+1} \oplus \mathtt{AnnaThaws_E}), & \mathtt{AnnaThaws_E}) \\ \mathtt{ProtectAnna.goal}'(\mathtt{S}_{i+1}, \mathtt{AnnaThaws_E})), & \wedge\, \mathtt{IsNoticeable}(\mathtt{ProtectAnna}, \mathtt{S}_{i+1}, \\ & \mathtt{AnnaThaws_E}, \epsilon_J) \\ \emptyset, & \mathit{Otherwise} \end{cases}$$

Joy elicitation depends on the evaluation of `IsCloserAfterEvent` and `IsNoticeable` (Chapter 9.4.1). Focusing on those pieces and using the definition of $\mathtt{S}_{i+1}$ from Table 12.2 gives:

$$\begin{gathered} \mathtt{IsCloserAfterEvent}(\mathtt{ProtectAnna}, \mathtt{S}_{i+1}, \mathtt{AnnaThaws_E}) \\ \wedge\, \mathtt{IsNoticeable}(\mathtt{ProtectAnna}, \mathtt{S}_{i+1}, \mathtt{AnnaThaws_E}, \epsilon_J) \\ \rightsquigarrow \mathtt{ProtectAnna.goal}(\mathtt{S}_{i+1}) > \mathtt{ProtectAnna.goal}\,(\mathtt{S}_{i+2}) \\ \wedge\, |\, \mathtt{ProtectAnna.goal}'\,(\mathtt{S}_{i+1}, \mathtt{AnnaThaws_E})\,| > \epsilon_J \\ \text{where } \mathtt{S}_{i+2} = \{\mathtt{S}_{i+1} \oplus \mathtt{AnnaThaws_E}\} \rightsquigarrow \{\mathtt{Anna.Health} = h_E, \mathtt{Anna.IsAlive} = \mathit{True}\}, \\ h_{i+1} \in (\mathtt{MIN}\%, 25\%],\ \text{and } h_E \in [75\%, 100\%] \end{gathered}$$

Looking up the values of $\mathtt{ProtectAnna.goal}(\mathtt{S}_{i+1})$, $\mathtt{ProtectAnna.goal}(\mathtt{S}_{i+2})$, and $\mathtt{ProtectAnna.go-al}'(\mathtt{S}_{i+1}, \mathtt{AnnaThaws_E})$ in the EMgine-specific test case specification (Table 12.2) gives:

$$\begin{gathered}
\rightsquigarrow \texttt{ProtectAnna.goal}(\texttt{S}_{i+1}) > \texttt{ProtectAnna.goal}\,(\texttt{S}_{i+2}) \\
\wedge\,|\,\texttt{ProtectAnna.goal}(\texttt{S}_{i+2}) - \texttt{ProtectAnna.goal}(\texttt{S}_{i+1})| > \epsilon_J \\
\rightsquigarrow \left(\frac{75\% - h_{i+1}}{75\%} + \infty\right) > 0 \wedge \left|0 - \left(\frac{75\% - h_{i+1}}{75\%} + \infty\right)\right| > \epsilon_J \\
\rightsquigarrow \infty > 0 \wedge |\,0 - \infty| > \epsilon_J \\
\rightsquigarrow \textit{True} \wedge |-\infty| > \epsilon_J \\
\rightsquigarrow \textit{True}
\end{gathered}$$

$$\text{where } \texttt{S}_{i+2} = \{\texttt{S}_{i+1} \oplus \texttt{AnnaThaws}_\texttt{E}\} \rightsquigarrow \{\texttt{Anna.Health} = h_E, \texttt{Anna.IsAlive} = \textit{True}\},$$
$$h_{i+1} \in (\texttt{MIN}\%, 25\%], \text{ and } h_E \in [75\%, 100\%]$$

Therefore, the model outputs a tuple indicating that the event $\texttt{AnnaThaws}_\texttt{E}$ elicits *Joy* from Elsa:

$$(dist_{prev} = \infty, dist_{now} = 0, dist_\Delta = -\infty)$$

Recalling the *Joy* intensity model (Equation 9.5.2):

$$J_\Delta(g : \mathbb{G}, d_\Delta : \mathbb{D}_\Delta) : \mathbb{I}_\Delta \mathrel{\hat{=}} |d_\Delta| \cdot g.\texttt{importance}$$

Substituting ("$\rightsquigarrow$") data from the output of the *Joy* elicitation evaluation into J_Δ gives:

$$\begin{gathered}
J_\Delta(g = \texttt{ProtectAnna}, d_\Delta = -\infty) \\
\rightsquigarrow |-\infty| \cdot \texttt{ProtectAnna.importance} \\
\rightsquigarrow |-\infty| \\
\rightsquigarrow \infty
\end{gathered}$$

The intensity of Elsa's *Joy* is maximized because she believed that her goal to ProtectAnna was unachievable and the event $\texttt{AnnaThaws}_\texttt{E}$ made it achievable again, which *should* elicit a very strong reaction. Assuming that the intensity change of *Joy* is proportional to that of *Acceptance* due to their interconnection ($\mathbb{I}_{\Delta\,Joy} \propto \mathbb{I}_{\Delta\,Acceptance}$), this aligns with the expected outcome $\texttt{Joy}_{i+2} \propto \texttt{Acceptance}_{i+2}$ (Table 12.2).

Evaluating EMgine's *Acceptance* Elicitation and Intensity Models

The *Acceptance* elicitation model (Equation 9.4.6) requires a social attachment, goal, WSV, event, and two "tolerance" values for distance changes between WSVs. The test case defines all of these except for the "tolerance" values, which rely on Elsa. Recalling the *Acceptance* elicitation model:

$$Acc(r_A : \mathbb{SA}^?, g : \mathbb{G}, s_{prev} : \mathbb{S}, s_\Delta : \mathbb{S}_\Delta, \epsilon_{A1} : \mathbb{S}_\Delta, \epsilon_{A2} : \mathbb{S}_\Delta) : (r_A : \mathbb{SA}, \textit{distAttribToA}_\Delta : \mathbb{D}_\Delta)^?$$
$$\mathrel{\hat{=}} \begin{cases} (r_A, dist_\Delta - \epsilon_{A2}), & r_A \neq \text{None} \wedge |J(g, s_{prev}, s_\Delta, \epsilon_{A1}).dist_\Delta| > \epsilon_{A2} \\ & \wedge\, \texttt{CausedBy}(s_\Delta, A) \\ \emptyset, & \textit{Otherwise} \end{cases}$$

Substituting ("$\rightsquigarrow$") data from Table 12.2 into the *Acceptance* elicitation model *Acc* gives:

$$Acc(r_A = \texttt{Anna}, g = \texttt{ProtectAnna}, s_{prev} = \texttt{S}_{i+1}, s_\Delta = \texttt{AnnaThaws}_\texttt{E}, \epsilon_{A1} = \epsilon_J, \epsilon_{A2})$$
$$\rightsquigarrow \begin{cases} & \texttt{Anna} \neq \text{None} \\ (\texttt{Anna}, dist_\Delta - \epsilon_{A2}), & \wedge\, |J(\texttt{ProtectAnna}, \texttt{S}_{i+1}, \texttt{AnnaThaws}_\texttt{E}, \epsilon_J).dist_\Delta| > \epsilon_{A2} \\ & \wedge\, \texttt{CausedBy}(\texttt{AnnaThaws}_\texttt{E}, \text{Anna}) \\ \emptyset, & \textit{Otherwise} \end{cases}$$

Acceptance elicitation depends on the evaluation of *Joy* elicitation and some externally defined `CausedBy` function. Focusing on those pieces and using the output of the *Joy* elicitation acceptance test case example gives:

$$\begin{gathered}\texttt{Anna} \neq \text{None} \wedge |-\infty| > \epsilon_{A2} \wedge \texttt{CausedBy}(\texttt{AnnaThaws}_\texttt{E}, \text{Anna}) \\ \texttt{Anna} \neq \text{None} \wedge \infty > \epsilon_{A2} \wedge \texttt{CausedBy}(\texttt{AnnaThaws}_\texttt{E}, \text{Anna}) \\ \mathit{True} \wedge \mathit{True} \wedge \texttt{CausedBy}(\texttt{AnnaThaws}_\texttt{E}, \text{Anna}) \\ \texttt{CausedBy}(\texttt{AnnaThaws}_\texttt{E}, \text{Anna})\end{gathered}$$

The components that EMgine evaluates—$\texttt{Anna} \neq \text{None}$ and $|-\infty| > \epsilon_{A2}$—resolve to the expected value *True*, so the output is $(\texttt{Anna}, -\infty)$ if $\texttt{CausedBy}(\texttt{AnnaThaws}_\texttt{E}, \text{Anna}) = \mathit{True}$. This external function depends on how Elsa attributes causality to entities, which likely relies on some reasoning process unless users hard-code values (Chapter 9.4.5). Therefore, the output depends on the assumption that Elsa attributes Anna's thawing to Anna herself. Anticipating that Elsa attributes the event $\texttt{AnnaThaws}_\texttt{E}$ seems reasonable because Elsa knows that she is not responsible, no one else is capable of reviving Anna, and Elsa does not appear to attribute the event to a spirit or higher being. However, the output of `CausedBy` is not known for certain and is beyond the model's scope.

Recalling the *Acceptance* intensity model (Equation 9.5.7):

$$Acc_\Delta(r_A : \mathbb{SA}, r_{min} : \mathbb{SA}, d_\Delta : \mathbb{D}_\Delta) : \mathbb{I}_\Delta \mathrel{\hat{=}} \begin{cases} |d_\Delta| \cdot \dfrac{r_A}{r_{min}}, & r_A < r_{min} \\ |d_\Delta|, & \mathit{Otherwise} \end{cases}$$

Substituting ("$\rightsquigarrow$") data from the output of the *Acceptance* elicitation evaluation into Acc_Δ gives:

$$\begin{gathered} Acc_\Delta(r_A = \texttt{Anna}, r_{min}, d_\Delta = -\infty) \\ \rightsquigarrow \begin{cases} |-\infty| \cdot \dfrac{\texttt{Anna}}{r_{min}}, & \texttt{Anna} < r_{min} \\ |-\infty|, & \mathit{Otherwise} \end{cases} \\ \rightsquigarrow \begin{cases} \infty \cdot \dfrac{\texttt{Anna}}{r_{min}}, & \texttt{Anna} < r_{min} \\ \infty, & \mathit{Otherwise} \end{cases} \end{gathered}$$

In this case, the value of r_{min} does not matter because anything multiplied by ∞ is ∞. However, as with *Joy* intensity, it makes sense that Elsa's *Acceptance* is maximized because she believed that her goal to `ProtectAnna` was unachievable and the event $\texttt{AnnaThaws}_\texttt{E}$ that was *caused by Anna* made it achievable again, which *should* elicit a very strong reaction. This aligns with the expected outcome $\texttt{Acceptance}_{i+2}$ (Table 12.2).

12.3 Documenting EMgine's Verification and Validation

Since EMgine's chosen Software Requirements Specification (SRS) template draws from an IEEE standard (Smith et al., 2007, p. 94), it bases its test plan and report documentation[1] on IEEE Standard 829-2008 for Software and System Test Documentation (IEEE Computer Society, 2008) and modifies it to match the order and structure of EMgine's other documentation.

[1]See EMgine's Master Test Plan at https://github.com/GenevaS/EMgine/blob/main/docs/TestPlans/MTP/EMgine_MTP.pdf.

12.4 Summary

Extending the acceptance test case templates of Elsa's *Grief* and *Admiration* demonstrates a way to translate them into EMgine-specific data types while remaining consistent with the original test case and associated character study of Elsa. This suggests that it is possible to transform implementation-agnostic acceptance test case templates into other comparable forms, serving as a common point to begin comparing CMEs. Preliminary evaluations of EMgine's models for *Sadness*, *Acceptance*, and—by extension—*Joy* elicitation and intensity "on paper" using these test cases starts to build confidence in EMgine's models for those emotions, justifying subsequent implementation and testing efforts.

Key Points

- Although they share some data types, the acceptance test case template specifications and EMgine's models are intentionally different because they have different concerns—one models a scenario without knowing about the underlying processes and the other models the underlying processes with no conception of specific scenarios
- Extensions of the implementation-agnostic test case templates of *Grief* and *Admiration* show how the translation into EMgine's data types remains consistent with the original test case and associated character study
- Preliminary evaluations of some EMgine models "on paper" demonstrate that the models and test case extensions are consistent, building confidence in their correctness
- EMgine bases its test plan and report documentation on IEEE Standard 829-2008 for Software and System Test Documentation, modified to match the structure of its other documents

Part III

Continue?

The future is our time.

Agent Smith, *The Matrix*

You made it!

This part reviews the motivation and work on EMgine. "Looking Up at the Sky From Down the Rabbit Hole" (Chapter 13) revisits the work as a whole, reflects on its limitations, and suggests avenues for future work. The bibliography and supplementary material follow (Appendices A, B, C, and D).

Would you like to Continue?

Chapter 13

Looking Up at the Sky From Down the Rabbit Hole

> Well, certainly no one could have been unaware of the very strange stories floating around before we left.
>
> HAL 9000, *2001: A Space Odyssey*

Player engagement is part of "good" player experiences (PX) which believable Non-Player Characters (NPCs) can help build (Chapter 2). This work focuses on NPC emotion (Chapter 3) because it can help players empathize with an NPC and build stronger attachments to them. However, creating NPCs that have "correct" emotional reactions to an unpredictable, dynamic world is challenging. A designer's predictions of possible scenarios limit rule and logic-based approaches such as scripts and state machines, and would quickly multiply to unmanageable amounts as the game grows. Another approach is tools that generate NPC emotions and/or emotional behaviours by modelling game world information. This led to EMgine: a Computational Model of Emotion (CME) for generating emotion in game entities. EMgine is a response to the research questions from the start of this journey (Chapter 1):

RQ0 *What software engineering-based methods and/or techniques can aid the creation of game development tools for believable characters with emotion?*

The focus on NPC emotions led to CMEs—software systems influenced by emotion research—as the basis for building game development tools. This work assumes that game developers find processes for creating tools more useful than any single tool itself so that they can tailor make them for their needs. Delving into accounts of common CME development practices revealed that there is little information about some areas such that they appear *ad hoc*, making it difficult to achieve desirable software qualities like reusability and replicability (Chapter 4). For example, a CME's desired qualities, reasons for choosing them, and how they translate to a CME's underlying theories is often vague. This leads to low reusability and replicability in those CMEs. The systematic approach and tools afforded by software engineering help address this challenge by encouraging developers to explain their design decisions and ensure traceability between concept and realization (Chapters 9 and 10). There are also opportunities for systematic methods in specific software development stages, such as requirements analysis and validation.

RQ1 *How can user-oriented software requirements and domain knowledge inform the selection of emotion theories and/or models for CMEs built as game development tools?*

The survey of existing CMEs (Chapter 5) suggests that designers use some qualities that they want the CME to have in a target domain to choose its theories. This suggests that there might be a systematic way to choose a CME's underlying theories based on its requirements. One of the challenges is the nature of the affective science literature itself. Descriptions of theories and models in the affective science literature often use natural language which means that they are informal and unsystematic. This makes it difficult to see how they could support a CME's needs without making subjective assumptions about unspecified behaviours. Document analysis, a qualitative research method, is one way to minimize subjectivity because it offers a structured approach for justifying decisions by encouraging documentation of assumptions and design decisions. Using the CME's software requirements—user-oriented or otherwise—and domain knowledge to form the analysis context for document analysis deeply embeds them in the theory selection process to improve its replicability and inform decisions about reuse in other designs (Chapters 6, 7, and 8).

RQ2 *How can existing narratives inform the development of test cases for evaluating CMEs built as game development tools?*

Acceptance testing evaluates systems to see if it meets its end-users expectations without knowing how the system works internally. Before conducting expensive acceptance tests with user studies, which directly involve end-users in the process, creating acceptance test cases from stable, known scenarios would help build confidence in the "correctness" of a CME's behaviours without additional conditions that could impact them. This works best when acceptance test development happens separately from system development to avoid biasing the tests in the systems favour. Accepting storytellers as domain experts of believable characters, the narratives they create are a rich source of test data. With methods and techniques from literary studies, testers can extract character data from those narratives to form the preconditions, inputs, and expected outputs of acceptance test cases to perform preliminary evaluations of believable NPCs (Chapters 11 and 12).

RQ3 *What steps can be taken during the development of domain-specific CMEs to improve their reusability and replicability?*

Reusability and replicability are possible when there is sufficient information available to: trace a CME's implementation through its design and requirements; see how its verification and validation efforts build confidence in its "correctness"; and allow others to use a CME's components independently of the larger system. A CME's code and documentation is usually the primary way to relay the thought processes behind its design choices because there are few opportunities to communicate with the designers directly. Therefore, significant effort went into documenting EMgine's development process using highly organized templates that support traceability between components in the same document, across different documents, and in the code base (Chapters 9.8, 10.3, and 12.3). To further encourage reusability and replicability, EMgine's code and documentation is in a public GitHub repository:

https://github.com/GenevaS/EMgine

13.1 A Journey of Many Disciplines

This work began by asking what seemed like a simple question: would video games be more entertaining if NPCs were not oblivious of the player? There are many examples of strange NPC behaviours: becoming angry with the player, but immediately forgetting that when they choose a different conversation option or enter another area; continuing to interact cheerfully with their surroundings while the player repeatedly hits them with a stick or damages their home; not reacting at all while the player does an odd series of little jumps and crouches; and many others. The only certainty at the beginning of this work was that NPCs usually act like robots—it is difficult to take them seriously and it can detract from PX. This led to a curious rabbit hole of vastly different research and creative disciplines using qualitative and quantitative techniques.

Although the target domain suggests otherwise, game design proper does *not* have a starring role in this work. The goal is to help game developers by providing tools and methods for them to realize their own designs rather than proposing designs for them, which would have a narrow use scope. Instead, the initial focus was Human-Computer Interaction (HCI) because creating the best possible PX is a common game design goal (Chapter 2). Knowing how games engross players would help explain why "broken" NPC behaviour significantly interrupts their experience to make "fixing" them worthwhile. The impact of game narratives—and the NPCs in them—on a player's emotional engagement suggest that it is worthwhile. The key is something that artists have long since solved: *believability* and the illusion of personality and self-awareness when there is none.

One of the elements that make a believable character is emotion, which led to Affective Science to define what an "emotion" is (Chapter 3), then Affective Computing for Computational Models of Emotion (CMEs, Chapter 4) because the plausibility of character behaviours depends on their psychological validity—they must be grounded in affective science. This idea of grounding behaviours in real-world observations is also true in the arts, where artists observe the real world and draw from their life experience to create their work. Artists do not need to formally study affective science to make their work believable, suggesting that it is not knowledge of the exact workings of emotions that drives believability—it is the effects that they have on behaviour. This matches the purpose of a domain-specific CME, whose first concern is the qualities and behaviours it should have rather than accurately simulating affective processes and structures. This is also ideal for game development tools because it means that they do not require their users to have a formal understanding of emotion either. It should be enough to have a layperson's understanding of emotion to use the tool, which hides the underlying structures and processes.

Some common issues in CME development include difficulties in reusing, replicating, and verifying them, which also makes it difficult to compare different CMEs. It was here that software engineering could help because it has a repertoire of processes and techniques to address those issues. The difference between domain-specific CMEs and research-oriented ones appear to involve two areas: requirements analysis and validation.

13.1.1 Domain Versus Research: Requirements Analysis

The purpose of research-oriented systems is to test hypotheses about affect and its elicitation, so it already knows which affective theories, models, structures, and/or mechanisms to build. In contrast, domain-specific CMEs want to emulate aspects of affect without a care for how it happens. During *requirements analysis*, this affords both the freedom and stress of choosing the CME's underlying theories, models, structures, and/or mechanisms while ensuring support for the CME's high-level design goals. This also comes with additional work because documenting the decision is critical to that CME's reusability, replicability, and the ability to compare it to other systems by describing assumptions and early design decisions that impact its design. A survey of existing CMEs (Chapter 5) revealed that it is uncommon to report why a CME uses a theory/model and how it supports its high-level design goals. However, the survey also revealed trends between what a CME needs to do and the theories/models it uses. This suggested that there might be a systematic way to decide which ones to use.

Developing the proposed methodology for choosing a domain-specific CME's theories/models (Chapter 4.2.1) hinged on two key elements:

1. The criteria for evaluating and comparing theories/models, and
2. Controlling and minimizing the inherent subjectivity in readings of the affective literature because of its natural language descriptions.

The chosen criteria are the CME's high-level requirements and design scope because they can critically influence the CME's usefulness to the intended users. Introducing them into theory selection helps integrate them into the CME's design early and has a trickle down effect such that there is some implicit support for those requirements in each development stage.

It is impossible to completely eliminate subjectivity from the process because it largely exists as non-numerical data and simply taking careful notes of the literature is insufficient for replicability. Qualitative research methods are the only viable option where subjectivity is expected so that it can be controlled and minimized rather than eliminated outright. This led to document analysis, which formed the foundation of the proposed CME theory/model selection methodology. By embedding CME-specific concerns into this process—requirements and scope as the context, groups of theories/models as the "themes", and organizing information by level of requirement "satisfaction"—the methodology emerged as a way to improve a CME's software qualities by encouraging systematic documentation of the CME developer's thought process so that others can see and trace decisions from the literature, through the CME's design goals, out to the selected theories and/or models.

13.1.2 Domain Versus Research: Validation

A research-oriented CME is valid if it proves the hypothesis it is built to test because a system that disproves it implies that the underlying structures and mechanisms are not responsible for the phenomena under study. In contrast, domain-specific CMEs are valid if they meet some developer and/or user acceptance criteria. This implies that the methods and data for validating domain-specific CMEs must come from its intended domain. For a CME that is to produce believable characters through emotion, this means looking to believable characters and extracting test case specifications from them.

Believable characters primarily exist in fictional stories where there are no true quantitative measures, so qualitative methods are necessary. Therefore, the proposed methodology for building acceptance test cases for believable character-focused CMEs draws from literary art and analysis and identifies character analysis/studies as a useful method of qualitative data collection (Chapter 4.2.4). Rather than proposing character studies broadly, creating a methodology provides a direction for test case designers so that they have a guide for identifying and extracting salient information about a character. This forwards the test case's verifiability and replicability by providing a trace from the narrative source to the specification while further separating test case design from the models it must evaluate.

13.1.3 Putting Theory into Practice: EMgine

Stopping at proposals for methodologies and good development practices has limited value because there is no practical demonstration. This is where EMgine comes in, putting the proposed methodologies to work while also aiming to emulate good documentation practices.

The methodology for choosing affective theories/models based on a CME's requirements led to EMgine's complementary set of theories—Oatley & Johnson-Laird, Plutchik, and PAD Space (Chapters 6 and 7). This process also inspired a series of short examples showing how changes in the methodologies "inputs", the CME's high-level requirements and design scope, lead to reasonable and different selections for other kinds of CME (Chapter 8). This provides additional examples to study and builds confidence in the methodology's capabilities.

The role of animated films in the example acceptance test case specifications (Chapters 11 and 12) draws on visual art and analysis to identify their emotion from their visual elements as well as their audio cues and narrative context. In doing so, this highlights the undeniable medium-agnostic interconnection of believable characters and art which ultimately does not prevent the creation of formal specifications describing them.

Evaluating the viability of the acceptance test case building methodology required models to test. Therefore, creating formal specifications of emotion elicitation and intensity for EMgine (Chapter 9) became a larger concern than anticipated. However, this also presented an opportunity to propose an approach for transforming a natural language description of an affective process or structure into a formal specification. Consequently, a three-stage process emerged. The "intermediary" step helps clarify implicit assumptions and design decisions by describing connections between the source description and the CME developer's interpretation of it.

Although there is room for improvement, realizing the architecture design, module specification, and implementation of EMgine's models (Chapter 10) builds further confidence in the choice of EMgine's theories and model and, consequently, provides additional support for the viability of the proposed theory/model selection methodology.

13.2 Avenues of Future Work

This work began with what seemed like a simple question: how can the development of a CME for believable NPCs "with emotion" leverage software engineering? What at first looked like a regular piece of glass turned out to be a prism, refracting into many distinct and overlapping components. Just like light, not all questions are visible from here. These are only a few questions, and it is not obvious how many—if any—others they might rouse and how many are yet to be found.

Although EMgine's design emphasizes user's needs (Chapter 6.1), there was no opportunity to solicit their feedback on it nor elicit additional requirements. Consequently, EMgine's usefulness to them is not known. Investigating this requires direct interaction with EMgine's intended users, which can answer questions such as:

FRQ1 *To what degree does EMgine help or hinder game developers in the creation of NPCs "with emotion"?*

FRQ2 *What features would make EMgine attractive as a game development tool (e.g. visual representations of emotion kinds, analysis tools)?*

FRQ3 *What types of agent architectures that game developers want to use can EMgine integrate with?*

FRQ4 *How can EMgine's performance be improved so that it is feasible to use in commercial games?*

FRQ5 *To what degree do players attribute their engagement with a game to its NPCs "with emotions" that are created with EMgine?*

FRQ6 *How much testing is necessary for game developers to consider a CME for game development sufficiently validated?*

EMgine's component-based software architecture seems like the optimal choice to satisfy the known user requirements, but there are other potential the module decompositions that might be better suited for EMgine (Chapter 10.1.2). Drawing from knowledge about software design patterns and architectures, some of which are CME-specific (Osuna et al., 2021, 2022, 2023), the obvious question that follows is:

FRQ7 *What kinds of software design would improve EMgine's module's information hiding while maintaining the flexibility of EMgine's component-based architecture?*

An element integral to test case specification but not EMgine itself is the many ways to *express* emotion (Chapter 11.2). This is a necessary component of believable NPCs because it conveys their invisible, internal state and/or processes to external observers (Chapter 2.3). Therefore, it might play an equal—or even greater—role in the believability of NPCs "with emotion". Some questions that follow are:

FRQ8 *What expression modalities (e.g. facial expressions, gestures) should NPCs have to maximize a player's engagement with them?*

FRQ9 *How complex do the processes driving emotion expression need to be to effectively communicate an NPC's internal emotion state?*

While surveying other CMEs (Chapter 5), it was common to find designs that integrated more types of affect alongside emotion such as personality—a critical component of believable characters (Chapter 2.3)—and mood, which might prevent unnaturally fast fluctuations in emotion states (Becker-Asano, 2008, p. 88). Since other CMEs have already shown that it is possible to computationally model other types of affect, the next question to ask with respect to EMgine is:

FRQ10 *What additional models are necessary to extend EMgine with other types of affect (e.g. personality, mood, attitudes)?*

The development of acceptance test cases and EMgine's models showed their dependence on knowledge that exists independently of emotion processes. This "world" knowledge and an NPC's perception of it (Chapter 9.4.5) proved indispensable for describing information "outside" of the NPC. This is unsurprising because of the connection between emotion and an individual's environment (Chapter 3.1). However, it raises questions about this information's availability that impacts EMgine's viability as a game development tool such as:

FRQ11 *How can CMEs built as game development tools use existing information in games to support their tasks?*

FRQ12 *How should "world" knowledge and "self" knowledge be represented so that CMEs built as game development tools can use them in their processes?*

The acceptance test case for *Joy* and *Acceptance* (Chapter 12.2.1) also raised questions about emotion elicitation and intensity models:

FRQ13 *What are some best practices for tuning EMgine's models that require inputs such as "threshold" values?*

FRQ14 *How should a CME decide which emotion kind to prioritize for scenarios that satisfy more than one elicitation model and have comparably strong intensities?*

With respect to emotion representation models, EMgine uses a function that maps Plutchik's emotion kinds to intensities whose underlying representation is a real value (Equations 9.3.4 and 9.3.1 respectively). One of the attractive features of Plutchik is its account of emotion "mixtures", which a different type of emotion representation might better support. Due to the similarity-based ordering of Plutchik's Circumplex, modelling emotion kinds as fuzzy sets is another potential way to represent them (Russell, 1997, p. 209, 215). Creating emotion "mixtures" could then be a matter of defining the membership of each component set, which could be organized as a fuzzy hierarchy to mimic an inheritance-based one without needing strict class inclusion. Alternatively, polar coordinates use the native language of a circle and could make emotion "mixing" a matter of defining Circumplex axes and using them for factorial composition on those axes (Gurtman, 1997, p. 89, 91–92). These alternatives for representing Plutchik's Circumplex begs the question:

FRQ15 *How do other formal representations of emotion compare to EMgine's type-based ones?*

Continuing the development of EMgine itself is another way forward, improving it so that it can stand as an example of reusable and maintainable CME development. Addressing this, the proposed questions, or any other questions they inspire would be an asset—big or small—to the Affective Computing community.

Chapter 14

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End of Line.

Master Control Program, *TRON*

Appendix A

Supplementary Material for CME Survey[1]

I think he suffered from mood swings, personally. I'm not a therapist in any way, but I—you let me know when I'm rambling!

B.E.N., *Treasure Planet*

This material is part of the survey of emotion theories in Computational Models of Emotion (CMEs) (Chapter 5).

A.1 Search Protocol

We created a search protocol following the PRISMA-S guidelines (Rethlefsen et al., 2021) to answer the questions:

What emotion theories do designers use to build their emotion-generating Computational Model of Emotion (CME)? Why do they use these theories?

A.1.1 Information Sources and Methods

1. Databases Searched

   - IEEE Xplore
   - ACM Digital Library
   - AAAI Digital Library
   - SpringerLINK
   - ScienceDirect (Elsevier)

   Rationale: These represent some of the major organizations that publish work in affective computing as conference proceedings and journals. They tend to be limited to English publications only.

2. Multi-Database Searching

- Not used

3. Study Registries

   - Not applicable

4. Online Resources and Browsing

   The following publications are available online, listed by the database where they are located.

   One author examined their table of contents (TOC) by hand for relevant papers. Paper relevancy was assessed by its title and abstract. The author examined a paper's contents if relevancy could not be determined from the title and abstract.

   - IEEE Xplore
     - IEEE Transactions on Affective Computing
     - IEEE Transactions on Computational Intelligence and AI in Games
   - ACM Digital Library
     - Proceedings of the ACM International Conference on Intelligent Virtual Agents
   - SpringerLINK
     - Proceedings of the International Conference on Intelligent Virtual Agents
     - Proceedings of the International Conference on Agents and Artificial Intelligence (Selected and Revised Papers)

   Rationale: They focus on intelligent virtual agents.

5. Citation Searching

   The references/citations listed in papers found using Databases [Section A.1.1, Item 1] and Online Resources and Browsing [Section A.1.1, Item 4] were manually screened for potential papers.

   Rationale: Part of understanding why a design decision was made is understanding what influenced it. Here, that includes cited CMEs. This method also reduces the probability of missing a CME that frequently appears in the literature reviews of subsequent ones, as there is a high probability of multiple papers citing it directly or citing another paper that leads back to it.

6. Contacts

   - Not used

7. Other Methods

   Some papers were found by fellow researchers during their own searches. One author examined these by hand for relevancy. Paper relevancy was assessed by its title and abstract. The author examined a paper's contents if relevancy could not be determined from the title and abstract.

   Rationale: There were few papers gathered this way, so it was worth examining them in case they were not found by other search strategies (Section A.1.2).

A.1.2 Search Strategies

1. Full Search Strategies

   The initial search followed strategy (a) to gather results from databases (Section A.1.1, Item 1). Additional results were added after searching online resources (Section A.1.1, Item 4) and using other methods (Section A.1.1, Item 7).

   After reducing the total results using paper eligibility criteria (Section A.1.2, Item 3), strategy (b) was executed on the papers in the reduced list to gather results from citations (Section A.1.1, Item 5).

   (a) Keyword Search

      i. IEEE Xplore
      Search executed from `Advanced Search > Command Search`. Query split into two parts due to limitation on wildcard (*) characters.
      Search results were downloaded as a CSV file using IEEE Xplore's built in `Export` function.

      - ((“comput* model*”) AND “emotion*”) NOT (“recognition*” OR “predict*”)
      - (“affective comput*” OR “comput* emotion engine*” or “emotion engine”) NOT (“recognition*” OR “predict*”)

      ii. ACM Digital Library
      Search executed from `Advanced Search` using `The ACM Full-Text Collection` and `Search Within ‘‘Anywhere’’`. Query split into three parts to manage search terms.
      Search results were downloaded by navigating to each results page, checking `Select All` and using `Export Citations` to download a text file of the results in `ACM Ref` format.

      - “computational emotion model” OR “computational emotion models” OR “computational model of emotion” OR “computational models of emotion” -predict* -recognition*
      - “affective computing” -predict* -recognition*
      - “emotion engine” OR “computational emotion engine” -predict* -recognition*

      iii. AAAI Digital Library
      Search executed from the search bar at the top right corner of `www.aaai.org`. There were no Advanced Search functions.
      Since the AAAI Search function is a “Google Custom Search” and limits the results to the first 10 pages, these searches were repeated in `Google Search` by pre-pending `site:www.aaai.org` to each query.
      There was no method for exporting search results, so each item was examined individually. Potentially relevant results were manually saved in an Excel sheet.

      - computational model of emotion -recognition* -predict*
      - emotion engine -recognition* -predict*
      - affective comput* -recognition* -predict*

      iv. SpringerLINK
      Search executed from the main search bar. Searches omit wildcards because search function is designed to look for words with the same “stem” (e.g. “computer” also finds “computes” and “computation”).

Search includes "Include Preview-Only Content".
Search was filtered by sub-disciplines [Section A.1.2, Item 2b].
Search results were downloaded as a CSV file using SpringerLINK's built in `Download` function.

- computational model of emotion NOT predict NOT recognition
- emotion engine NOT predict NOT recognition
- computational emotion engine NOT predict NOT recognition
- affective computing elicitation generation NOT predict NOT recognition

v. ScienceDirect (Elsevier)
Searches executed with `Advanced Search` to search for individual articles rather than full journals. They were filtered by Publication Title [Section A.1.2, Item 2c]. Searches capture spelling variations (e.g. "color" and "colour") and plural forms of search terms (e.g. "code" and "codes").
Search results were downloaded by navigating to each results page, checking `Select All` and using `Export` to download a text file of the results as citations.

- computational model of emotion -recognition -prediction
- affective computing generation elicitation -recognition -prediction
- emotion engine -recognition -prediction

(b) One author screened the reference lists of included papers found from [Section A.1.2, Item 1a] by hand for relevancy. Paper relevancy was assessed by its title and abstract. The author examined a paper's contents if relevancy could not be determined from the title and abstract.

2. Limits and Restrictions

Papers were limited to those written in English because it is a language shared by both authors. Specific database restrictions were as follows:

(a) IEEE Xplore, ACM Digital Library, and AAAI Digital Library
No additional restrictions.
Rationale: These databases specialize in electrical, computer, and software engineering, and computer science. There was little chance that papers from unrelated fields would be captured in the search.

(b) SpringerLINK
Search results are limited to the sub-discipline of "Artificial Intelligence".
Rationale: Of the available sub-disciplines, this most closely matched the kinds of CMEs that the authors wished to examine. Limiting results to this sub-discipline better focused the results so that there were fewer to examine by hand.

(c) ScienceDirect (Elsevier)
Search results restricted to the following journals:

- Biologically Inspired Cognitive Architectures
- Cognitive Systems Research
- Computers & Education
- Computers & Graphics
- Computers in Human Behaviour

- Expert Systems with Applications
- Information and Software Technology
- International Journal of Human-Computer Studies
- Journal of Systems and Software
- Knowledge-based Systems
- Neurocomputing
- Procedia Computer Science
- Trends in Cognitive Sciences

Rationale: These journals focus on computer science and engineering.

3. Paper Eligibility Criteria

One author examined the results gathered from the search strategies (Section A.1.2, Item 1) for papers to include in the survey using the following criteria:

Inclusion Criteria

- Papers describing CMEs with an emotion generation/elicitation/appraisal component that is built on at least one emotion theory

  Rationale:

  - Directly relates to research question
  - Disqualifies CMEs that use empirical data, neurology/brain anatomy, and psychological/sociological theories of human behaviour
  - Disqualifies CMEs that lack an emotion generation component

- Papers representing the most recent version of a CME that had emotion generation-related design decisions (i.e. CME is given the same/variation of a name, has at least one common author, has the same designer intent, and uses the same emotion theories as its predecessors)

  Rationale:

  - Assumes that the most recent paper reflects current understanding of CME requirements and available emotion theories

Exclusion Criteria

- Papers describing experiments on/with CMEs where a previously published paper describes the design of that CME

  Rationale:

  - Do not focus on the CME's design or why decisions were made, therefore they do not serve research question
  - Citation Searching (Section A.1.1, Item 5) would find paper(s) describing the design of these CMEs

- Papers describing CMEs that are solely/primarily combinations of other CMEs

  Rationale:

  - Do not help understand why the component CMEs made their design decisions, therefore they do not serve research question
  - Citation Searching (Section A.1.1, Item 5) would find paper(s) describing the design of component CMEs

- Papers that are surveys or describe design guidelines/frameworks
  Rationale:
  - Do not directly serve research question
  - Citation Searching (Section A.1.1, Item 5) would find additional paper(s) describing CMEs discussed
- Papers that describe CMEs designed solely on brain structures and/or empirical data
  Rationale:
  - Do not directly serve research question

4. Search Filters
   - Not used
5. Prior Work
   - Not used
6. Updates
   All searches rerun at worst three months before submission on June 14th, 2022.
7. Dates of Searches
   Table A.1 lists the last dates that full search strategies were executed (Section A.1.2, Item 1).

A.1.3 Peer Review

Two research librarians, one familiar with surveys, reviewed the protocol. Their feedback resulted in a more thorough list of databases to search and eliminated the need for Google Scholar results.

A.1.4 Managing Records

1. Total Records
   Table A.2 lists the total records found using Keyword Search (Section A.1.2, Item 1a).
2. Deduplication
   Search results were manually combined in an Excel spreadsheet, then sorted by “Title” and “Author(s)” to identify potential duplicate papers. These were manually removed so that there was only one record per unique paper.

Table A.1: Date Searches Were Last Executed © 2022 IEEE

Source	Last Run Date
IEEE Xplore	
((“comput* model*”) AND “emotion*”) NOT (“recognition*” OR “predict*”)	April 21, 2022
(“affective comput*” OR “comput* emotion engine*” or “emotion engine”) NOT (“recognition*” OR “predict*”)	April 21, 2022
ACM Digital Library	
“computational emotion model” OR “computational emotion models” OR “computational model of emotion” OR “computational models of emotion” -predict* -recognition*	April 25, 2022
“affective computing” -predict* -recognition*	April 25, 2022
“emotion engine” OR “computational emotion engine” -predict* -recognition*	April 25, 2022
AAAI Digital Library	
computational model of emotion -recognition* -predict*	April 26, 2022
emotion engine -recognition* -predict*	April 26, 2022
affective comput* -recognition* -predict*	April 26, 2022
SpringerLINK	
computational model of emotion NOT predict NOT recognition	April 26, 2022
emotion engine NOT predict NOT recognition	April 26, 2022
computational emotion engine NOT predict NOT recognition	April 26, 2022
affective computing elicitation generation NOT predict NOT recognition	April 26, 2022
ScienceDirect (Elsevier)	
computational model of emotion -recognition -prediction	April 29, 2022
affective computing generation elicitation -recognition -prediction	April 29, 2022
emotion engine -recognition -prediction	April 29, 2022
Online Resource Browsing	
IEEE Transactions on Affective Computing TOC	April 22, 2022
IEEE Transactions on Computational Intelligence and AI in Games TOC	April 22, 2022
Proceedings of the International Conference on Intelligent Virtual Agents TOC	May 2, 2022
Proceedings of the ACM International Conference on Intelligent Virtual Agents TOC	May 2, 2022
Proceedings of the International Conference on Agents and Artificial Intelligence (Selected and Revised Papers) TOC	May 2, 2022

Table A.2: Total Records Found with Keyword Search © 2022 IEEE

Source	**Total Results**
IEEE Xplore	
((“comput* model*”) AND “emotion*”) NOT (“recognition*” OR “predict*”)	565
(“affective comput*” OR “comput* emotion engine*” or “emotion engine”) NOT (“recognition*” OR “predict*”)	1,069
ACM Digital Library	
“computational emotion model” OR “computational emotion models” OR “computational model of emotion” OR “computational models of emotion” -predict* -recognition*	32
“affective computing” -predict* -recognition*	465
“emotion engine” OR “computational emotion engine” -predict* -recognition*	61
AAAI Digital Library	
computational model of emotion -recognition* -predict*	754
emotion engine -recognition* -predict*	169
affective comput* -recognition* -predict*	58
SpringerLINK	
computational model of emotion NOT predict NOT recognition	7,213
emotion engine NOT predict NOT recognition	1,061
computational emotion engine NOT predict NOT recognition	537
affective computing elicitation generation NOT predict NOT recognition	37
ScienceDirect (Elsevier)	
computational model of emotion -recognition -prediction	501
affective computing generation elicitation -recognition -prediction	134
emotion engine -recognition -prediction	282

A.2 CME "Genealogy"

Table A.3 highlights some key systems that contributed to the design of a CME.

Table A.3: Overview of the Contributing Designs of CMEs © 2022 IEEE

	System	Builds On
1	**AffectR**	–
2	**Cathexis**	–
3	**EmMod**	–
4	**FLAME**	–
5	**SCREAM**	AffectR (1), Em/Oz (66)[1]
6	**MAMID**	–
7	**TABASCO**	3T (Bonasso et al., 1997)[2]
8	**WASABI**	MAX (Becker et al., 2004)[3]
9	**Maggie**	–
10	**AKR**	Will (25)[2], GOLEM (Castelfranchi et al., 1997)[2]
11	**GVH**	Autonomous Virtual Human Dialog System (Magnenat-Thalmann and Kshirsagar, 2000)[3]
12	**ParleE**	Cathexis (2)[2], FLAME (4), Émile (28)[1,2], Em/Oz (66)
13	**IM-PMEB**	ALMA (41)
14	**GenIA**[3]	EMA (24), ALMA (41), ERDAMS (45), O3A (Alfonso et al., 2014)[3], AgentSpeak (Vieira et al., 2007)[2]
15	**InFra**	FLAME (4)
16	**FAtiMA-M**	FAtiMA (37)[3], ORIENT (Lim et al., 2012)[2], Computational Appraisal Architecture (Marsella et al., 2010, p. 31)
17	**HybridC**	EMIA (Jain and Asawa, 2015)[3,4]
18	**GEmA**	FLAME (4)[2]
19	**SOM**	–
20	**Soar**	Em/Oz (66)[1], PEACTIDM (Newell, 1990)[2]
21	**LIDA**	Computational Appraisal Architecture (Marsella et al., 2010, p. 31)
22	**CLARION**	–
23	**ACRES**	–
24	**EMA**	AffectR (1), Soar (20)[2], Will (25)[2], Émile (28)
25	**Will**	ACRES (23)[3]
26	**ELSA**	–
27	**GAMA-E**	SocioEmo (59)[2], OCC Logical Formalism (Adam, 2007), GAMA (Grignard et al., 2013)[2]
28	**Émile**	AffectR (1), Cathexis (2)[1], Em/Oz (66), NML1 (Beaudoin, 1994)[2], Steve (Rickel and Johnson, 1999)[5], Affect Editor (Cahn, 1989)[5]
29	**EMOTION**	GVH (11): Generic Model (Egges et al., 2004)

Continued on next page

Table A.3: (*Continued.*) Overview of the Contributing Designs of CMEs © 2022 IEEE

	System	Builds On
30	**HumDPM-E**	HumDPM (Luo et al., 2010)[2]
31	**JBdiEmo**	Jadex (Pokahr et al., 2005)[2]
32	**DETT**	MANA (Lauren and Stephen, 2002)[1,2]
33	**EP-BDI**	–
34	**MicroCrowd**	Soar (20)[2]
35	**Puppet**	S3A (67)[2]
36	**CBI**	–
37	**FAtiMA**	TABASCO (7)[2], EMA (24), CBI (36), S3A (67), FearNot!(Aylett et al., 2005)[3]
38	**TARDIS**	Greta (40)[5], ALMA (41)[2], SocioEmo (59)[2]
39	**PUMAGOTCHI**	–
40	**Greta**	–
41	**ALMA**	EmotionEngine (Gebhard et al., 2003), (Gebhard et al., 2004)[3]
42	**Eva**	ALMA (41)[2]
43	**PPAD-Algo**	ALMA (41), Eva (42)[2]
44	**Peedy**	–
45	**ERDAMS**	AffectR (1), ParleE (12)[1], DER (Tanguy et al., 2005), Émile (28)/“Jack and Steve”[1], Em/Oz (66), Corpora Coding (Ochs et al., 2007)[3]
46	**TEATIME**	–
47	**MMT**	–
48	**Presence**	PPP (André et al., 1999)[2,3]
49	**POMDP-CA**	–
50	**iPhonoid**	Interactive Robot System with Memory (Masuyama et al., 2017)[3], AEIS (Han et al., 2013)[2]
51	**EEGS**	Computational Appraisal Architecture (Marsella et al., 2010, p. 31)
52	**PWE-I**	HED (Steephen, 2013)[2], Mood Prediction (Katsimerou et al., 2015)[2]
53	**Kismet**	Cathexis (2)[3]
54	**R-Cept**	Vickia (Bruce et al., 2002)[2,5]
55	**GRACE**	EmotiRob (Saint-Aimé et al., 2007)[3]
56	**TAME**	–
57	**AEE**	–
58	**FeelMe**	–
59	**SocioEmo**	ParleE (12)[2], Émile (28), ALMA (41)[2], Em/Oz (66), E/P Model (Sehaba et al., 2007)[3]
60	**The Soul**	ALMA (41)[2], Animating Expressions (Schaap and Bidarra, 2008)[3]
61	**GAMYGDALA**	Em/Oz (66)[1]
62	**MobSim**	ALMA (41)
63	**APF**	SocioEmo (59)

Continued on next page

Table A.3: (*Continued.*) Overview of the Contributing Designs of CMEs © 2022 IEEE

	System	Builds On
64	**MEXICA**	–
65	**NPE**	Emotional Planner (Gratch, 1999), Possible Worlds Model(Shirvani et al., 2017)[2,3]
66	**Em/Oz**	Tok (Bates et al., 1992)[2], Hap (Loyall, 1997)[2]
67	**S3A**	Will (25)[4], Em/Oz (66)

[1] *For domain specific agent capabilities that are affective in nature, but have unclear theoretical roots.*
[2] *For domain specific agent capabilities that do not explicitly model agent emotion, influence emotion via other factors, map emotion to another affective type, or are implementation-specific.*
[3] *Direct or close descendant of this system.*
[4] *The relationship is inferred from chosen affective theories and model definitions (Jain and Asawa, 2019, p. 61), (Martinho et al., 2000, p. 37, 48).*
[5] *For agent embodiment only.*

Appendix B

Affect and Emotion (In Theory)

Could you please continue the petty bickering? I find it most intriguing.

DATA, *Star Trek: The Next Generation*

One way that researchers categorize affective theories/models for analysis is in four broad perspectives[1]: *discrete*, *dimensional*, *appraisal* or *componential*, and *neurophysiologic* (Lisetti and Hudlicka, 2015, p. 95–99). Designers have used theories from each perspective to generate and express emotions in computer-driven agents.

The discrete, dimensional, and appraisal perspectives use states, dimensions, and processes to explain emotion generation. This makes them good candidates for a Computational Model of Emotion (CME) for believable Non-Player Characters (NPC), since they are not dependent on specific component implementations. The neurophysiologic perspective explains emotion generation via neural circuitry and physiology. Simulating parts of the brain and body is likely to be too complex for entertainment-focused CMEs (Ojha and Williams, 2016, p. 234) but examining these theories is useful for finding other ideas.

B.1 Discrete Theories

The discrete, or categorical, perspective has roots in Darwin's theory of evolution which assumes that emotions have an adaptive functions and must have developed via natural selection due to their complexity (Darwin, 1872). It emphasizes a small set of fundamental emotions, often called *basic* or *primary* emotions, that have evolved via natural selection (Hudlicka, 2014a, p. 305). These theories commonly assume that emotions are innate, hard-wired features with dedicated neural circuitry. This circumvents cognitive processing entirely (Reisenzein et al., 2013, p. 250). However, this also means that discrete theories have been unable to define a general framework for evaluating a variety of emotions using the same terms (Smith and Ellsworth, 1985, p. 816–817). Theories differ in their definitions of "primary" emotions but these are not mutually exclusive (Ortony, 2022, p. 2). However, they do change which emotions a theory considers "basic". Ekman & Friesen and Izard are part of the "biologically basic" view which tend to focus on facial expressions as indicators of primality, whereas Plutchik is part of the "elemental" view that seeks "atomic" emotions that others cannot define (i.e. "mixtures" of other emotions) (Ortony, 2022, p. 2–3).

The discrete perspective has the most empirical data available for building emotion signatures (Chapter 3.1) because specific effects link to each emotion category (Hudlicka, 2014b, p. 10). The

[1]There are finer-grained distinctions (Scherer, 2021, p. 280).

data mainly focuses on facial expressions and language (Ortony, 2022, p. 2), likely due to the difficulty, complexity, and time necessary to collect it (Johnson-Laird and Oatley, 1992, p. 219).

Discrete theories are appealing for CMEs because they have a clear mapping between a small set of universal antecedents to emotion kinds and related action tendencies (Lisetti and Hudlicka, 2015, p. 100). CMEs using this approach "sense" a set of triggers and respond with reflexes using action-reaction rules. This suggests that CMEs using discrete theories script the emotion generation process.

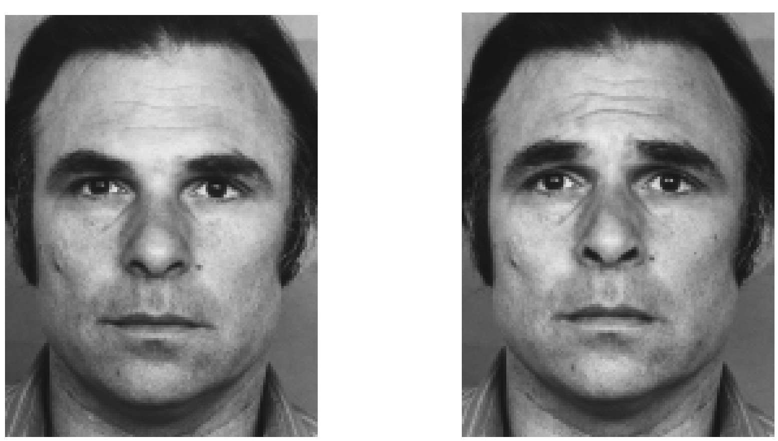
B.1.1 Ekman & Friesen

This theory assumes that universal, innate triggers and learned variations of them cause emotion (Ekman, 2007). The brain stores these triggers in a mental "database". Individuals experience an emotion when there is a match between stimuli and this "database" of triggers. Emotion intensity is a function of the degree of "mismatch" such that a closer match produces a more intense emotion. Ekman & Friesen identify seven "universal" emotions: *Happiness*, *Sadness*, *Fear*, *Anger*, *Surprise*, *Disgust*, and *Contempt*. Facial expressions play a critical role in Ekman & Friesen's theory. The theory accounts for cultural differences in facial expressions with display rules—socially learned rules about when and to whom an emotional expression can be shown.

This theory has had appeal for CMEs because it created the Facial Action Coding System (FACS) (Ekman et al., 2002), which maps facial muscles and movements to individual changes in facial expressions (Figure B.1). CMEs have used it to identify configurations for the seven named "universal" emotions.

B.1.2 Izard's Differential Emotions Theory (DET)

DET is a personality-focused theory, where emotions contribute to personality development and individual differences (Izard et al., 1993; Izard and Ackerman, 2000). It suggests that the perceptional, cognitive, and behavioural patterns of emotion manifest in stable ways and that emotion kinds interact in individual-specific relationships. These patterns develop in infancy and remain stable, producing personality and individual differences. DET proposes that there are twelve emotion kinds: *Interest*, *Enjoyment*, *Surprise*, *Sadness*, *Anger*, *Disgust*, *Contempt*, *Fear*, *Guilt*, *Shame*, *Shyness*, and *Self-Hostility* (Izard et al., 1993). DET suggests that the discrete and dimensional



(a) Neutral (b) Active

Figure B.1: Movement of FACS Action Unit 1 "Inner Brow Raiser" (Ekman et al., 2002, p. 20)

(a) Sadness

(b) Anger

Figure B.2: Examples of MAX-coded Expressions (Izard, 1995)

emotion perspectives are complementary but discrete emotion kinds provide more information. DET suggests that facial expressions are innate to emotion kinds, developing the lesser used Maximally Discriminative Facial Movement Coding System (MAX) (Izard, 1995). Researchers generally use the MAX system in infants and young children research (Figure B.2).

B.1.3 Plutchik's Psycho-evolutionary Synthesis (PES)

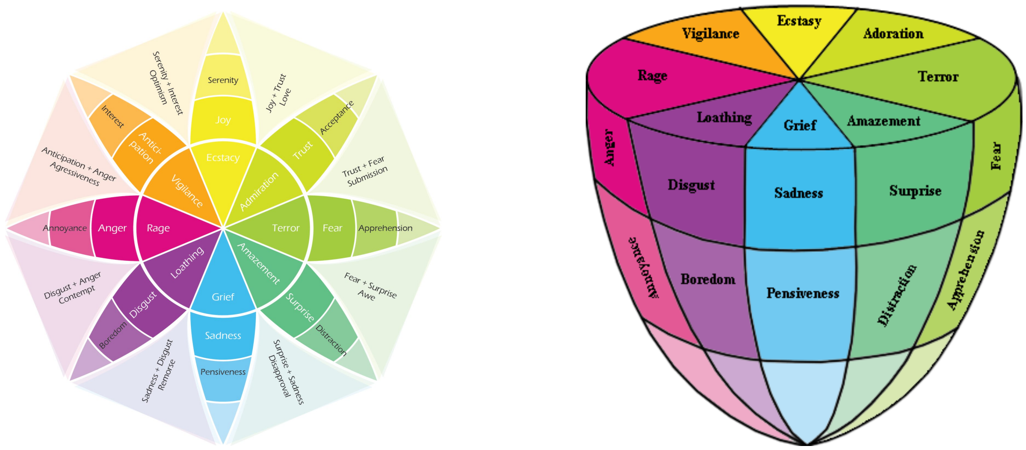
PES aims to synthesize four major, but traditionally separated, fields of study: evolution, psychophysiology, neurology, and psychoanalysis (Plutchik, 1980, 1984, 1997). PES proposes that emotions are responses to survival issues common to all organisms. It derived one of its criteria for claiming a state is an "emotion" from this proposal—association with goal-directed behaviour. PES's eight primary emotions therefore follow from the identification of four adaptational issues that have two, opposing response behaviours (Table B.1). The theory organizes these emotions—*Joy*, *Sadness*, *Fear*, *Anger*, *Anticipation*, *Surprise*, *Disgust*, and *Trust*—into a Circumplex structure by their relative similarities based on layman evaluations of everyday language (Plutchik, 1980; Block, 1957; Conte, 1975). The resulting arrangement places "opposing" emotions opposite each other as predicted (Figure B.3a). PES treats emotion intensity as a third dimension, extending from most intense to a state of "deep sleep" where organisms experience no emotion at all (Figure B.3b). The Circumplex nature of PES's structure implies that the primary emotions need not have equidistant spacing between them because there are no fundamental axes. There is also the implication that there is conflict between opposing elements on the circle, representing polarized behaviours (e.g. approach versus retreat). The mathematical concept of the Circumplex suggests other implications which also implies that PES has more depth than explicitly described.

PES compares its Circumplex structure to the colour wheel. This has some interesting implications such as the ability to "mix" the emotions like primary colours. This creates "complex" emotions that have the prototypical behaviours of each component emotion (Table B.2). For example, mixing the primary emotions *Disgust* and *Anger* creates the secondary emotion *Contempt*, which has the prototypical behaviour tendencies of both component emotions—rejection and destruction. The theory does provide evidence for some mixtures collected from studies that asked participants to name the underlying primary emotions. PES also says that mixing could produce a valid emotion that does not yet have a name.

PES proposes that the necessary sequence of events between a stimulating event and emotion is cognitive appraisal, subjective reaction, and behavioural reaction. It theorizes that cognition developed to predict future needs and events based on prior experience, a mental model of the environment, and available information. Sensory input and expanded memory gives organisms the

Table B.1: Connection Between Behaviours and Emotions in PES

Event	**Cognition**	**Behaviour**	**Emotion**
Threat	“Danger”	Protection	*Fear*
Obstacle	“Enemy”	Destruction	*Anger*
Loss of a valued individual	“Abandonment”	Reintegration	*Sadness*
Potential Mate	“Possess”	Reproduction	*Joy*
New Territory	“What’s out there?”	Exploration	*Interest*
Unexpected Object	“What is it?”	Orientation	*Surprise*
Gruesome Object	“Poison”	Rejection	*Disgust*
Group Member	“Friend”	Incorporation	*Trust*



(a) 2D Circumplex (b) Circumplex with Intensity

Figure B.3: PES Structural View (Plutchik, 1984, p. 203, 205)

Table B.2: Examples of Emotion “Mixtures” in PES

Emotion Label	**“Mixture” Of**
Pride	*Joy* + *Anger*
Outrage	*Anger* + *Surprise*
Panic	*Terror* + *Interest*
Hope	*Trust* + *Interest*
Hatred	*Loathing* + *Anger*

capacity to name objects, create concepts, and identify relationships between them. Therefore, cognitive processes evolved with the brain to serve emotions and biological needs.

B.2 Dimensional Theories

Dimensional theories focus on what kind of mental states emotions are, how to construct them, and how they fit into a general taxonomy of mental states (Reisenzein et al., 2013, p. 250). They define a coordinate space for “core” affect (Chapter 3.1) using two or three affective dimensions, such as *Valence*, *Arousal*, and *Dominance* or *Stance* (Lisetti and Hudlicka, 2015, p. 97). Psychologists have located emotions in this space (Hudlicka, 2014b, p. 9), suggesting that affective states are systematically related. However, dimensional representations can lose information about an emotional state if its resolution exceeds the named dimensions (Schaap and Bidarra, 2008, p. 172). This results in a lower resolution of information than other perspectives. Defining an emotion with dimensions can also be unreliable, as their meaning changes with the context (Lazarus, 1991, p. 61), and the chosen statistical analysis technique could bias the dimensions found in the data (Smith and Ellsworth, 1985, p. 825).

Although appealing in their simplicity and relative ease to implement (Rodríguez and Ramos, 2015, p. 440), dimensional theories say relatively little about how to generate emotions and what their effects are (Hudlicka, 2014b, p. 10) making them unsuitable for defining a complete CME (Reisenzein et al., 2013, p. 250).

B.2.1 Valence-Arousal (V-A)

Perhaps the simplest way to approximate affect, V-A describes emotion with two dimensions—*Valence* and *Arousal*—which appear more consistently across affective dimension studies than any other dimensions (Smith and Ellsworth, 1985, p. 814, 816). Psychologists have treated *Valence* and *Arousal* as independent dimensions, although affect fits more consistently in a Circumplex structure (Barrett and Russell, 1999, p. 12).

The idea of the V-A dimensions forming part of affective space goes at least as far back as Wundt (1912) (Izard, 1971, p. 83; Lang, 1995, p. 373; Barrett and Russell, 1999, p. 10). Other iterations of these dimensions appear in more recent affective models such as Russell (1980).

B.2.2 Pleasure-Arousal-Dominance (PAD) Space

This theory views emotion as a mediator between stimuli and behaviours (Mehrabian, 1980, 1996b). With the goal of quantifying different types of affective phenomena and drawing from studies in a variety of related fields, PAD Space describes three nearly orthogonal dimensions for analyzing emotional states and behaviours while relating them to other affect types and experiences:

- *Pleasure* measures the positive-negative aspects of the emotion state,
- *Arousal* is how alert and active the individual is in that state, and
- *Dominance* is how much control the individual feels they have in that state.

These dimensions are present in all affective reactions operative in a situation. Three dimensions are optimal for general characterizations and measurements of emotional states because two dimensions cannot distinguish between clusters of affect and more than three does not further improve cluster distinctions.

B.3 Appraisal Theories

Appraisal theories emphasize distinct emotion components such as appraisal dimensions or variables (Lisetti and Hudlicka, 2015, p. 97). Appraisal variables represent particular emotions by mapping onto an n-dimensional space (Hudlicka, 2014a, p. 306) which might appear identical in a lower-dimensional space (Lerner and Keltner, 2000, p. 489). Analyzing stimuli for meaning and consequences with respect to an individual generates values for these variables (Reisenzein et al., 2013, p. 250; Smith and Ellsworth, 1985, p. 819), regardless of process sophistication (Gratch and Marsella, 2004, p. 273) and independent of biological processes (Arbib and Fellous, 2004, p. 559). Appraisals are continuous and change with the situation, the individual's behaviours, and their attempts to appraise the situation differently (Siemer and Reisenzein, 2007, p. 28).

Individuals appraise situations differently, accounting for different reactions to the same situation (Siemer et al., 2007, p. 598; Smith and Kirby, 2009a, p. 1353) due to their personality and biases. This makes appraisal theories of particular interest for decision-making, action selection, facial animations, and personality-based CMEs (Gratch and Marsella, 2004, p. 274). Models of social intelligence could also use appraisals because they also seem important for mediating social relationships. However, there is little empirical data associating individual appraisal variables to expressive behaviours or behavioural choices (Hudlicka, 2014b, p. 10).

B.3.1 Frijda's Concern Realization (CR)

CR views emotions as "changes in action readiness" that prepare individuals to change their behaviours in response to or to change something about their current environment (Frijda, 1986). Action readiness can relate to features in the environment or to a general "activation mode".

Concerns, including goals, are dispositions towards internal conditions. Cognitive processes use concerns to assign emotional significance to events and stimuli. CR provides empirical evidence for several appraisal dimensions relating events and stimuli to concerns, including (Frijda, 1987):

- *Valence*, describing the pleasantness or unpleasantness of an event,
- The *impact* of the event, or if it is an event at all,
- *Interestingness*, similar to novelty, which naturally accompanies the emotion of *Interest*,
- *Globality*, or if the individual can locate the event in space,
- The *uncertainty* of the event's outcome,
- If the *responsibility* of the event's occurrence was due to the self or another, and
- If the event was *relevant* to the individual.

Studies also found weak evidence for the dimensions of *certainty*, *controllability*, *accessibility*, *self-esteem*, *modifiability*, *manageability*, and *time reference*. CR then connected the appraisal dimensions to proposed action tendencies and some named emotions and moods (Table B.3).

CR compares the emotion process to a continuous information processing system (Figure B.4). The emotion system constantly takes in information, analyzing its relevance to an individual's concerns. The system then determines what the individual can do to cope and if it should interrupt the individual's current behaviours to address this information. Finally, the system proposes an action readiness change—an action plan, tendency, or activation mode—which tries to take control precedence and instigates physiological and behavioural changes. Any of these processes can take additional inputs or feedback from subsequent processes. The system can skip, interrupt, or evaluate processes in different orders. In this view, what psychologists see as primary emotions are discrete events that emerge from a continuous system that can produce a much broader range of affect.

Table B.3: Relationship Between Action Tendencies and Some Emotions and Moods in CR

Action Tendency	**Emotion/Mood**
Approach	Energetic Mood
Avoidance	Fear
Being-With	Happiness, Energetic Mood
Attending	Happiness, Energetic Mood
Rejection	–
Indifference	–
Antagonism	Anger, Irritable Mood, Distrust
Interruption	–
Dominance	–
Submission	Sadness𓅞
Apathy	Sadness, Tired, Uninterested
Excitement	Anger𓅞, Energetic Mood, Distrust𓅞
Exuberance	Happiness, Energetic Mood
Passivity	Tired, Uninterested
Inhibition	Fear
Helplessness	Nervousness
Blushing	–
Rest	–

𓅞 *Only somewhat related.*

B.3.2 Lazarus's Cognitive Appraisal (CA)

CA is a system theory focusing on both the transactional nature of emotions and recurrent, stable patterns in the environment and individual that can explain stable emotion patterns (Lazarus, 1991). It relies on the concept of the person-environment relationship—a series of adaptational encounters between the individual and their environment, influenced by the individual's personality. An individual evaluates the person-environment relationship's relevance to themselves with *primary* and *secondary* appraisals to assign personal significance to their knowledge (e.g. goals, beliefs). Their relative importance orders appraisals—if the results of primary appraisal determine the event to be irrelevant, then secondary appraisal has limited, if any, value.

Primary appraisal asks if the current person-environment relationship is: relevant to the individual's well-being, establishing benefits and harms; and if the benefits/harms are a certain, currently observable outcome, or a potential future outcome. It has three components:

- *Goal Relevance* establishes if there are personal goals or stakes affected by the current person-environment relationship,
- *Goal Congruence* is the extent to which an encounter benefits or harms the affected goal, and
- *Type of Ego-involvement* establishes what aspect of the self is affected—self or social esteem, moral values, ego ideals, meanings and ideas, other persons and their well-being, and life goals.

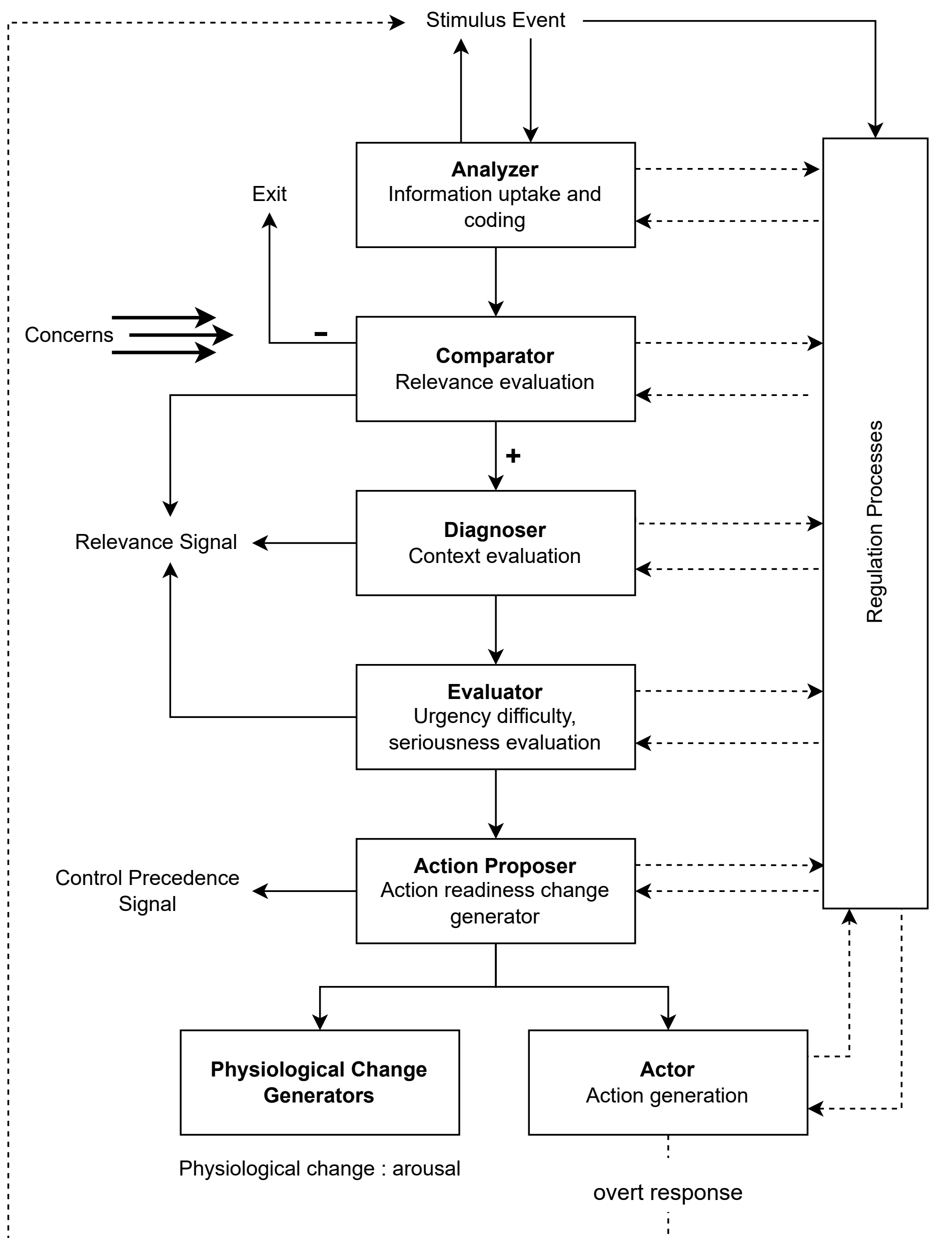


Figure B.4: System View of CR (Adapted from Frijda, 1986, p. 454)

This differentiates similar emotions such as *Joy* (no involvement) and *Affection* (identity).

Secondary appraisal asks what resources and actions are available to the individual for coping with the person-environment relationship, dictating the experienced emotion. Expectations and beliefs about potential actions and the individual's ability to act on them can influence it. It establishes:

- *Accountability*, assigning blame and credit for the person-environment relationship. It requires knowledge of who or what is responsible for the current situation and if they had control over the action that caused it.

- *Coping Potential*, evaluating if and how the individual can manage the current individual-environment relationship's demands or actualized personal commitments. At this point, the individual does not act. How much energy the individual believes they have is likely a factor, as the pursuit of goals must require it.
- *Future Expectations* is the predicted likelihood of psychological change in the future (i.e. a change in goal congruence).

Answers to appraisal questions filter potential emotions in a structure reminiscent of a decision tree, from least to most specific emotion, starting with its *goal congruence*. CA calls a configuration of these variables a *core relational theme*. It uniquely associates each theme with an emotion kind (Table B.4), which is itself partially defined by an action tendency (Lazarus, 1991, p. 59). How the individual interprets these themes depends on their personality and learned meanings.

CA's system view, when taken as a series of time slices, shows how emotions develop and change with an individual's evaluation of their situation (Figure B.5). This view also emphasizes how system variables impact each other, and the integral role of coping—an individual's ability

Table B.4: The Core-Relational Themes of Emotions in CA (Lazarus, 1991, p. 122)

Emotion	**Core Relational Theme**
Anger	Demeaning offence to me and mine
Fright	Imminent physical harm
Anxiety	Uncertain, existential threat
Guilt	Having transgressed a moral imperative
Shame	Failure to live up to an ego-ideal
Sadness	Irrevocable loss
Envy	Wanting what someone else has
Jealousy	Resenting a third party for loss *OR* threat to another's affection
Disgust	Taking in or being too close to an indigestible object or idea (metaphorically)
Happiness/Joy	Making reasonable progress towards our goals
Pride	Enhancement of one's ego-identity by taking credit for a valued object or achievement, either our own or that of someone or group with whom we identify
Love/Affection	Desiring or participating in affection, usually but not necessarily reciprocated
Relief	A distressing goal incongruent condition has changed for the better or gone away
Hope ✍	Fearing the worst but yearning for better
Compassion ✍	Being moved by another's suffering and wanting to help
Aesthetic Emotions ✍	✎

✍ *"Problematic" emotions that have uncertain status as proper emotions in CA.*
✎ *Does not involve new emotions; generated emotion determines core relational theme.*

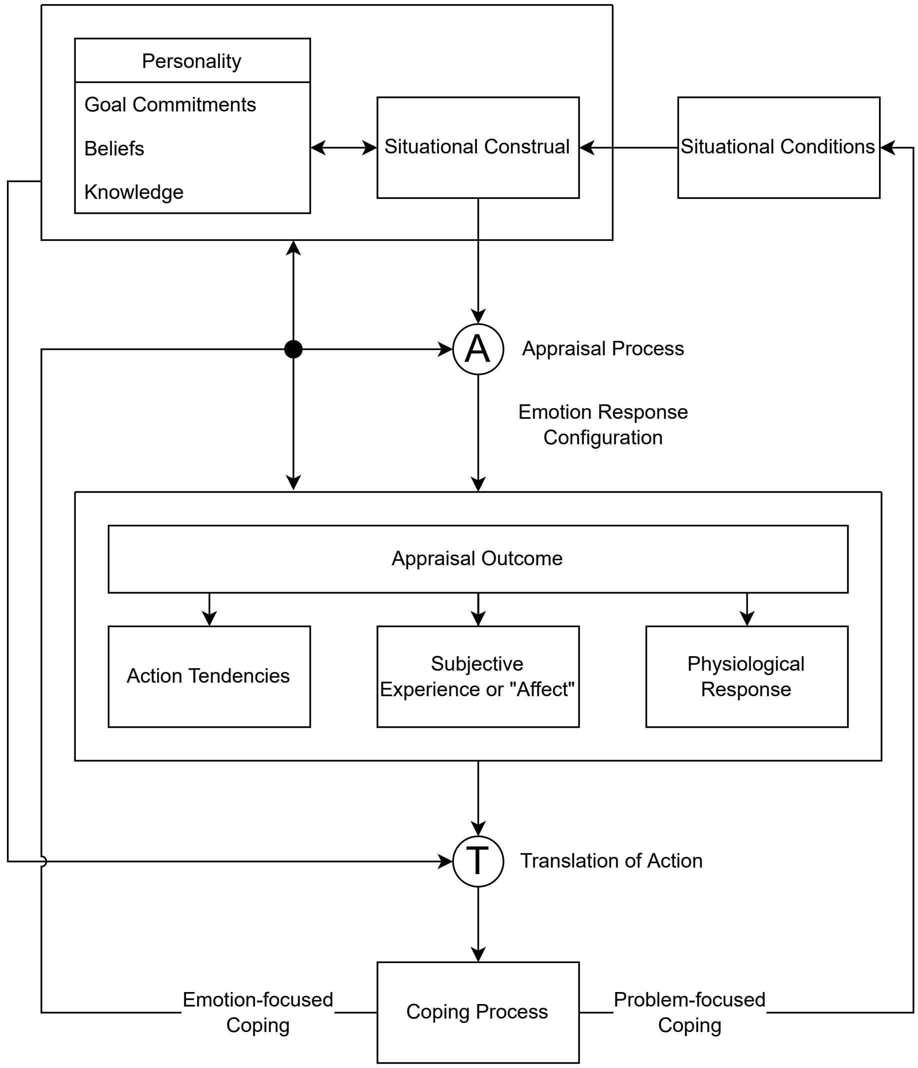


Figure B.5: System View of CA (Smith and Lazarus, 1990, p. 623)

to change their relationship with the environment—in the process. Coping is a more deliberate process than action tendencies (Lazarus, 1991, p. 39, 197) and typically causes a *reappraisal* to consider how it changed the person-environment relationship. In contrast to general appraisals, reappraisals are usually a conscious and deliberate decision.

B.3.3 Scherer's Component Process Model of Emotion (CPE) and Sequential Check Theory of Emotion Differentiation (SCT)

This theory views emotion as a continuous mechanism that developed through evolution to afford flexible adaptation to a changing environment by decoupling stimuli from responses (Scherer, 2001). This creates latency time for optimizing responses that affect subsystems such as the central nervous system. An emotion, then, is an episode of interrelated, synchronized changes across cognition, physiology, motivation, expression, and subjective feelings in response to an evaluation of events that are relevant to the organism.

SCT is a component of CPE, describing how to evaluate events and how they lead to specific emotions. It defines Stimulus Evaluation Checks (SECs) as a minimal set of criteria necessary to differentiate emotion families (Table B.5). SCT organizes SECs, which can be scalar or multidimensional, by appraisal objective:

- *Relevance* to determine if the event impacts the organism and warrants further processing;
- *Implication* to evaluate the extent of the impact on the organism's survival, adaptation, and goal satisfaction;
- *Coping potential* to see what responses are available and the consequences each one will have on the organism; and
- For social species, the *normative significance* of an event is an evaluation of how the organism expects its social group members and its own self-concept to perceive its response.

CPE assumes that a SEC sequence can predict emotions. Proposed SEC sequences for predicting modal emotions ("kinds") include: *Enjoyment/Happiness*, *Elation/Joy*, *Displeasure/Disgust*, *Contempt/Scorn*, *Sadness/Dejection*, *Despair*, *Anxiety/Worry*, *Fear*, *Irritation/Cold Anger*, *Rage/Hot*

Table B.5: CPE/SCT Stimulus Evaluation Checks (SECs)

Appraisal Objective	**Component**	**Evaluations**
Relevance	Novelty	Suddenness, Familiarity, Predictability
	Intrinsic Pleasantness	Feature of the stimulus
	Goal Relevance	Affected Goals
Implication	Causal Attribution	Responsibility Assignment, Motive/Intention Inference
	Outcome Probability	Likelihood/Certainty of Event Outcomes
	Discrepancy from Expectation	Number of features in current situation matching original expectation of it
	Goal/Need Conduciveness	Conduciveness of the event to goal achievement
	Urgency	Event significance to goal, temporal contingencies
Coping Potential	Control	Extent that people or animals can influence the event
	Power	(If Control is possible) Evaluation of resources to change contingencies and outcomes according to individual interests
	Adjustment	Ability to adapt to the outcomes of the event, especially if Control and Power are poor
Normative Significance	Internal Standards	Comparison of an action to internal standards (e.g. self-ideal)
	External Standards	Comparison of action to the social norms, values, and standards of a reference group (e.g. culture)

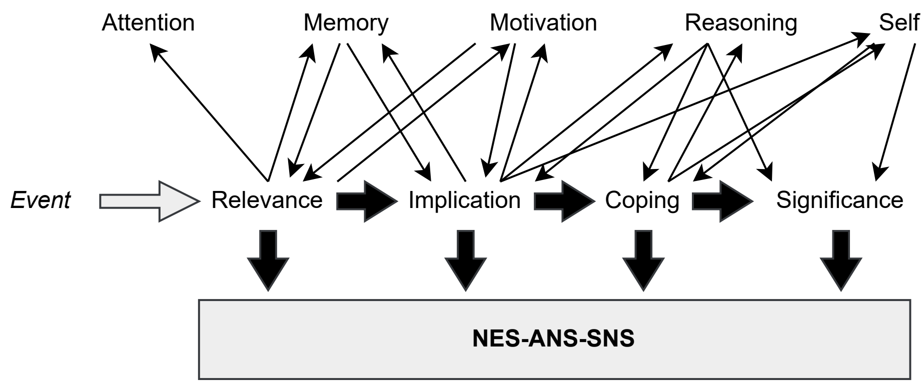


Figure B.6: SCT Appraisal Process (Scherer, 2001, p. 100)

Anger, *Boredom/Indifference*, *Shame*, *Guilt*, and *Pride*.

SCT evaluates SECs sequentially in a fixed order so that they act as conditions for further processing (Figure B.6). For example, evaluating the nature and consequences of an event—its *implications* for an organism—is not worth the processing expense if it does not pass at least one of the *relevance* checks. Due to the continuous nature of detection, events can trigger reappraisal cycles. These cycles update SECs until the monitoring subsystem signals termination or an adjustment to the original stimulating event. CPE can process SECs in parallel, but does not finalize a result until prerequisite SECs are complete. Realizing SECs as registers makes this possible where each SEC stores its own results, holding the best estimate of the current evaluation for reference at any time. The process combines values in SEC registers using weighted functions.

The evaluation speed of different criteria within a SEC can differ because they can involve mechanisms of varying complexity at the sensory-motor, schematic, and conceptual levels. These levels account for the variation of an emotional response over time, representing feature detection and reflexes, learned responses, and deliberate reasoning.

SEC evaluations cause underlying, highly interdependent subsystems to change what they do such that it records a "historical account" of the original stimulus. An outcome profile collects the changes that each SEC makes to its predecessor's changes, creating patterns that can distinguish between emotion types (Scherer, 2001, p. 114–115) and evaluate their intensity.

B.3.4 Roseman's Emotion System Model (ESM)

The ESM states that, given the number of appraisal theories available, moving towards a unified theory requires a consideration of the empirical evidence of emotion appraisals (Roseman et al., 1996). To this end, the ESM continues to undergo incremental revisions as new evidence emerges (Roseman, 2011, p. 436; Roseman, 2018, p. 149). The ESM also proposes mediating answers to debated topics such as the discrete versus dimensional nature of emotions (Roseman, 2011, p. 435; Roseman, 2013, p. 146–148). For example, it proposes that the discrete and dimensional perspectives are complementary and a single system can represent them (Roseman, 2011, p. 441). Appraisal dimensions are thought to be continuous, but their combinations result in categories of coping strategies that are characteristic of discrete emotions (Roseman, 2013, p. 147).

Improving on previous work (Roseman et al., 1996), a study presented subjects with an experience involving either two negative or two non-negative discrete emotions. Evaluators asked subjects to describe the experience, what they felt caused their reaction, and rate the extent to which proposed appraisals from competing appraisal theories caused the emotion. A model of the 17 discrete

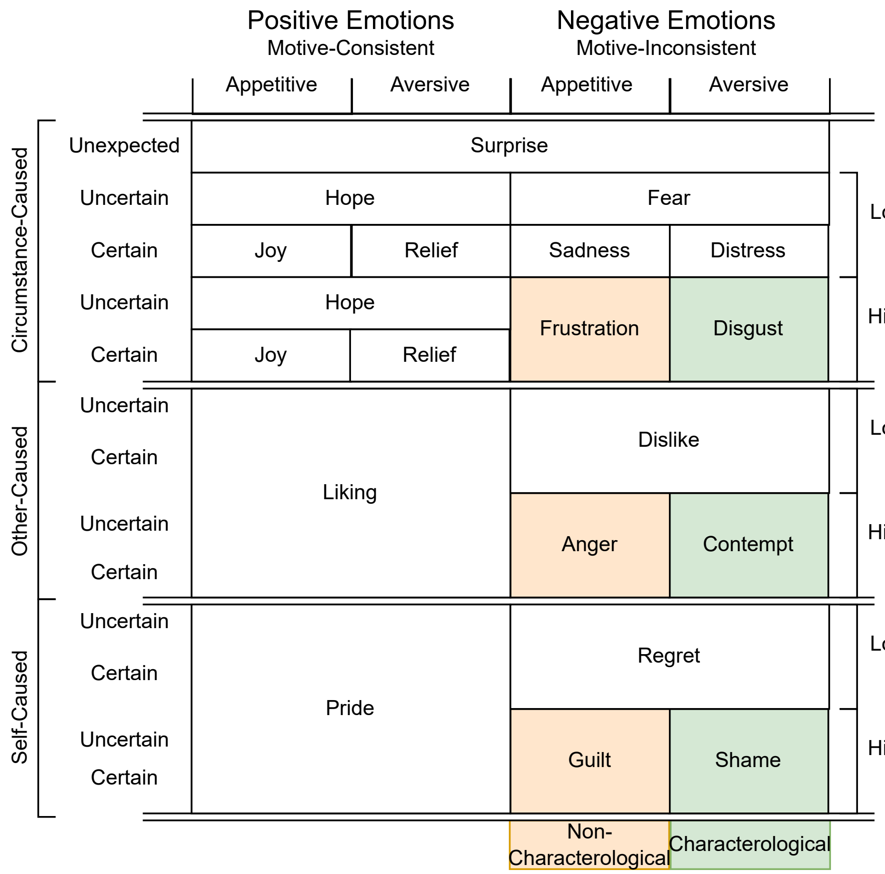


Figure B.7: ESM Structure (Roseman et al., 1996, p. 269; Roseman, 2013, p. 143)

emotions from the study incorporated statistically significant appraisal dimensions (Figure B.7). The dimensions in the revised ESM are:

- *Situational state*, or if the event aligns with the individual's motives (motive-consistent) or not (motive-inconsistent);
- *Motivational state*, describing if the individual sees a potential reward (appetitive) or punishment (aversive) in the event;
- The *unexpectedness* of the situation, exclusively for the appraisal of *Surprise*;
- *Agency*, describing if the situation was circumstantial, caused by others, or caused by the individual (self)[2];
- *Probability*, or the uncertainty of the event's outcome;
- *Control potential*, a combined evaluation of the individual's ability to do something about the situation and their coping potential; and
- The *problem source*, or if the problem is intrinsic to the source of the event (characterological) or not (non-characterological), necessary to distinguish similar negative emotions such as *Anger* and *Contempt*.

[2] Smith and Ellsworth (1985, p. 825) found a similar multi-part representation of *agency*.

B.3.5 The Ortony, Clore, and Collins (OCC) Model

The OCC model focuses on the system of cognitive representations (i.e. value system) underlying emotions (Ortony et al., 2022). It proposes structures for the overall organization and individual structure of emotions, as well as how to evaluate their intensity with respect to personal and interpersonal situation descriptions. These rely on the structure, content, and organization of knowledge and the processes that work on them. An individual's construal of the eliciting conditions determines what kind of emotion the scenario elicits. This accommodates individual and cultural differences without changing the structure or definitions of the emotions themselves.

The OCC model defines emotions as valenced reactions to three types of world aspects associated with knowledge structures:

- *Events* and their consequences for an individual's Goals (i.e. representations of desired world states)
- *Agents*—which contribute to *Events* either instrumentally or by the attribution of agency—whose actions an individual compares to their Standards (i.e. representations of points of reference or criteria, often moral in nature)
- *Objects* and their qualities as they relate to an individual's tastes (i.e. representations of dispositional likes and dislikes)

Each emotion definition is modular, differentiated by their cognitive origins. The OCC model organizes the global emotion structure by types (Figure B.8) recognizable with many linguistic "tokens" such as *Content* and *Elated* for *Joy*. The structure groups emotion types by their structurally-related eliciting conditions. Each group contains two emotion types representing the positive and negative emotions arising from one of three central appraisal variable evaluations: *desirability* and *undesirability* for Events relative to Goals; *praiseworthiness* and *blameworthiness* for Agents relative to Standards; and *appealing* and *unappealing* for Objects relative to Tastes.

The OCC theory also proposes a method for evaluating emotion intensity based on its appraisal variables (Table B.6). The *desirability*, *praiseworthiness*, and *appeal* central variables drive all emotion intensity evaluations, which other global and local variables influence. Each emotion type specification includes a list of such variables impacting its intensity. These variables follow from the emotion type structure which appraisal collects as it progresses through the structure.

Variables have a value and an assigned weight. Appraisal mechanisms produce values from information available to the individual. These do not have to be precise—if a mechanism cannot evaluate a variable, it retains its default value. Default values tend to skew towards the positive ones. A variable's weight is its "degree" of influence over intensity, which can vary between emotion types and members in the same type. Finally, the process compares the raw intensity value (i.e. emotion potential) with an emotion-specific threshold value. Individuals only experience an emotion if its potential exceeds this threshold and the experienced intensity is the difference between them.

The OCC model is clear about its goals and limitations: it focuses on the cognitive structure of the emotion system and its emotion types without relying on language and cultural meanings of emotion words; it does not theorize about the the physiological, behavioural, or expressive components of emotion; it does not propose a way to conceptualize how to appraise or combine variables; it does not associate action tendencies with emotion kinds because OCC hypothesizes that they are not characteristic of all emotions; it is meant to be sufficiently specific for empirical testing; and the design aims to be computationally tractable (Figure B.9).

Other work puts OCC's conception of emotion into a three-layered information processing structure (Figure B.10). Guided by neurophysiological findings, each layer represents different

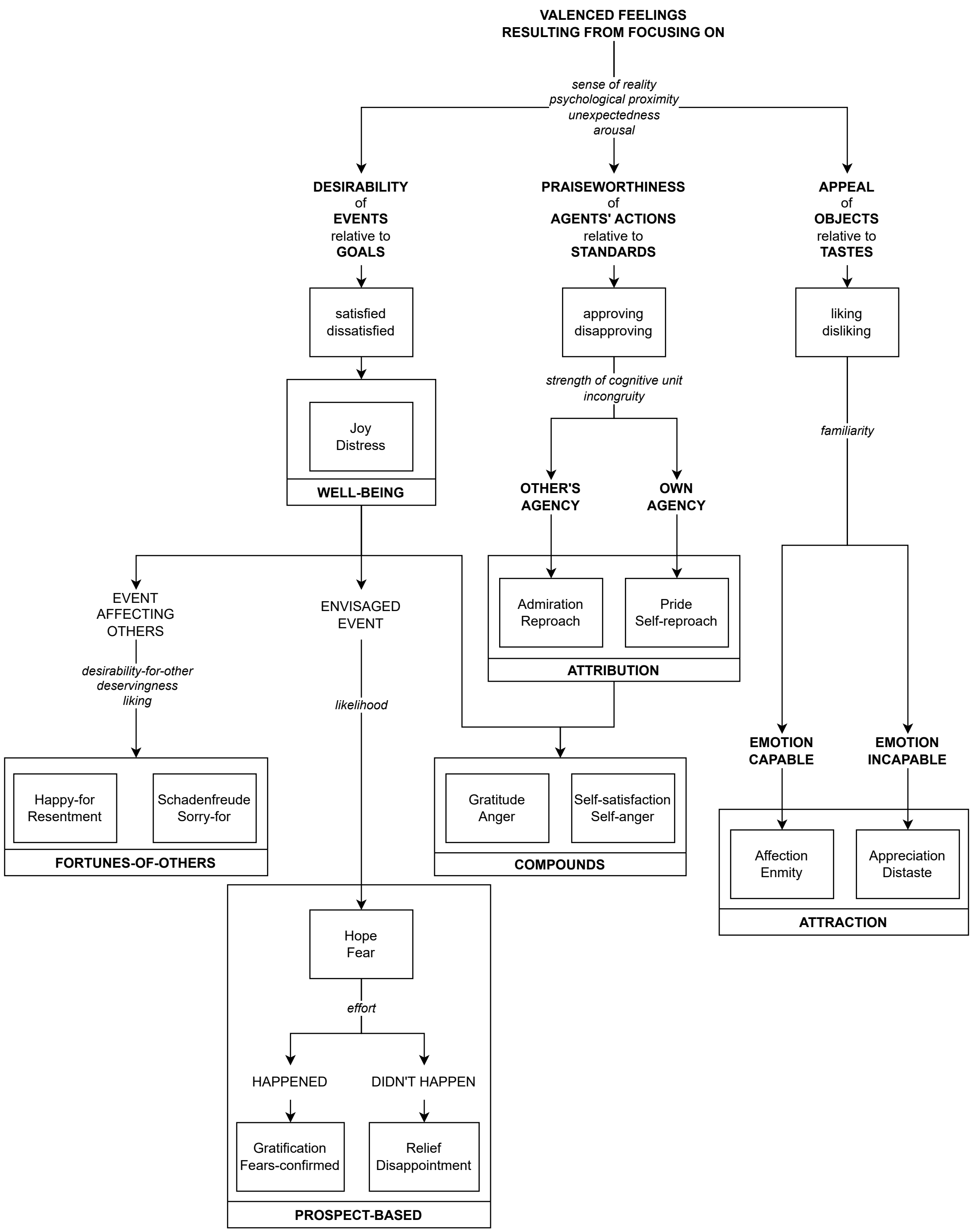


Figure B.8: Global, Logical Structure of Emotion Types in OCC (Appraisal Variables are *italicized*) (Ortony et al., 2022, p. 29, 84)

Table B.6: OCC Appraisal Variables

Location	Variable	Definition
Global	Sense of Reality	How "real" the Event/Agent/Object is to the individual (e.g. probability of success); based on cognitive interpretations of the appraisal target (e.g. imagined scenarios)
	Psychological Proximity	How psychologically "close" the appraisal target is (e.g. spatially, temporally); connected to, but not dependent on, "Sense of Reality"
	Unexpectedness	Degree of mismatch between the appraisal target and what was predicted (i.e. mispredicted or not predicted at all, retrospectively)
	Arousal	A state of enhanced mental activation/excitement; slow to decay; non-emotional effects can impact and carry the value forward; must be attributed to the appraisal target or previous reactions to the same situation
Events	Desirability ✍ / Undesirability ✍	Evaluated on Goals; the total values of Goals that achieving this currently impacted Goal helps (desirability) and hinders (undesireability)
	Desirability-for-Others	An evaluation of the presumed desirability of an Event with respect to another individual's Goal(s)
	(Dispositional) Liking	The degree to which this individual likes another individual
	Deservingness	The degree of belief that the outcome of an Event is fair to another individual
	Likelihood	Perceived chances of an Event's outcome (prospectively); comparative and qualitative, not constant over time
	Effort	The investment an individual has made towards an Event's desirable outcome; includes mental, physical, and materialistic investments
Agents	Praiseworthiness ✍ / Blameworthiness ✍	Evaluated on Standards; the degree to which an Agent appears to uphold (praiseworthiness) and violate (blameworthiness) a Standard with their action(s)
	Strength of Cognitive Unit	The degree that this individual associates with the Agent; accommodates cases where the individual experiencing the emotion is not the target Agent, but is affiliated with them
	Incongruity	The degree that an Agent deviates from what the individual expects from them; can be a mismatch between the Agent's social role and their actions
Objects	Appealing ✍ / Unappealing ✍	Evaluated on Tastes; the individual's disposition towards liking (appealing) and disliking (unappealing) something; does not require an evaluation of significance
	Familiarity	The level of exposure the individual has experienced with the target Object

✍ Central Variable

"Joy" emotions
Type Specification: (a positive feeling about) **a desirable event**
Tokens: cheerful, contented, delighted, ecstatic, elated, euphoric, glad, gleeful, happy, joyful, jubilant, overjoyed, pleasantly surprised, pleased, thrilled, etc.
Variables Affecting Intensity
(1) Central
(i) the degree to which the event is desirable
(2) Local
None
Example: The team was elated after winning the game.

(a) Description

`IF DESIRE(`*p*`,` *e*`,` *t*`) > 0 THEN` ***set***
`JOY-POTENTIAL(`*p*`,` *e*`,` *t*`) =` f_{joy} `[ |DESIRE(` *p*`,` *e*`,` *t* `)|,` I_{global}`(`*p*`,` *e*`,` *t*`) ]`

where `|DESIRE(` *p*`,` *e*`,` *t* `)|` is the absolute value of a function that returns the degree of desirability that a person, ***p***, assigns to some construed event, ***e***, at time ***t***, and where I_{global}`(`*p*`,` *e*`,` *t*`)` represents the combined effects of any operative global intensity variables.

(b) Computational Rule

Figure B.9: Example of OCC *Joy* (Ortony et al., 2022, p. 102, 220)

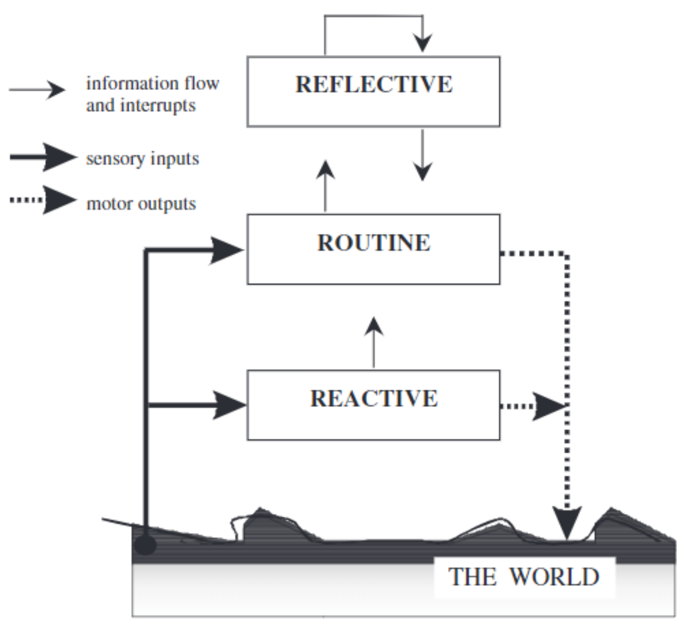


Figure B.10: Schematic of OCC Processing Levels and their Main Interactions (Ortony et al., 2005, p. 175) process types that get progressively more complex as one moves through them (Ortony et al., 2005):

- At the reactive level, the system assigns value to a stimuli—called "proto-affect"—which has multiple potential meanings. It represents simple environmental interpretations that have hard-wired responses. The routine level encompasses automatic, learned responses and cognitive processes that do not need to be consciously controlled.
- The routine level has enough information to identify four "primitive" emotion states: *Happiness/Joy*, *Distress*, *Excitement*, and *Fear*. They can exist separately from cognition, so they are not yet "full" emotions.
- "Full" emotions are only possible at the reflective level, where complex reasoning, representation, and planning processes live. This allows it to interpret "proto-affect" and "primitive" emotion states from the lower levels and generate a discrete emotion label. This means that organisms cannot experience emotion without conscious reflection.

B.3.6 Smith & Kirby

This theory's goal is to improve the validity of appraisal theories through theoretical and empirical efforts (Smith and Kirby, 2001, 2000b; Smith and Ellsworth, 1985). Smith & Kirby focus on answering if and to what degree the appraisal construct can explain the antecedents and organization of physiological activity in emotion. They constructed the model using a functionalist perspective and take Lazarus as a starting point[3], "...recast[ing] the theory in more computational terms" (Gratch and Marsella, 2015, p. 58). The theory describes appraisal in two distinct, but complementary, ways:

- *Dimensional appraisal components*—which closely correspond with appraisal dimensions—representing questions that an individual evaluates, and
- *Categorical relational themes*[4] representing significant answers to appraisal components and associated with distinct emotion kinds.

Smith & Kirby put significant effort into matching the functions an emotion serve with a theme and appraisal component pattern. They identify seven appraisal components:

1. *Motivational relevance*: How important is the situation to the individual?
2. *Motivational congruence*: To what extent is the situation consistent or inconsistent with the individual's current goals?
3. *Problem-focused coping potential*: To what extent can the individual act on the situation to increase or maintain its desirability?
4. *Emotion-focused coping potential*: To what extent can the individual psychologically adjust to the situation if it does not go favourably?
5. *Self-accountability*: To what degree is the individual responsible for the situation?

[3]Specifically the work of Smith and Lazarus (1990).

[4]Although they have the same origin, these themes are *different* from Lazarus's core relational themes (Smith and Kirby, 2001, p. 138). The themes proposed by Smith & Kirby are both more limited in scope and tightly linked.

6. *Other-accountability*: To what degree is someone or something else responsible for the situation?

7. *Future expectancy*: For any reason, how much does the individual expect the situation to become more or less desirable?

Smith & Kirby assume that appraisals are relational, representing a stimulus evaluation relative to an individual's needs, goals, beliefs, and values. This allows appraisal to address the adaptivity of emotion and individual, temporal, and contextual differences. They partially explored the relational nature of emotions by creating test-specific relational antecedent models for the *motivational relevance* and *problem-focused coping potential* appraisal components. Smith & Kirby made similar efforts to empirically link physiological activity with individual appraisal components. Separate studies found appraisal patterns for *Affection*, *Amusement*, *Anger*, *Anxiety*, *Awe*, *Compassion*, *Determination*, *Disgust*, *Embarrassment*, *Fear*, *Gratitude*, *Guilt*, *Hope*, *Interest*, *Joy*, *Pride*, *Relief*, *Sadness*, *Shame*, and *Tranquility* (Yih et al., 2016a; Yih et al., 2020, p. 489). These studies also identified the appraisal dimensions of *acceptability*, *goal attainment*, *vastness*, *involvement of others*, *involvement of unknown*, *likeability*, *negative evaluation by others*, *positive evaluation by others*, and *urgency*.

Appraisal theory critics believe that the process is too slow and deliberate to account for the quick, automatic, and unconscious nature of emotion. To address this, Smith & Kirby propose a process model with multiple, parallel appraisal processes that use distinct cognitive mechanisms (Figure B.11). This model represents a process that produces information rich signals—emotions—while limiting attentional resource use (Smith and Kirby, 2000a, p. 91).

Smith & Kirby link quick, reactive cognition to associative processing, including priming and memory activation (Smith and Kirby, 2001). This happens automatically and continuously such

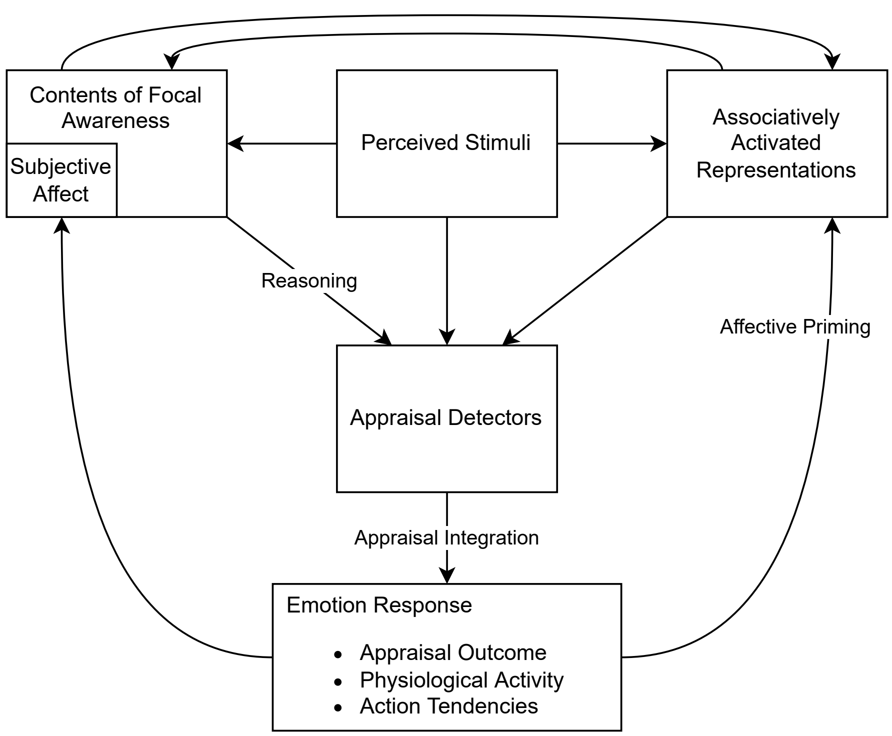


Figure B.11: Appraisal Process Model Sketch (Smith and Kirby, 2001, p. 130) that an individual is always monitoring the environment with minimal attentional cost. The theory ties deliberative cognition to reasoning, which is more controlled, deliberate, and flexible. Associative processing can use any type of information but reasoning can only access semantically-encoded information. A third appraisal source is inherent to stimuli, which might carry appraisal meanings an individual can detect directly.

Appraisal detectors gather information from each appraisal process by continuously monitoring and responding to incoming appraisal information. The detectors combine and feed the information into appraisal evaluation whose outcome initiates other processes that generate emotional response components. This includes physiological activity, subjective feelings, and action tendencies. The resulting emotion also influences associative processing and deliberative cognition (Smith and Kirby, 2000a, p. 96).

B.3.7 Oatley & Johnson-Laird's Communicative Theory of Emotions (CTE)

CTE's aim is to be a formally testable emotion system representation for simulation and other computationally-based theories of language and perception (Oatley and Johnson-Laird, 1987; Johnson-Laird and Oatley, 1992; Oatley, 1992). CTE proposes that emotions are functional, preparing an individual for action and helping them construct plans and new parts of their mental models and cognitive system. Emotions are central to cognitive processing, coordinating multiple goals, plans, and agents under time, knowledge, and resource constraints while operating in uncertain environments and imperfect rationality. A key assumption is that the cognitive system is modular and asynchronous. A top level module holds a model of the whole system and can reorganize:

- *Goals*, symbolic representations of the environment, and
- *Plans*, transformations from environment representations to goals that the system can act on.

Each goal and plan has its own monitoring mechanism evaluating success probabilities (Oatley, 1992, p. 50–51, 54, 62–63, 101–102). This decoupling of concerns affords the ability to satisfy multiple goals in an unpredictable environment. CTE proposes a schema-driven emotion generation process that follows a set of steps:

1. One or more cognitive modules—acting as monitors—evaluate an event to determine if there is a change in the probability of achieving an active or latent goal (usually at plan junctions)
2. If the modules detect a change, they emit a distinctive emotion control signal or "alarm"[5] that sets up an emotion "mode",
3. The emotion "mode" becomes input to other cognitive modules and "colours" the resulting emotional state. This allows for rapid module calls to create a unified response and maintain focus on the affected goal or plan. Semantic signals typically influence these states, generated parallel to the control signal. They carry information about the cause of the change and/or plan components if it is available.
4. The emotion state brings the affected goal or plan into focus, shifting cognitive resources to the current situation and the possibility of doing something about it, reminiscent of problem and emotion-focused coping. This can create additional semantic information and change the type of emotion experienced

[5]Emotions lack symbolic representations.

CTE treats emotions as products of both nature and nurture—biological and involuntary events whose interpretation changes with culture and social rules (Oatley, 1992, p. 216). Instinctual actions, which act at recurring plan junctions, are default plans that evolution has hard-wired. With the evolution of cognition, the system built additional processes on these existing structures to bridge the gap between fallible, time-consuming reasoning processes and fixed action patterns.

CTE considers an emotion to be "universal" if it has some biological basis that is recognizable across languages and cultures (Oatley, 1992, p. 113–115, 119). It emphasizes that the labels assigned to the basic emotions only represent the closest descriptor in the English language—different terms might be more appropriate in other languages. CTE identifies five basic emotion "modes" that can be elicited unconsciously and by instinct—*Happiness*, *Sadness*, *Fear*, *Anger*, and *Disgust* (see Table 9.1 in Chapter 9.4.1)—heavily influenced by the work of Ekman & Friesen (Oatley, 1992, p. 55, 91, 103, 212; Johnson-Laird and Oatley, 1992, p. 209, 217)[6]. "Modes" are heuristic in nature to afford flexible responses to an unpredictable environment (Oatley, 2000, p. 87). These responses are effectively the opening phases of new plans (Oatley, 1992, p. 75). CTE hypothesizes that moods and personality are directly related to emotion—moods are either temporary dispositions or self-sustaining low intensity emotion "modes" that are divorced from their initial cause, and personality traits are enduring predispositions to "modes".

CTE emphasizes the social role of emotions, which become important as early as infancy. Emotion signals like facial expressions and vocal tone relay information to the social group to coordinate their behaviour when accompanied by semantic information understood by all parties (Oatley, 1992, p. 66, 212). CTE argues that many human actions are joint ventures to take advantage of collective resources, the distribution of cognitive labour and agency, and the ability to criticize assumptions and biases. This requires cognition and a model of the self, developed by culture and language (Oatley, 1992, p. 195). CTE also describes the concept of a group plan—a mutual plan with others whose implicit parameters vary with culture and between individuals (Oatley, 1992, p. 178–179, 192, 196, 204–205, 212). This augmentation of individual plans can account for interpersonal emotions and those based on evaluations of the self and the self-in-relation-to-others. The semantic content afforded by social interactions varies by cultural and social context, changing interpretations of emotion "modes".

CTE suggests that emotion descriptions can exist in ways recognizable in everyday language (Oatley, 1992, p. 74–75, 125, 414–417). This is just as important as empirical data and scientific inference because an understanding of emotion is also based in life experiences and interpretations of them by both actors and observers. CTE argues that part of emotional development is the ability to simulate mental states and imagine the emotions of others (Oatley, 1992, p. 122). This is also crucial for understanding and enjoying stories. CTE proposes that narrative literature is a good source for collecting information about emotion because, by viewing a story plot as a plan, it can combine the experience of an emotion with an understanding of it (Oatley, 1992, p. 6–7, 127, 220). CTE uses notable pieces of literature such as Tolstoy's *Anna Karenina* as case studies of emotion episodes.

B.4 Neurophysiologic Theories

Biological neural circuitry and brain structures inspire the *neurophysiologic* theories of affect, which offer a grounded view of potential organizations of emotion systems and their connection

[6] Johnson-Laird and Oatley (1992, p. 209) list *Desire/Interest* as a primary emotion. However, they need more evidence to confirm its status (Oatley, 1992, p. 61). Other emotions in the same situation are *Surprise*, *Disgust*, *Hatred*, and *Contempt*

to the body (Lisetti and Hudlicka, 2015, p. 98–99). Though uncommon in Affective Computing (Rodríguez and Ramos, 2015, p. 451) and fundamentally different from psychologically-based theories (Hudlicka, 2014b, p. 7), they often influence biologically-inspired CMEs.

B.4.1 Sloman

This theory frames emotion as a consequence of intelligence rather than a separate subsystem (Sloman, 1987; Sloman et al., 2005). Emotions—whose type depend on the underlying architecture and the host's needs—are states of powerful motivations that respond to relevant beliefs, triggering mechanisms in a system with limited resources. In this view, emotion serves a functional purpose and is inseparable from cognition, but it is possible to suppress or override affective states. This also means that searching for discrete emotions is not as productive as finding a set of core processes that create different affective states. Interestingly, Sloman does not believe that physiological changes are necessary to define emotion.

Goals are essential to Sloman's theory, representing motivations. Their ability to interrupt other processes is directly proportional to their urgency, whose intensity determines how aggressively the system pursues it. Planning generates new goals in service to a higher level one, possibly under constraints. Unlike the parent goal, a system can easily replace or abandon these goals if it cannot satisfy them. This tightly links planning to emotion, leading to the claim that no taxonomy of emotion terms can sufficiently capture all the potential behaviours of such a system.

Sloman also differentiates between different types of affect: moods are dispositions of the system without a clear focus; attitudes are a collection of beliefs, motivations, and mechanisms focused on one thing expressed as tendencies to certain actions in a particular situation; and personality is a collection of long-term attitudes.

Sloman's theory is computationally-friendly, describing itself as a computational theory of mind, harmonious with the concepts of "beliefs", "intentions", and "desires" in a Belief-Desire-Intention (BDI) system. Beliefs have the same structure as goals. Sloman lists design constraints that are consistent with computational ones, including: multiple, often inconsistent, internal and external motivations; speed limitations; missing and erroneous beliefs about the environment; and motivations with different degrees of urgency. This necessitates a fast and "stupid" system to react to immediate changes, a specialized central decision-making mechanism, a meta-management process, and the ability to learn new information.

B.4.2 Damasio

This theory posits that "emotion" is a product of body state changes that trigger neural activity causing dispositional responses that affect the body and mind (Damasio, 1995). It hypothesizes that there are two types of emotion—primary and secondary—that share expression channels but serve different purposes:

- Primary emotions are innate, powerful manifestations of drives and instincts relevant to survival, and
- Secondary emotions build on these regulation structures by incorporating social, cultural, and environmental influences via learning. They are the product of systematic connections between object and situation categories and primary emotions.

Secondary emotions begin with cognition, which create signals that the brain unconsciously picks up, triggering the primary emotion system and causing the associated changes. The signals are a product of the association between emotion and experience. Some emotion-causing cognitive evaluations can bypass the body via symbolic states. These are another product of learning and can aid decision-making.

"Feelings" are cognitive evaluations of body state changes—a monitor—that juxtapose those changes with some other mental image. Feeling can be present in the absence of emotion, in a way similar, but not equivalent, to mood. This led to the creation of the Somatic Marker Hypothesis (SMH). Somatic markers are a special instance of feeling generated by secondary emotions causally linked to its trigger. Learning connects them in service of predictive functions, which can account for individual differences. Somatic markers act as a biasing device, raising alarms or indicating incentives for decision-making. They depend on attention and memory, driven by biological regulation processes, "tagging" information with bodily states. Damasio hypothesizes that intuition (i.e. "gut feelings") is the work of unconscious somatic states. In the full SMH, somatic states can also boost attention and memory, energizing the cognitive system, a consequence of knowing that something is being evaluated for an individual's preferences and goals.

B.4.3 LeDoux

This theory views emotions as biological functions with different neural systems that evolution has maintained across species (LeDoux, 1998). It refers to what one would call an emotion as the subjective feeling of it, which requires the conscious brain's awareness of unconscious processes to realize. This requires working memory, the amygdala and arousal systems to be active, and bodily feedback. LeDoux's research focuses on the defensive behaviour system, which is consciously recognized as *Fear*.

At the neural level, each emotion system has a set of inputs and outputs and an appraisal mechanism. The system programs the mechanism to detect innate stimuli relevant to its function, but it can also learn about other stimuli that it tends to associate with, or predict the occurrence of, innate ones. This ability afforded by cognition allows the systems to learn new triggers while retaining the same behaviour as innate ones. These systems bypass cognition, improving their speed, but cannot distinguish similar stimuli. This results in "quick and dirty" responses that could be correct and life-saving, drawing attention to and buying time for cognition to form plans about those stimuli. A separate type of memory associates stimuli with others present at the time the system learned the trigger, which can elicit a response even if the core trigger is missing. The ability to unconsciously and quickly perceive and form persistent emotional memories is one of the brain's most efficient learning and memory functions (LeDoux, 1998, p. 266).

B.5 A Brief Analysis of the Theories by Perspective

While each perspective has its strengths and weaknesses, the theories within them differ in their approach towards the perspective's goals. This implies that different theories from the same perspective might be better or worse suited to an application than the others. A brief analysis and comparison of the theories in each perspective highlights some of these differences and proposes the type of CME that might benefit from them.

B.5.1 Discrete Theories

Ekman & Friesen (Section B.1.1), DET (Section B.1.2), and PES (Section B.1.3) generally agree on six primary emotions: a variant of *Joy*, *Sadness*, *Fear*, *Anger*, *Surprise*, and *Disgust*. What other emotions a theory considers primary depends on its focus.

Ekman & Friesen's theory focuses on facial expressions. The associated set of primary emotions reflect seven "universal" facial expressions found in all humans, which they tested in a number of cultures (Ekman, 2007, p. 1). The theory also defines display rules that inform expression mechanisms. However, Ekman said that the presence of a unique facial expression is not enough to identify all emotions because some emotions might lack one (Ekman, 1999, p. 48)[7]. Izard connects emotions to personality development and includes additional emotion categories thought to correlate with personality traits (Izard et al., 1993, p. 850). Due to this, a significant portion of DET's validation is from data collected from infants and young children. Izard also forwards the idea that facial expressions unique to an emotion. He mostly agrees with Ekman & Friesen's findings, but adds some additional facial expressions (Izard, 1971, p. 236–237). PES focuses on "universal" adaptation problems, expanding the list of emotion kinds with additional behaviours. Plutchik developed the theory's structure as a Circumplex and organizes emotion kinds on it based on how people evaluated the similarity and dissimilarity of affective terms (Plutchik, 1997, p. 24). Like Izard, Plutchik also connected emotion with personality traits (Plutchik, 1997, p. 27). There is also a shared concept of interacting emotions: Ekman describes "blends" of facial expressions (Ekman, 2007, p. 69); Izard suggests interacting emotion patterns connected to personality (Izard and Ackerman, 2000, p. 254); and Plutchik proposes that complex emotions are combinations of primary ones in the same vein as colour mixing (Plutchik, 1984, p. 204–205).

For applications where emotion expression is critical, Ekman & Friesen's theory of facial expressions is the strongest candidate. CMEs can use it alone, or extend it with the facial expressions from DET. Ekman & Friesen's display rules have potential for defining mechanisms to control when and how to express an emotion. If personality is a focus, DET is likely the best choice because it proposes ways that personality develops from ongoing emotional experiences. As a behaviour-oriented theory, PES seems to be a good general choice for modelling emotion. It focuses on classes of behaviours, which can connect to facial expressions and other tendencies associated with an emotion. There is also potential to develop a personality model due to the connection between its emotion and personality circumplexes. Perhaps most useful is the ability to create complex emotions by blending the given primary ones. While both Ekman & Friesen's theory and DET appear to have a fixed set of defined emotions, PES affords the inclusion of additional emotions that a user might need including those from other discrete theories and ones that it does not consider to be primary.

B.5.2 Dimensional Theories

There is a clear increase in complexity between V-A (Section B.2.1) and PAD Space (Section B.2.2). The V-A structure is general, describing affective space with two bipolar dimensions. Given that the surveyed CMEs (Chapter 5) tend to use the Valence and Arousal as independent dimensions (André et al., 2000, p. 162; Breazeal, 2003, p. 133–134; Hudlicka, 2019, p. 136), there is little to analyze. Therefore, the analysis uses the Russell Circumplex (Russell, 1980) to compare V-A and PAD space. The Russell Circumplex is a reasonable stand-in for V-A because the space represented by the dimensions tend to fit a Circumplex structure better than a simple structure (Barrett and Russell, 1999, p. 12) and it emerges across several European and Asian languages (Yik et al., 2002, p. 82, 90). There is also evidence that several Circumplex representations of affect might be variations on the same space (Yik et al., 1999, p. 615–617; Yik et al., 2002, p. 80–82).

The Russell Circumplex describes a two-dimensional Circumplex using *Valence* and *Arousal*. Researchers validated this structure with empirical data gathered from laymen's self-reports and

[7] There is also evidence that a person's visual and social perception influences how they evaluate facial expressions (Brooks and Freeman, 2019, p. 42).

judgment tasks on affective terms (Russell, 1980, p. 1174–1176). The resulting Circumplex can account for a significant portion of the data variance. Including a *dominance-submission* dimension is one hypothesis to explain the remaining variance, which accounts for a small, but significant, portion of it. PAD Space adds this third dimension to the affective space to differentiate data clusters like *Fear* and *Anger* (Mehrabian, 1996b, p. 264). Mehrabian validated the PAD dimensions with self-report data (Mehrabian, 1980, p. 21–24). Independent studies found comparable dimensions (Elefant-Yanni et al., 2005, p. 30–32; Li et al., 2005, p. 517) and links to other psychological theories (Bakker et al., 2014, p. 12–13). PAD Space can also define personality traits (Mehrabian, 1996b, p. 266–267).

PAD Space seems to be well-suited for CMEs because its computations are simple, yet better explains data variance than V-A. It captures and expands the information in both V-A and the Russell Circumplex. The addition of a third dimension, *dominance*, distinguishes affective states that many would consider emotions, such as *Fear* and *Anger*. It also has the potential to expand a CME's capabilities with personality traits using its common space. If a CME is modelling general affect or needs a very simple model, V-A or the Russell Circumplex is likely the best choice. They have equivalent dimensions, but the Russell Circumplex is better defined and validated than the general V-A dimensions.

B.5.3 Appraisal Theories

The appraisal theories tend to follow the same process steps, modifying or expanding them according to their focus and goals (Figure B.12[8]). The description and form of the steps vary between theories based on the affective phenomena that they want to explain. The final outcome of this process can impact the person-environment relationship due to the closed-loop nature of the system.

[8]This work focuses on CME components, but appear to work just as well for decomposing the theories themselves.

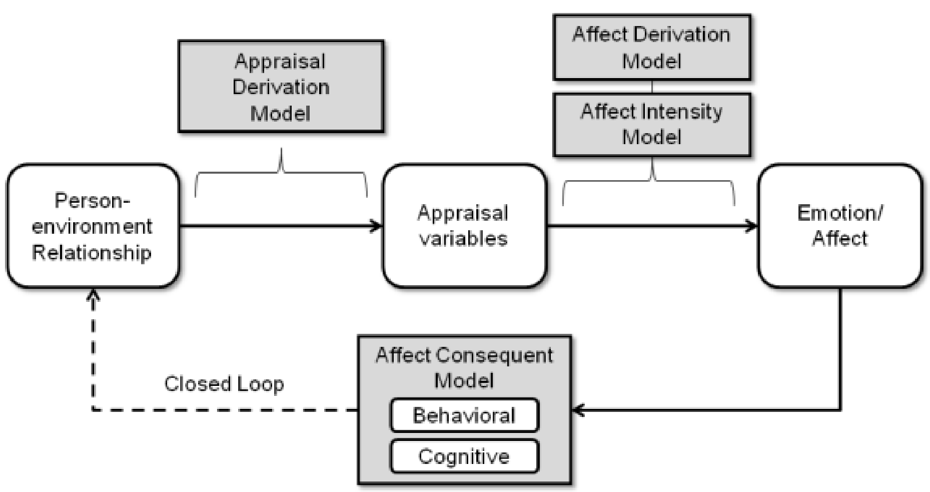


Figure B.12: Idealized Component Model of Computational Appraisal Models (Marsella et al., 2010, p. 31)

Appraisal Derivation Model

The appraisal derivation model translates an individual-environment relationship representation into appraisal variables[9] or dimensions (Marsella et al., 2010, p. 32). There are many commonalities in the theories' appraisal dimensions (Table B.7).

The presence of some variation of a *goal congruence* appraisal dimension[10] implies that all examined theories operate on an individual's goals or motivations (Frijda, 1987, p. 116; Smith and Kirby, 2000a, p. 87). CR proposes that goals and motivations[11] are intimately linked to the emotion system (Frijda, 1986, p. 467). CA echoes this, including an individual's goal hierarchy in their personality (Lazarus, 1991, p. 94), as well as OCC whose goal hierarchy is critically linked to some appraisal mechanisms (Ortony et al., 2022, p. 59–60). A *goal relevance* dimension acts as a gatekeeper to the appraisal process. It could perform a similar function in CMEs to prevent resource use when environmental changes do not affect the agent. A relevance dimensions is not present in OCC and ESM, but one could easily add it due to their reliance on goals. CTE lacks *goal relevance* and *goal congruence*. However, it does tie changes in goal achievement probability to the emotion's quality (Oatley, 1992, p. 49–50, 98) which could implicitly define these dimensions. This conception also decouples Valence from the "pleasantness" label, making it possible to talk about events like watching horror films for fun. Instead, Valence simply indicates if the system should continue the current plan or change it.

A *responsibility* dimension is also present in all the examined theories (Frijda, 1987, p. 116; Smith and Kirby, 2000a, p. 87), although it is implicit and non-critical[12] in CTE (Oatley, 1992, p. 62). This suggests that there is a mechanism for assigning causality to person-environment relationship changes. Some variant of a *controllability* or *coping* dimension is also common, enforcing the transactional nature of emotions and an individual's ability to act on appraisal inputs and processes. CTE appears to have a comparable dimension implicitly because it describes what should happen in response to changes in plan junctures (Oatley, 1992, p. 55, 102). The ways that an individual can respond can be construed as a measure of their coping potential. This dimension is not present at all in OCC, possibly because it is for reasoning about emotions instead of generating them (Ortony et al., 2022, p. 219).

Some variation of a *certainty* and/or *uncertainty* dimension appears in most of the examined theories (Frijda, 1987, p. 116). CTE appears to incorporate a version of this dimension based on its evaluation of changes in goal and/or plan outcomes (Oatley, 1992, p. 48, 98). CA and Smith & Kirby lack this dimension, instead defining a *future expectancy* dimension. One could view this as a specialized certainty evaluation focusing on changes in *goal congruence*. This implies a mechanism for predicting future events or the outcomes of a proposed action.

Less common is a *self-esteem* related dimension, also implicit but non-critical[13] in CTE (Oatley, 1992, p. 44–45, 114), demonstrating the role of self-perception in emotion processes. Evaluating this dimension requires a mechanism for reasoning about the self and what the person-environment relationship means for it. ESM lacks a *self-esteem* dimension, which the associated study appears to omit (Roseman et al., 1996, p. 275–277), and neither does the OCC model—potentially due to its focus on reasoning and understanding emotions. The remaining dimensions only appear in half of the examined appraisal theories. The focus of each theory accounts for this wider variation and a CME will need additional mechanisms depending on the dimensions it models.

[9] They could also be viewed as features for feature analysis where *emotion* is the object to be recognized (Oatley, 1992, p. 101).

[10] With the exception of CTE, which lacks explicitly defined appraisal dimensions.

[11] Frijda collectively calls them *Concerns*.

[12] This would require semantic content, which is not necessary for triggering an emotion signal (Oatley, 1992, p. 76).

[13] See footnote 12.

Table B.7: Approximately Comparable Appraisal Dimensions Across Appraisal Theories[icon]

CR (Frijda, 1987)	**CA** (Lazarus, 1991)	**CPE/SCT** (Scherer, 2001)	**ESM** (Roseman et al., 1996)	**OCC** (Ortony et al., 2022)	**S & K**[icon] (Yih et al., 2016a, 2020)	**CTE**[icon] (Oatley, 1992)
Relevance	Goal Congruence	Relevance	Motivational State	Desirability, Desirability-for-Others	Motivational Congruence/Incongruence	[icon]
Responsibility	Accountability	Causal Attribution	Agency	Praiseworthiness/ Blameworthiness	Self/Other Accountability	[icon] [icon]
[icon]	Goal Relevance	[icon]	[icon]	[icon]	Motivational Relevance	[icon]
Controllability + Modifiability + Manageability	Coping Potential	Control + Power + Adjustment	Control Potential	–	Problem-focused/Emotion-focused Coping Potential	[icon]
Uncertainty of Outcome	–	Outcome Probability	Probability	[icon]	–	[icon]
Certainty of Outcome	–	Expectation	[icon]	Likelihood	–	[icon]
Self-Esteem	Type of Ego-Involvement	Internal Standards	–	–	Acceptability	[icon] [icon]
Event Impact	–	Urgency	–	–	Urgency	–
Interestingness	–	Novelty	–	–	Vastness	–
Globality + Time Reference	–	–	Situational State	Psychological Proximity	–	–
Valence	–	Intrinsic Pleasantness	–	Appealing/ Unappealing	–	–
–	–	Suddenness[icon]	Unexpectedness	Unexpectedness	–	–
–	–	External Standards	–	–	Positive/Negative Evaluation by Others	[icon] [icon] (p. 114)
–	Future Expectancy	–	–	–	Future Expectancy	–

Continued on next page

Table B.7: Approximately Comparable Emotion Kinds Across Appraisal Theories✎ (*Cont'd*)

CR (Frijda, 1987)	CA (Lazarus, 1991)	CPE/SCT (Scherer, 2001)	ESM (Roseman et al., 1996)	OCC (Ortony et al., 2022)	S & K✉ (Yih et al., 2016a, 2020)	CTE☽ (Oatley, 1992)
—	—	Discrepancy from Expectation	—	Incongruity	—	—
—	—	Familiarity♃	—	Familiarity	—	—
—	—	—	—	Liking	Likeability	—
Accessibility	—	Goal/Need Conduciveness	—	—	—	—
—	—	Predictability♃	—	—	—	—
—	—	—	Problem Source	—	—	—
—	—	—	—	Sense of Reality	—	—
—	—	—	—	Arousal	—	—
—	—	—	—	Deservingness	—	—
—	—	—	—	Effort	—	—
—	—	—	—	Strength of Cognitive Unit	—	—
—	—	—	—	—	Goal Attainment	—
—	—	—	—	—	Involvement of Others	—
—	—	—	—	—	Involvement of Unknown	—

✎ *Inferred from definitions given by each theory and guided by Frijda (1987, p. 128–131) and Gratch and Marsella (2015, p. 56)*
✉ *Smith & Kirby*
☽ *Due to the nature of CTE, all dimensions are implied/inferred from descriptions*
♅ *Implied/inferred dimension*
✈ *Non-critical dimension because it requires semantic content which is not needed for emotion signals (Oatley, 1992, p. 76)*
♃ *Component of Novelty*
(+) *Combined effect*

While the theories are somewhat clear on *what* the appraisal derivation model produces, they are relatively silent on *how* it does this in terms of inputs and transformations. This is unsurprising because most theories are structural and more concerned with the contents of cognition than the processes that produce it (Smith and Kirby, 2000a, p. 88). ESM says nothing about *how* derivation works, but seems to agree with the general implication that an individual combines what they take in from the environment with internal knowledge structures such as goals and beliefs. This creates an interpretation of the situation to examine for affective patterns.

Smith & Kirby appears to be the only theory that has begun to derive the inputs necessary for evaluating explicitly defined dimensions. So far, it has derived inputs for *problem-focused coping potential* (Smith and Kirby, 2009a, p. 1361; Smith and Kirby, 2009b, p. 483, 97–499; Smith and Kirby, 2001, p. 127–128), *emotion-focused coping potential* (Smith and Kirby, 2009a, p. 1365; Smith and Kirby, 2009b, p. 483–485, 495), and *motivational relevance* (Smith and Kirby, 2001, p. 125–127; Smith and Kirby, 2009a, p. 1358, 1361). It has not yet begun testing the remaining dimensions (Smith and Kirby, 2009a, p. 1357, 1369). However, this might be transferable knowledge to theories that share these dimensions. The OCC model provides another piece of the puzzle, stating that the appraisal derivation model does not need to be precise because of the assumed imprecision of psychophysics[14] (Ortony et al., 2022, p. 96). It also does not need to produce values for all dimensions, using default values where necessary.

The theories of CPE/SCT, Smith & Kirby, and CTE describe some mechanisms for appraisal derivation that transform inputs into appraisal dimension values. CPE/SCT proposes a four stage process following a fixed sequence which controls information processing by predetermining if evaluations are necessary and activating them in increasing levels of cost (Scherer, 2001, p. 99–100). The multi-stage appraisal also accounts for different processing levels such that appraisals can access quick, simple information as well as deliberative and slow information (Scherer, 2001, p. 102–103). Smith & Kirby propose a general mechanism for gathering and combining information from multiple sources (Smith and Kirby, 2001, p. 129–130). An appraisal detector consistently monitors for changes in different, interacting information sources. When it detects a change, the detector gathers and combines information into a single unit and triggers its appraisal. CTE proposes that each goal and plan has its own monitoring mechanism that triggers a global emotion signal when there is a change in success probability (Oatley, 1992, p. 98).

The affect derivation model appears to need some common elements in the examined theories: goal representation; a causality assignment mechanism; the ability to predict the outcome of actions and their chances of causing change; and possibly a representation of the self. Unfortunately, the theories emphasize the *what*, not the *how*, of appraisal derivation. This makes them insufficient for modelling. However, the theories offer pieces that form the begin of an appraisal derivation model. OCC seems to have the best developed structure for goals, accounting for the intimate link described by CR and further developing the hierarchical structure from CA. It also provides a theoretically grounded reason for imprecision and missing values in the model's outputs. CMEs that can access multiple information sources could use CPE/SCT to design variable cost cognitive processes and incremental appraisals to control their execution. Smith & Kirby offer a mechanism for combining multiple information sources into a single unit for appraisal, while CTE offers an option for plan-focused designs. It is likely that any given CME will take one of these theories as their foundation and take parts from other theories as needed.

[14]The study of the relationship between the objective characteristics of stimuli and the subjective perception of it.

Affect Derivation Model

The affect derivation model maps appraisal variables to emotions or affect, specifying an individual's reaction-based appraisal value patterns (Marsella et al., 2010, p. 33). All examined appraisal theories have patterns for *Fear*, *Joy*, *Anger*, and *Sadness* (Table B.9). After this, they begin to diverge based on the definition and kinds of emotion under study (Frijda, 1987, p. 117; Oatley, 1992, p. 104).

There does not appear to be a correlation between the number of appraisal variables and emotions that a theory offers (Table B.8). Assuming that a CME wants to use the fewest dimensions for the most emotion kinds, CA looks to be the best choice at first glance. However, its mappings between dimensions and emotions is somewhat ambiguous. For example, the patterns for *Anxiety* and *Disgust* only differ in how they describe *type of ego-involvement* (Lazarus, 1991, p. 237, 261). What distinguishes "protection" from "risk of contamination"? This question leaves room for unintentional assumptions that might conflicts with CA. Smith & Kirby have a similar problem—*Affection* and *Compassion* are one instance of emotions sharing an appraisal pattern (Yih et al., 2020, p. 489). There is a clear difference in the statistical significance of the elements in the pattern, but only an assumption can make the difference explicit. CTE, too, has this issue because it lacks explicit appraisal dimensions. However, its descriptions of changes at plan junctures seems to remove some ambiguity (Oatley, 1992, p. 55, 104–106). It names evaluations of goal and plan types that precede emotion "modes" which do not appear to overlap. CTE also seems to account for simultaneous goal or plan evaluation, proposing that more than one emotion "mode" can be active with each containing different semantic contents from different interpretations of the same situation. As with CA and Smith & Kirby, assumptions are still necessary to make terms like "major plan" and "gustatory goal" unambiguous.

ESM, OCC, and CPE/SCT created their affect derivation models systematically, assigning values to all appraisal dimensions for each emotion. ESM visually delineates the boundaries between emotion kinds based on empirical studies of the appraisal-emotion relationship (Roseman et al., 1996, p. 269). The model includes elements of what they would look like, leaving little room for assumptions (Roseman, 2013, p. 143). The OCC model organizes its emotion "families" in a hierarchy based on their logical description such that a derived emotion becomes more specific as it considers more dimensions (Ortony et al., 2022, p. 36–38). While it appears to be clear, a group

Table B.8: Comparison of the Number of Appraisal Dimensions and Emotion Kinds in Appraisal Theories

Theory	# of Dimensions	# of Emotions
CR	14	9 (18)
CA	6	15
CPE/SCT	15	13
ESM	7	17
OCC	19	29 (22)
Smith & Kirby	17	20
CTE	5 ♀	5

Count of action tendencies
Count of unique emotion "families"
♀ *Inferred/implied necessary dimensions*

Table B.9: Approximately Comparable Emotion Kinds Across Appraisal Theories

Emotion	CR (Frijda, 1987)	CA (Lazarus, 1991)	CPE/SCT (Scherer, 2001)	ESM (Roseman et al., 1996)	OCC (Ortony et al., 2022)	S & K (Yih et al., 2016a, 2020)	CTE (Oatley, 1992)
Fear	X	(Fright)	X	X	X	X	X
Happiness/Joy	X	X	X	X	X	X	X
Anger	X	X	X	X	X	X	X
Sadness	X	X	X	X	(Distress)	X	X
Disgust		X	X	X	(Reproach/ Distaste)	X	X
Anxiety	(Nervousness)	X	X		(Fear)	X	
Guilt		X	X	X	(Self-Reproach)	X	
Shame		X	X	X	(Self-Reproach)	X	
Pride		X	X	X	X	X	
Love/Affection		X		(Liking)	X, (Liking/ Appreciation)	X	
Relief		X		X	X	X	
Hope		X		X	X	X	
Distress			(Despair)	X	X		
Contempt			X	X	(Reproach)		
Irritability			X	(Frustration)	(Anger)		
Compassion		X			(Sorry-For)	X	
Uninterested	X		(Boredom/ Indifference)				
Interest	♅					X	
Envy		X			(Resentment)		
Jealousy		X			(Resentment)		
Dislike				X	X, (Enmity/ Distaste)		

Continued on next page

Table B.9: Approximately Comparable Emotion Kinds Across Appraisal Theories (*Cont'd*)

Emotion	**CR**[bat] (Frijda, 1987)	**CA**[quill] (Lazarus, 1991)	**CPE/SCT** (Scherer, 2001)	**ESM** (Roseman et al., 1996)	**OCC** (Ortony et al., 2022)	**S & K**[S&K mark] (Yih et al., 2016a, 2020)	**CTE** (Oatley, 1992)
Regret				X	(Self-anger)[OCC family mark]		
Surprise				X	♀		
Gratitude					X	X	
Appreciation					X		
Awe					(Admiration/ Appreciation)[OCC family mark]	X	
Embarrassment					(Self-Reproach)[OCC family mark]	X	
Distrust	X						
Tired	X						
Happy-For					X		
Schadenfreude					X		
Satisfied					X		
Dissatisfied					X		
Gratification					X		
Fears-Confirmed					X		
Disappointment					X		
Self-satisfaction					X		
Approving					X		
Disapproving					X		
Amusement						X	
Determination						X	
Tranquility						X	

[bat] *Excludes moods.*
[quill] *Excludes "Aesthetic Emotions" because it lacks an explicit appraisal profile.*
[S&K mark] *Smith & Kirby*
[OCC family mark] *OCC emotion token identifying that this emotion word is part of an emotion "family".*
♅ *Mentioned as an explanation for the `Interestingness` dimension.*
♀ *Not an emotion, but elicited by Unexpectedness appraisal dimension.*

of computer scientists and logicians proposed an alternative hierarchy to remove some lingering ambiguities (Steunebrink et al., 2009). The assignment of "tokens" to the OCC emotion families is not empirically supported (Ortony et al., 2022, p. 205), so using them to compare to other emotions within and without the same family is dubious and leaves room for implicit assumptions. CPE/SCT views emotion "families" as labels for common responses, so affect derivation is not necessarily limited to them (Scherer, 2001, p. 113). It clearly notes which dimensions have multiple valid appraisal values, claiming them as potential points of within-"family" variation. Different intensity levels in a dimension could also indicate differences between similar emotion families. However, like OCC, this is only speculation and defining new emotion kinds this way might not be theoretically sound. CTE also considers its emotion "modes" as related families of emotion sharing similar antecedents and responses but differing in semantic contents (Oatley, 1992, p. 76–78, 105). The connection to folk understanding of the contents of different emotions indicate what additional cognitive processes their identification might need. However, like OCC and CPE/SCT, this might not be theoretically sound. Depending on the application, this might still be a viable option for systematically adding more emotions to a CME.

CR differs from the other theories in this regard, mapping appraisal values to action tendencies instead of emotion kinds (Frijda, 1986, p. 455, 479). This affords a continuous system where emotion kinds are discrete events. CR assumes that appraisals and action tendencies are correlated and emotion kinds are labels that relate different types of affective data (Frijda, 1987, p. 141).

Surprise and *Interest* appear to be special cases of affect derivation. ESM and OCC state that the *unexpectedness* dimension alone indicates *Surprise* (Roseman et al., 1996, p. 257; Ortony et al., 2022, p. 45–46). However, OCC does not consider *Surprise* an emotion because it is not an inherently positive or negative state. CR and Smith & Kirby recognize *Interest*, tying it to the comparable dimensions of *interestingness* and *vastness* respectively (Frijda, 1987, p. 130; Yih et al., 2020, p. 493). Smith & Kirby use additional dimensions to distinguish *Interest* from other emotions, with preliminary results suggesting that it is a positive emotion.

In general, the emotion kinds that a CME needs should determine which model to use. Given the number of ambiguities, one should avoid CA for affect derivation. Smith & Kirby could be an alternative due to its notes on statistical significance, but assumptions are unavoidable since no mention is made about how they make a difference. Assumptions are also unavoidable in CTE, although there seem to be fewer to make. ESM, OCC, and CPE/SCT appear to be computationally-friendly, ensuring that each emotion has appraisal values for all dimensions. However, one should avoid defining individual members of the emotion families given in CPE/SCT and OCC as there are no guidelines for doing so. CTE also has no explicit guidelines for defining different members of an emotion family, but its ties to everyday understanding of emotions might make it viable for some applications. CR offers an alternative model, mapping appraisal values to action tendencies. This could be useful for systems that are more interested in how emotion affects behaviour rather than producing specific emotion states. One could use a secondary mapping to match action tendencies with an emotion label. ESM is ideal for modelling *Surprise*, as it is the only appraisal theory in the survey that considers it a proper emotion. Either CR or Smith & Kirby could act as a guideline for defining an appraisal mapping for *Interest* as neither appear to have an obvious advantage.

Affect Intensity Model

The affect intensity model specifies the strength of the emotion response given the appraisal values (Marsella et al., 2010, p. 33). Unfortunately, there is precious little research on it (Frijda et al., 1992, p. 60; Marsella et al., 2010, p. 33) and the examined theories do not offer much insight. ESM and Smith & Kirby hypothesize that their dimensions of *motivational state* and *motivational* *relevance* are factors of emotion intensity (Roseman, 2013, p. 147; Smith and Kirby, 2001, p. 125), but do not state how they work. CTE has a similar proposal, claiming that the importance of an affected goal and/or plan is one factor of emotion intensity, likely in relation to the change in success probabilities at plan junctions (Oatley, 1992, p. 23, 98). CTE does not list other factors, their evaluation, or their combination. This does, however, imply that goal/plan importance is scalar so that intensity can vary with it. CR proposes that appraisal dimensions use thresholds that determine if the system should trigger a response (Frijda, 1986, p. 300). The individual's personality, physical and mental state, and event history influence threshold values. While CR is clear that intensity changes over time, becoming more or less sensitive to changes, it is less clear on how factors combine in a single time step. OCC provides a more developed intensity model:

- It assumes that all global and local variables exert their influence through the three central variables: *desirability*, *praiseworthiness*, and *appealing* (Ortony et al., 2022, p. 99).
- It calculates an emotion potential such that emotion intensity is the difference between the potential and a context-sensitive, emotion-specific threshold (Ortony et al., 2022, p. 220–222). Therefore, an emotion only manifests if its potential exceeds the threshold.
- It also assigns weights to appraisal values, which can vary between and within emotion families (Ortony et al., 2022, p. 96–97). This affords control over how changes in those factors change the overall emotion experienced.

Unfortunately, OCC does not specify what the emotion thresholds, variable weights, or default values should be due to a lack of empirical data (Ortony et al., 2022, p. 132).

Ultimately, none of the examined theories are sufficient for designing the affect intensity model. At best, CR or OCC could act as a guideline for the affect intensity model but it is equally helpful to look at other Affective Science research for this component.

Affect Consequent Model

The affect consequent model maps appraisal outputs to behavioural and cognitive changes (Marsella et al., 2010, p. 34). In most cases, this means mapping affect to those changes. Notable exceptions are CR—which maps directly from appraisals to action tendencies—and OCC, which is silent on the matter by design[15] (Ortony et al., 2022, p.6).

There is general agreement that the affect consequent model includes physiological and behavioural changes. CR calls this an *action readiness change* which is a signal that presses for control of the individual (Frijda, 1986, p. 455). CTE specifies that this "readiness for action" is a call for a predetermined plan suite that can prompt a quick and resource-friendly response to manage transitions between individual and social plans at plan junctures (Oatley, 1992, p. 19–21, 176–179). A distinctive feeling, differentiating them from other mental and body states, pairs with the transition and might also be accompanied by conscious preoccupation, bodily disturbances, and outward expressions. ESM also cites expressive changes, as well as emotion-specific goals and general strategies for achieving them (Roseman, 2013, p. 143–144). It describes profiles for each emotion kind with entries for each consequent type. Both CA and Smith & Kirby call the behavioural changes *action tendencies* and include a subjective feeling aspect. CA groups the subjective feeling and appraisal outcome, but Smith & Kirby include it as part of deliberative cognition (Lazarus, 1991, p. 210; Smith and Kirby, 2001, p. 130). These theories group the changes together into a single appraisal

[15] One author started to change this, but the work appears unfinished (Gilboa and Ortony, 1991) or does not cover all emotions from the original theory (Ortony, 2002, p. 198, 201).

outcome. In contrast, CPE/SCT distributes changes between SECs such that each group affects physiological systems, cognition, and other SECs independently (Scherer, 2001, p. 99–100). These become interrelated and synchronized changes that CPE/SCT calls emotion as the system evaluates each SEC group (Scherer, 2001, p. 93). This creates tightly linked physiological changes, behaviours, and appraisal outcomes.

The examined theories also generally agree that the appraisal process is a closed loop system. An individual's actions might change their relationship with the environment, triggering a new appraisal cycle. Both CR and CA state that the changes can be direct actions on the environment or cognitive changes (Frijda, 1986, p. 456). However, CA differentiates the two because of its intentional inclusion of coping which the individual's personality modulates (Lazarus, 1991, p. 112, 134). Problem-focused coping is about directly acting on the environment, changing the external information coming into the appraisal process. Emotion-focused coping involves internal, cognitive actions that can change the individual's goals, beliefs, or knowledge, which changes their interpretation of the situation, the appraisal process itself, or the appraisal outcome. CA calls this initiation of another appraisal process *reappraisal*. Smith & Kirby also split the emotional response into two paths (Smith and Kirby, 2001, p. 130): a priming signal for associative processing, which can direct memory activation; and deliberative cognition as the subjective feeling component of the response. The differences in CA and Smith & Kirby might not be mutually exclusive in this area. One can imagine the outcome of emotion-focused coping from CA as input to the two paths from Smith & Kirby. CTE heavily implies that emotion generation is a closed loop system (Oatley, 1992, p. 102). Shifting cognitive resources and attention can change a situation's interpretation and any actions taken to modify it can also result in shifting goal evaluations. This can cause changes in emotion intensity and quality. The distinction between control and semantic messages also implies the presence of two pathways—a quick, reactionary path and another that is slower and deliberate (Oatley, 1992, p. 51)—comparable to the pathways in Smith & Kirby.

Excluding OCC, all the examined theories imply—if not explicitly describe—a closed-loop system. This means that any changes elicited by the affect consequence model feeds back into the emotion process and might initiate another cycle. ESM is ideal for systems that produce specific emotion categories because it organizes information into profiles reminiscent of discrete theories. Both CR and CPE/SCT describe an emergent system such that recognizable "emotion" is the product of overlapping system changes. These theories are ideal for CMEs that are more interested in how affective processing influences behaviours and internal processes than producing discrete emotion kinds. CR is the more lightweight option because CPE/SCT's described changes are tightly linked to external systems. CR also offers a control signal for affective processing to gain control of behavioural and cognitive resources. Due to its focus on goals and plans, CTE is likely ideal for planning applications, including narrative planning and multi-agent coordination.

Both CR and CA separate appraisal outcome effects into two pathways for independently impacting the external environment and internal processes. CA is likely the better choice for specifying this because it associates the pathways with problem-focused and emotion-focused coping respectively. It also indicates that the affected internal processes are the appraisal process and outcome, as well as the individual's goals, beliefs, and knowledge. CR does not appear to make comparable distinctions between the paths. Smith & Kirby further divide the emotion-focused coping path by sending an affective priming signal to associative processing and memory, and a signal to deliberative cognition that manifests as subjective affect. This makes it ideal for CMEs with different internal information gathering mechanisms. Smith & Kirby do not, however, say how the process affects the external environment. CTE could be a candidate for this, as it seems to mirror the pathways in Smith & Kirby, but allows for the potential to connect to both the internal and external environment like CA can.

B.5.4 Neurophysiologic Theories

Of the explored perspectives, the neurophysiologic theories agree the most. They all propose that emotion: is part of a functional mind; aids decision-making; and operates under time constraints. They also agree that learning can mediate "stupid" emotional behaviours. The differences between theories is a matter of their focus.

The conceptual, schematic, and sensorimotor processing levels described by Leventhal and Scherer (1987, p. 17) can relate the neurophysiologic theories:

- Sloman operates on the highest level of the mind—the conceptual level—where cognition is agnostic of the body, evident in the central role it assigns to goals and planning;
- Damasio operates on the schematic level, as the SMH describes how emotions incorporate new information to regulate survival-based processes; and
- LeDoux operates on the sensorimotor level, describing how emotions are fundamental biological functions that evolution has tuned to react quickly and unconsciously to survival issues.

Damasio and LeDoux have more in common than Sloman does with either. Both Damasio and LeDoux assign bodily feedback a critical role in emotion processes, claiming that the layman's notion of "emotion" is a conscious, cognitively driven assignment of meaning to the collective effect of emotion processes (LeDoux, 1998, p. 329). The processes themselves have dedicated neural pathways that react automatically and unconsciously to innate stimuli and mediating structures can "tune" the affective response through learning and "created" stimuli.

The constraints that these theories imply as part of their implementation could limit the type of CMEs that could use them to their full capacity. Therefore, the decision to use these theories is highly dependent on the CME's requirements. Damasio and LeDoux could complement each other in a CME because they have nearly identical assumptions. The theories' basis in brain structures and replicable studies suggests that this combination could create a more plausible emotion processing model than other theories. Damasio's claim that LeDoux has the most comprehensive study on primary emotions (Damasio, 1995, p. 133) and LeDoux's that Damasio's work is notable (LeDoux, 1998, p. 36, 250, 293) further supports this idea. However, emotion processes' dependency on bodily feedback could impose constraints that cannot be easily addressed in virtual environments. A virtual environment itself does not contain the information richness that the real world does innately. However, since they operate in the real world, robots are a good platform for CMEs using neurophysiologic theories. For example, researchers use Damasio to justify the inclusion of emotions in robots (Malfaz and Salichs, 2004, p. 806). In contrast, Sloman designed this theory for computers using symbolic representations and transformations. However, it depends on an underlying system that operates with symbolic goals and plans. Sloman's emphasis on beliefs, desires, and intentions (Sloman, 1987, p. 230) implies that it works best with a BDI-based system. Overall, this strengthens the proposal that Sloman is best suited to the domain of agent planning.

Table B.10: Summary of Potential Uses for Examined Theories

Perspective	**Theory**	**Potential Uses**
Discrete	Ekman & Friesen	• Defining facial expressions • Defining display rules for emotion expression
	DET	• Personality developed by ongoing emotional experiences • Supplementing facial expressions from Ekman & Friesen
	PES	• General emotion model • Can connect to facial expression and action tendencies • Potential for personality model development • Supplement existing emotions by mixing them to create new ones
Dimensional	V-A	• General model of affect
	PAD Space	• Computation-friendly • Expands on V-A • Potential to integrate personality in a common space
Appraisal	CR	• Computation-friendly (Frijda and Swagerman, 1987) • Defining an alternative affect derivation model by mapping appraisal values to action tendencies • Guideline for defining an affect derivation model for *Interest* • Guideline for defining an affect intensity model • Specifying an affect consequent model that produces continuous, emergent changes • Specifying a control precedence signal for the affect consequent model
	CA	• Defining an affect consequent model with distinct pathways for influencing the environment and internal cognitive processes (i.e. coping behaviour)

Continued on next page

Table B.10: Summary of Potential Uses for Examined Theories (*Cont'd*)

Perspective	Theory	Potential Uses
Appraisal *Cont'd*	CPE/SCT	• Computation-friendly (Scherer, 2001, 2010a, p. 103–106) • Defining an appraisal derivation model with incremental processing stages based on cost and accounts for multiple processing levels • Defining an affect derivation model ✍ • Specifying an affect consequent model that produces continuous, emergent changes where there are cognitive processing systems
	ESM	• Defining an affect derivation model that accounts for all appraisal dimensions for each emotion kind • Defining an affect derivation model for *Surprise* • Defining an affect consequent model that treats emotion kinds as discrete entities
	OCC	• Computation-friendly • Defining a goal hierarchy for the appraisal derivation model • Justifying imprecision and missing values in the appraisal derivation model's outputs • Defining an affect derivation model ✍ • Guideline for defining an affect intensity model
	Smith & Kirby	• Defining a mechanism for the appraisal derivation model that combines multiple input sources into one unit for evaluation • Guideline for defining an affect derivation model • Guideline for defining an affect derivation model for *Interest* • Potential guideline for defining an affect derivation model in place of CA • Defining an affect consequent model with distinct pathways for independently influencing fast, reactive associative processing and slow, deliberative cognition (emotion-focused coping)

Continued on next page

Table B.10: Summary of Potential Uses for Examined Theories (*Cont'd*)

Perspective	Theory	Potential Uses
Appraisal *Cont'd*	CTE	• Computation-friendly • Defining a plan-focused appraisal derivation model with implicit and variable dimensions • Guideline for defining an affect derivation model • Defining an affect consequent model with distinct pathways for independently influencing fast, reactive action and slow, deliberative cognition • Defining an affect consequent model that makes and alters computational plans (e.g. narrative planning, agent coordination) • Tied to narratives and character intentionality • Can rely on an "everyday" understanding of emotion to define some components
Neurophysiologi	Sloman	• Computation-friendly • When built on a system with goals and planning, does not require a separate emotion system
	Damasio	• Defines learned/conditioned emotional reactions as an associative network • Connected to a CME's "body"
	LeDoux	• Defines core emotion systems as discrete, dedicated circuits • "Quick and dirty" model of emotion elicitation • Connected to a CME's "body"

Can link to the affect consequent model in appraisal theories.
Can link to the affect derivation model in appraisal theories.
Could use the Russell Circumplex instead.
A secondary mapping can connect groups of behaviours to emotion kinds.
Strictly for the emotion families as there is no information for defining individual members.

Key Points

- Discrete theories of emotion emphasize a small set of fundamental emotions that are innate, hard-wired features with dedicated neural circuitry
- The discrete theory of: Ekman & Friesen has excellent support for describing the connection between emotion and facial expressions; DET has elements describing connections between emotion and personality; and PES has mechanisms describing a structural representation of emotion and emotion "mixtures"
- Dimensional theories define a coordinate space for affect using two or three dimensions and focus on connecting emotions to mental states in a general taxonomy and to their construction
- V-A is useful for describing a general affective space, whereas PAD Space can integrate multiple types of affect in the same coordinate space
- Appraisal theories tend to combine discrete and dimensional emotion characteristics, proposing different methods of emotion production and manifestation
- CR directly maps appraisals to action tendencies; CA describes how coping behaviours impact appraisal inputs; CPE/SCT is useful for defining complex systems with multi-stage appraisals that access different types of cognitive processing; ESM supports the emotion definitions using both appraisal patterns and discrete entities; OCC is useful for defining a goal hierarchy for appraisal derivation and mapping between appraisals and emotion kinds; Smith & Kirby is good for defining a mechanism that combines multiple appraisal inputs and for specifying how appraisal outcomes affect some types of cognition; and CTE is especially useful for plan and/or language-focused applications
- Neurophysiologic theories could produce more plausible behaviours than the other perspectives, but appear to have more constraints
- Sloman supports goal and plan-based emotion processes; Damasio describes a learning mechanism for learned or conditioned stimuli; and LeDoux describes emotion with dedicated neural processes

Appendix C

(Notes) Of High-Level Requirements and Emotion Theories

> If we all reacted the same way, we'd be predictable, and there's always more than one way to view a situation.
>
> Major Motoko Kusanagi, *Ghost in the Shell*

These are the notes about emotion theories with respect to high-level requirements made during analysis (Chapter 7). Notes for the dimensional theories and RF5 do not appear here because they serve as an example in Chapter 7. Tables 7.4, 7.5, 7.6, and 7.7 summarize the resulting scores.

A reminder that the scores are somewhat subjective and depend on one's understanding of the requirements and current state of Affective Science literature.

C.1 Discrete Theories

The discrete theories are the most likely candidates for satisfying high-level requirements that depend on understanding what emotion an NPC has, as this is their core focus. This includes the flexibility requirements for *Allowing the Integration of New Components* (RF4) and *Choosing Which NPC Emotions to Use* (RF5), and the ease-of-use requirements for *Having a Clear API (Output)* (RE2) and *Showing That Emotions Improve the Player Experience* (RE6).

C.1.1 Flexibility: Allowing the Integration of New Components (RF4)

All three discrete theories provide variable levels of native support for personality but only Plutchik does not touch on mood. None of them touch on core affect.

- **Ekman & Friesen** (☆)
  - Moods and personality are inferred from emotion signals (e.g. many *Joy*-related signals could suggest a cheerful mood) (Ekman, 1999, p. 48, 55–56)
  - Little information beyond these definitions → developers would need to create patterns of emotions for each mood and trait, could become too time consuming and error-prone
  - No coverage of Core Affect, Personality and Mood are error-prone and time consuming
- **Izard** (☆)

- Natively accounts for personality (Izard and Ackerman, 2000, p. 253–254; Izard, 1977, p. 44)
  * Emergent phenomena that begins at birth and develops as the individual interacts with their environment
  * Treated as a product of emotions associated with patterns in perception, cognition, and behaviour
  → Requires developers to create patterns for each personality trait which is likely to be too time consuming and error-prone
- Seems to acknowledge two definitions of mood
  * Defined as a "continuing total life condition" similar to what he calls an emotion trait, or tendencies towards certain emotion experiences (Izard, 1991, p. 17, 171) → in the view of stable traits and fluid states, conceptualization appears to be closer to personality than mood
  * As a state, defined as an enduring emotion state that is too mild to enter consciousness but can influence mental health and bodily systems such as the immune system (Izard, 1991, p. 21) → closer to working definition of mood in EMgine's context
  → could be realized as a timed function that monitors an NPC's emotion state and acts on those that have not surpassed a given threshold (minimal effort to implement)
- No coverage of Core Affect, Mood requires minimal effort, Personality is error-prone and time consuming

• **Plutchik** (☆☆)
  - Natively accounts for personality
    * Connects its emotion Circumplex directly to a Circumplex of personality traits[1] (Plutchik, 1997, p. 27–28) → could mechanize with a simple weighting mechanism such that emotions are easier or harder to elicit
    * Built around a layperson's understanding of personality → upholds the *Hiding the Complexity of Emotion Generation* (RE1) requirement
  - Circumplex is a way to incorporate a model of mood
    * Agreement that it can be represented by an elliptical Circumplex with Arousal as the shorter dimension (Feldman, 1995, p. 806, 812, 814)
    * Could add an additional element such that the length of the Arousal dimension changes with context → afford more creative freedom than a fixed model
    * Can uphold the *Hiding the Complexity of Emotion Generation* requirement (RE1) with a well-designed interface with details available for advanced users
  - Dimensional nature of theory could aid in a non-native representing core affect → could map the intensity dimension to Arousal and the relative positions of an emotion to some anchor points as Valence
    * Mapping might not be understandable due to debates about the valence of *Surprise* and its relation to *Anticipation* (Susanto et al., 2020, p. 98) → concessions could be made, such as listing some categories as zero Valence, since EMgine is unconcerned with realism

[1]The assumption that the circumplexes can be connected this way might be naive. They might be unique to the modelled domain rather than showing similarities across them (Feldman, 1995, p. 815).

    * Can uphold the *Hiding the Complexity of Emotion Generation* requirement (RE1) with a well-designed interface with details available for advanced users
  - Ability to build *some* type of Core Affect and Mood representation on top of existing theory, Personality native to theory and built on a layperson's perspective

C.1.2 Flexibility: Choosing What Emotions the NPC can Have (RF5)

Within each discrete theory's set of emotions, it would be easy to exclude any unneeded ones. However, *adding* more emotions to a set is less clear cut. There does not seem to be any convincing empirically validated or verifiable rules for creating "non-basic" emotions in discrete theories (Ortony, 2022, p. 6). This does not impact EMgine because it does not need to replicate true affective phenomena—it need only produce convincing results.

- **Ekman & Friesen** (☆)
  - Do not believe that there are "non-basic" emotions (Ekman, 1999, p. 55, 57)
    * Each emotion represents a family of related states that share a theme and variations between members are the result of learning
    → Requires developers to either associate different situations for the desired variations manually or create a learning mechanism to create them as the NPC interacts with the game environment
    * Unideal → Could be difficult to adapt this kind of system to simple games, violating the *Ability to Operate on Different Levels of NPC Complexity* requirement (RF7); requires some knowledge of psychology and neuroscience, violating the *Hiding the Complexity of Emotion Generation* (RE1) requirement
  - Facial expressions can be blends of prototypical primary ones (Ekman, 2007, p. 69)
    * A step removed from the emotion generation process, and would likely happen in an emotion expression component
    * Would need to translate the blended expression into an emotion to use it for emotion generation → feasible, but error-prone, method as facial expression interpretations can be subjective
  - No "non-basic" emotions, translating from facial expressions is error-prone
- **Izard** (–)
  - "New emotions" are the product of affective-cognitive structures (Izard, 1992, p. 564–565)
    * Association of primary emotion patterns or clusters with images, thoughts, and memories
    → Requires developers to either create these structures manually or create a learning mechanism to create them as the NPC interacts with the game environment
    * Unideal → Same reasoning as Ekman & Friesen, violating both the *Ability to Operate on Different Levels of NPC Complexity* and *Hiding the Complexity of Emotion Generation* requirements (RF7, RE1)
  - Difficult to adapt to different NPC complexities, requires knowledge for connecting emotions to cognitive patterns

- **Plutchik** (☆☆☆)
  - One of the better developed theories of emotion mixes (LeDoux, 1998, p. 113; Ortony, 2022, p. 3, 5)
  - Might be the only discrete theory to focus on this aspect of the "primary" emotions (Ekman, 1999, p. 47)
  - Colour wheel analogy uses concepts and terms that are generally understood by laypeople → does not require any knowledge of the theory to use
    - Lacks clarity about technical rules for combining emotions (Johnson-Laird and Oatley, 1992, p. 208–209; Ortony, 2022, p. 5) **BUT** laypeople tend to attribute the same underlying primary emotions to named emotions outside the primary set (Plutchik, 1984, p. 204–205)
    - → Implies that a game developer can apply their own experiences when deciding how to represent a new emotion with the Plutchik Circumplex
  - Ability to build additional emotions from existing set based on a layperson's understanding of emotions and their combinations

C.1.3 Ease-of-Use: Having a Clear API (Output) (RE2)

The discrete theories are generally easy for laypeople to understand. All three theories connect their emotions to distinctive behaviours applicable to situations of variable complexity. This makes for a clean output API, providing an emotion category that developers can attach to "buckets" of related behaviours and expressions that are "familiar".

- **Ekman & Friesen** (☆☆☆)
  - Have publications that are meant for the general public (e.g. Ekman (2007)) → accessible to laypeople
  - Use of facial expressions is a helpful tool for conveying meaning about their primary emotions
- **Izard** (☆)
  - Gains understandability by connecting its emotions to facial expressions, although some emotions are not connected to one
  - → Weakens its usability, as some developers might actively avoid the emotions that cannot be readily represented on the face
- **Plutchik** (☆☆)
  - Construction based on similarities and differences between affective terms as they are understood in (English) language → can help developers understand each emotion based on their understanding of the word's meaning and its relative position to other emotion words on the Circumplex
  - Each primary emotion is also connected to an intended behaviour pattern, like rejection and exploration (Plutchik, 1984, p. 202)
    - Addresses problems of "missing" facial expressions with characteristic or typical behaviours (Julle-Danière et al., 2020, p. 20–21; Schindler et al., 2013, p. 101)

Table C.1: Primary Emotions in Discrete Theories

Emotion	**Ekman & Friesen (Ekman, 2007)**	**Izard et al. (1993)**	**Plutchik (1997)**
Happiness/Enjoyment/Joy♃♀	✓	✓	✓
Sadness♃♀	✓	✓	✓
Fear♃♀	✓	✓	✓
Anger♃♀	✓	✓	✓
Surprise♃♀	✓	✓	✓
Disgust♃♀	✓	✓	✓
Contempt☽♀	✓	✓	𓅞
Interest♀		✓	✓
Guilt𓀿		✓	𓅞
Shame♀		✓	𓅞
Shyness♀		✓	
Acceptance𓀿𓆄			✓

♃ *Associated with a facial expression by Ekman and Friesen (2003).*
♀ *Associated with a facial expression by Izard (1971, p. 236–237), Izard (1977, p. 85–91).*
☽ *Associated with a facial expression by Ekman (2007, p. 184–186).*
𓅞 *As a mixture of the primary emotions.*
𓀿 *Might lack a characteristic expression (Keltner and Buswell, 1996, p. 155; Schindler et al., 2013, p. 106), but artistic renditions of facial expressions exist (e.g. Le Brun (1760)).*
𓆄 *Plutchik is noted as the only researcher to consider Adoration—the highest intensity of Acceptance—a primary emotion (Schindler et al., 2013, p. 87–88).*

- → Could help developers conceptualize what each emotion could look and act like, can include facial expressions

- Does not directly benefit from assigned facial expressions but some connections could be made with Ekman & Friesen and Izard (Table C.1) → understanding of emotion terms and associated behaviours is not as "clear cut"

C.1.4 Ease-of-Use: Showing that Emotions Improve the Player Experience (RE6)

Like the *Having a Clear API (Output)* requirement (RE2), discrete theories are generally understandable by laypeople. This helps identify ways to design studies to evaluate and ways to build the player experience.

- **Ekman & Friesen** (☆☆)
  - Emotions could be directly connected to an expression module built on the Facial Action Coding System (FACS), which is part of the theory itself (Ekman et al., 2002)
  - Players could report on their experiences based on NPC expressions → relatively easy to test how emotions impact a player but limited to facial expressions alone

- **Izard** (☆☆)
  - Considerable overlap between Ekman & Friesen and Izard regarding facial expressions (Ekman, 2007, p. 3) → could connect to an emotion expression component built on FACS, probably with minimal effort
  - Players could report on their experiences based on NPC expressions → relatively easy to test how emotions impact a player but limited to facial expressions alone
- **Plutchik** (☆☆)
  - Could be connected to facial expressions, but there is no obvious match for the *Acceptance* emotion type
  - Associates each emotion with a behaviour that could be applied to many actions and expressions that an NPC could need → design studies around these behaviour classes
  - Players could report on their experiences based on NPC expressions → relatively easy to test how emotions impact a player, but likely an element of subjectivity in matching behaviours to meaning

C.1.5 Examining the Remaining Requirements

The absence of a defined emotion elicitation tasks in the discrete theories is a double-edged sword—some requirements are trivial to satisfy, while others are impossible. The lack of elicitation processes makes it impossible for discrete theories to satisfy most task-related requirements. This means that they *cannot* be categorized for the component-level requirements (Tables 7.6 and 7.7). For the remaining system-level requirements (Tables 7.4 and 7.5), the theories satisfy the requirements in similar ways, so they are examined as a single unit.

- *Flexibility: Independence from an Agent Architecture (RF1)* (☆☆)
  - No specific tasks → effectively architecture-agnostic
  - Only require processes that satisfy input and output requirements
- *Flexibility: Allowing Developers to Specify How to Use Outputs (RF6)* (☆☆)
  - No specific tasks → affords flexibility for specifying how to use EMgine's outputs
  - Theoretically could hook up any process to EMgine using the emotions as "buckets" for collecting related behaviours
- *Flexibility: Ability to Operate on Different Levels of NPC Complexity (RF7)* (☆☆)
  - Could add processes and parameters as needed → does not affect core EMgine processes
- *Flexibility: Be Efficient and Scalable (RF8)* (☆☆)
  - Could add processes and parameters as needed → does not affect core EMgine processes
- *Ease-of-Use: Providing Examples of Novel Game Experiences (RE7)* (☆)
  - No immediately obvious features for novel game mechanics, challenges, or other elements

C.2 Dimensional Theories

The dimensional theories are the most likely candidates for satisfying requirements related to CME expansion, as they aim to discover the structure of emotion and how they relate to other mental states (Reisenzein et al., 2013, p. 250; Broekens, 2021, p. 353). This mainly concerns the flexibility requirements for *Allowing the Integration of New Components* (RF4) and *Choosing What Emotions the NPC can Have* (RF5).

This analysis treats the Valence-Arousal model as a Circumplex because it is a reasonable representation of affective states (Remington et al., 2000, p. 296) and is more consistent with affective structure (Barrett and Russell, 1999, p. 12). The Circumplex also tends to emerge regardless of the data collected, research domain, and analysis (Russell, 1997, p. 211). This representation still has issues, such as inclusion/exclusion of terms, self-report weaknesses, and the effect of context on state positions (Remington et al., 2000, p. 298). However, it also provides more structure to an otherwise two-dimensional and nebulous space.

C.2.1 Flexibility: Allowing the Integration of New Components (RF4)

Both V-A and PAD can trivially represent core affect because they both natively include the dimensions of Valence and Arousal. Like Plutchik, both dimensional theories could also model mood as an elliptical Circumplex with relative ease. Unlike Plutchik, this mapping is native due to the presence of both a Valence/*pleasantness* and Arousal dimension. This only leaves an evaluation of the ability to represent personality in V-A and PAD.

The dimensional theories seem to have variable levels of built-in support for representing personality. This analysis focuses on support for the Five-Factor Model OCEAN[2] personality traits (Costa and McCrae, 1992). With research ongoing in personality psychology, there is currently a good consensus on the usefulness of OCEAN as a descriptive model (Yik et al., 2002, p. 100–101; De Raad and Perugini, 2002, p. 3). OCEAN has, arguably, also become known among the general populace as a personality profile tool due to its accessible language (De Raad and Perugini, 2002, p. 1) and use in career counselling (Costa Jr. et al., 1995, p. 135; Howard and Howard, 1995; Hurtado Rúa et al., 2019, p. 528). This familiarity makes it ideal for EMgine which cannot assume that a user will have an academic understanding of psychology. For game design, the OCEAN model will also likely prove convenient for defining NPC personalities, as Costa and McCrae (1992) provide a questionnaire consisting of five-point Likert scales representing statement agreement to measure how each factor contributes to personality. It has also been translated to several languages (Yik et al., 2002, p. 84). This implies that a simple tool presenting game designers with the questionnaire is sufficient for defining a new NPC personality in EMgine with OCEAN traits.

- **V-A** (☆☆☆)
  - Relating OCEAN personality traits with Circumplex structures is more consistent than simple structures → two structures have close-fitting probability plots supporting an ideal Circumplex structure and the third has a convincing and serviceable, but less satisfactory, probability plot (Gurtman, 1997, p. 84–87, 90)
    - Some evidence that the interpersonal traits of Extroversion and Agreeableness are best described with a Circumplex → Extroversion can be related to the Valence dimension (McCrae and Costa, 1989, p. 590, 593)

[2] Defined as "psychological entities with causal force" (American Psychological Association, 2020b). Although they have the same dimensions, this differs from the Big Five Model which "views the five personality dimensions as descriptions of behaviour and treats the five-dimensional structure as a taxonomy of individual differences".

    * Extroversion/Neuroticism → represents the affective plane (Gurtman, 1997, p. 84–87, 90)
    * Unnamed or "mixed" Agreeableness/Neuroticism plane (Gurtman, 1997, p. 84–87, 90)
    * All three planes can be layered in the polar coordinate system (Gurtman, 1997, p. 84–87, 90)
    * Does not appear to be support for Openness or Conscientiousness (Gurtman, 1997, p. 84–87, 90)
  - Alternate hypothesis puts OCEAN traits as points on the Circumplex → a high value in a trait implies a higher tendency to experience the type of affect represented in the same space (Yik et al., 2002, p. 94–96)
    * Locates the angles for each trait in five languages—English, Spanish, Korean, Chinese, and Japanese
    * Configuration option → prebuild some cultural differences into EMgine

- **PAD** (☆☆☆)
  - Personality[3] can be inferred by averaging an individual's emotional states across a representative sample of day-to-day situations (Mehrabian, 1996b, p. 262)
  - As traits, the PAD dimensions were found to be a good base description of personality (Mehrabian, 1980, p. 64)
  - Other personality scales are represented as linear combinations of the three dimensions (Mehrabian, 1996b, p. 267), forming a line through the space
    * Provides lines estimates for the OCEAN personality traits[4] using *pleasure*, Arousal, and *dominance* (Mehrabian, 1996a, p. 91 Eq. 11C–13C), and from the dimensions to PAD space (Mehrabian, 1996a, p. 90 Eq. 1D–5D)
    * Gender agnostic (Mehrabian, 1996a, p. 89) → removes a layer of complexity that one might consider when adding the OCEAN model of personality to EMgine

C.2.2 Examining the Remaining Requirements

Dimensional theories are similar to the discrete theories in that they have no defined emotion elicitation tasks, so they also cannot satisfy the component-level requirements (Tables 7.6 and 7.7). However, for the remaining system-level requirements (Tables 7.4 and 7.5), the dimensional theories do not necessarily satisfy the same requirements as discrete theories. Again, the dimensional theories satisfy some requirements in similar ways, so they are examined as a single unit.

- *Flexibility: Independence from an Agent Architecture (RF1)* (☆☆)
  - Coordinate space that does not depend on its surrounding environment → effectively architecture-agnostic
  - Only require processes that satisfy input and output requirements

[3]Mehrabian refers to *emotional traits* or *temperament*. Since he defines them as "...stable over periods of years or even a lifetime" (Mehrabian, 1996b, p. 262) and temperament is a biologically-based bias in personality development (Kagan, 2009), they are assumed to be equivalent to personality traits in EMgine.

[4]*Trait Sophistication* is assumed to be equivalent to *Trait Openness* (McCrae and Costa Jr., 1997, p. 826–827).

- *Flexibility: Allowing Developers to Specify How to Use CME Outputs (RF6)* (☆☆☆)
  - Numerical representation → easy to pipe them to other computational processes such as facial expression generation and decision-making
  - Potential to violate *Having a Clear API (Output)* (RE2) → resolve by providing alternate definitions of the dimensions that are easier to understand for non-experts
- *Flexibility: Ability to Operate on Different Levels of NPC Complexity* (RF7) (☆) AND *Flexibility: Be Efficient and Scalable* (RF8) (☆)
  - Numerical representation could satisfy these requirements → requires one of:
    * Developers to have some understanding of what the dimensions mean and how different factors impact them → violates *Hiding the Complexity of Emotion Generation* (RE1)
    * Providing alternate definitions of the dimensions that are easy to understand as with *Allowing Developers to Specify How to Use CME Outputs* (RE2) → potential to violate *Hiding the Complexity of Emotion Generation* (RE1)
- *Ease-of-Use: Having a Clear API (Output) (RE2)* (☆)
  - Output API has three numerical components → requires developers to know how each dimension affects NPC behaviours
  - Inference on quantities like *pleasantness* (Valence) and *excitement* (Arousal) likely not as automatic as identifying *Joy* and *Fear*
    * Could minimize problem with a Circumplex structure
    * Disagreements between different models as to where certain data points should be (Remington et al., 2000, p. 287) → could reduce the psychological validity of EMgine
- *Ease-of-Use: Showing that Emotions Improve the Player Experience (RE6)* (☆☆)
  - Numerical representation with limited variables → easy to manipulate in experimental settings
  - Might be difficult for future user study participants to answer questions about combinations of values → could use a proxy mapping values to affective labels
- *Ease-of-Use: Providing Examples of Novel Game Experiences (RE7)* (☆☆)
  - Numerical representation → leverage as a game mechanic where players manipulate affective variables as they would other resources like character and item statistics (Adams, 2009, p. 292, 466, 559–560, 578)
  - Can be implemented alongside similar mechanics (e.g. status attributes in Computer Role-Playing Games (CRPGs), character-related puzzles in adventure and social simulation games)

C.3 Appraisal Theories

Due to their nature, the appraisal theories are the only ones that can satisfy the *component-level* requirements in addition to *system-level* ones.

C.3.1 Flexibility: Independence From an Agent Architecture (RF1)

Appraisal theories assume that cognition is essential to emotion processing (Gratch and Marsella, 2015, p. 55; Broekens, 2021, p. 354) and that emotions are *about* something that has been intentionally evaluated (Ortony, 2022, p. 11). This prevents complete separation from agent architectures because of the information required for the appraisal process. Therefore, the goal is *not* to identify theories that can exist independently of an external system—it is to identify which theories are agnostic about what that architecture is.

- **Frijda** (☆☆☆)
  - Core process is an information processing system (Frijda, 1986, p. 453–456) that begins with an encoding stage that tries to match incoming events with known types and their implications for causes and consequences
    - Also need to encode actions to evaluate coping potential
    - Matching process requires users to define event and action types, then tag relevant game elements with them
      - Event types are tailored to the external architecture → affords maximal architecture independence
  - Concerns are dispositions towards the achievement or non-achievement of situations that remain dormant as long as its satisfaction conditions are met (Frijda, 1986, p. 335–336, 466–467)
    - Do not have to generate emotion from "active" pursuits alone (e.g. goals and motivations), can also be driven by events that just *happen* that change a satisfaction condition
    - → Can account for a much wider range of events, supports independence from specific architectures and information structures
  - Action tendencies only specify *what* type of action should happen, not *how* (Frijda, 1986, p. 70)
    - Freedom to connect the actions represented in the architecture to any type of action readiness → separate process can decide which action to execute
    - → Can account for a much wider range of behaviours, supports independence from specific architectures and information structures
- **Lazarus** (☆☆)
  - Relational themes described in context of goal achievement, requires preexisting knowledge to drive appraisal (Lazarus, 1991, p. 81, 145) → goal-based architecture or system
  - Multiple references to goals, beliefs, and knowledge requirements (Lazarus, 1991, p. 39, 151, 177, 210) → implies a Belief-Desire-Intention (BDI) architecture, coping coded as intentions

    * Has been used to model players (Yannakakis and Togelius, 2018, p. 208–209), unsure of use for creating NPCs

- **Scherer** (–)
  - Conceptualizes theory as an information processing system (Scherer, 2001, p. 103–104)
    * Structure based on Cowan (1988)
      · Requires components for: attention, memory, goal/need/motivation, reasoning, and a self-model to evaluate appraisal dimensions (Scherer, 2001, p. 100)
      · Goals/needs/motivations do not have to be conscious (Scherer, 2001, p. 96, 119)
      · Potential to violate *Ability to Operate on Different Levels of NPC Complexity* (RF7) if some parts cannot be excluded
    * Assumes multiple processing levels of varying complexity (Scherer, 2001, p. 103)
      · Faster, less sophisticated levels call "higher" levels when they cannot resolve an evaluation
      · Add more processing layers as needed → potential to support *Ability to Operate on Different Levels of NPC Complexity* (RF7)
    * Parts of the system are represented with a neural network (Scherer, 2001, p. 105)
      · An implementation of Scherer this way was found to be at least partially black-box (Meuleman, 2015, p. 143–144) → violation of *Traceable CME Outputs* (RE4)
  → Emotion generation is *not* independent of the surrounding processes

- **Roseman** (☆☆)
  - Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81) → does not touch on the emotion process itself, effectively architecture-agnostic
  - Some appraisal dimensions have cognitive contents (Roseman et al., 1996, p. 265) → requires some type of architecture to provide appraisal inputs

- **OCC** (☆☆☆)
  - Requires modelling, planning, reasoning, and predictive processes (Ortony et al., 2005, p. 185–186) → not unique to emotion (Clore and Ortony, 2002, p. 36), do not require a separate architecture to support EMgine
    * Precursors to expectations about outcomes and world states, and self-reflection (Ortony et al., 2005, p. 195)
    * Inputs include memory and knowledge (Smith and Kirby, 2000a, p. 101)
    * Assumes that significance detection is cognitive (Clore and Ortony, 2002, p. 42)
  - Requires representations of goals/wants, standards/beliefs, and tastes/attitudes (Ortony et al., 2022, p. 54–59)
    * Evaluate different input types (Ortony et al., 2022, p. 59–60)
    * Can interact to help/hinder each other (Ortony et al., 2022, p. 59)
    * Must be coherent and relatively stable internal structure, like a goal hierarchy, to evaluate the environment by to produce consistent results in both kind and intensity (Ortony, 2002, p. 194–195) → coherence depends on how the user defines these structures, not directly dependent on EMgine

  - Acknowledges that there are different potential action outcomes (Clore and Ortony, 2002, p.41) → potential to create architecture-agnostic outputs
  - Later ties emotion to changes in the body similar to neurophysiological theories (Ortony et al., 2005, p. 174, 177, 188, 195; Clore and Ortony, 2002, p. 24–25, 28–29) → at least partially architecture dependent because of dependence on embodiment

- **Smith & Kirby** (☆☆☆)
  - Conceptualized as a process model, built from previously gathered findings on the effects of emotion and mood on cognition (Smith and Kirby, 2000a, p. 85)
    - Builds from the framework described by Smith and Lazarus (1990) (Smith and Kirby, 2001, p. 122)
      - Does not appear to have the same dependencies on goals, beliefs, and intentions → more likely to be architecture-agnostic
    - Views emotion as a well-being monitor or guidance system for attentional and motivational functions (Smith and Kirby, 2000a, p. 90–91) → idea of a "guidance system" does not belong to any single architecture, potential to apply to many
    - Not empirically tested → EMgine not concerned with "correct" results, just interesting ones
  - Accounts for more than one appraisal process, processes work in parallel (Smith and Kirby, 2000a, p. 91–92; Smith and Kirby, 2001, p. 129)
    - Specifies two appraisal types for automatic reactions (i.e. priming and activation of memories) and deliberative analysis (i.e. reasoning) → notes that concept appears in previous proposals (e.g. Leventhal and Scherer (1987), Sloman et al. (2005))
    - Proposes that memory is a network (Smith and Kirby, 2000a, p. 94, 102)
      - Allows priming and spreading activation → appraisal is continuous, activated quickly and automatically, and does not require much attention
      - Knowledge in memory does not have to be organized in schemas
    - Proposes that reasoning uses highly developed and abstract thinking processes (Smith and Kirby, 2001, p. 130; Smith and Kirby, 2000a, p. 95–96)
      - Requires that memory items be associated with semantic meaning → resulting appraisals can be integrated back into memory for associative processing (i.e. learning)
    - Users are not required to have these processes → core idea of appraisal unaffected because it does not rely on these two specific appraisal types or definitions

- **Oatley & Johnson-Laird** (☆☆☆)
  - Assumes that the cognitive system is modular and asynchronous, similar to Minsky (1986) (Oatley and Johnson-Laird, 1987, p. 31–32), model-driven rather than rule-driven (Johnson-Laird and Oatley, 1992, p. 205–206) → aligns with the idea of architecture independence
    - Top-level module organizes whole system, can reorganize system goals and plans (Oatley, 1992, p. 50–51) → top-level control module in software architecture
  - Implicitly assumes that individuals have beliefs, desires, and needs that they make goals about and plans to achieve (Johnson-Laird and Oatley, 1992, p. 213)

    * Defines "cognitive" as psychological explanations with knowledge representations and transformations that might not be conscious (Oatley and Johnson-Laird, 1987, p. 30) → acts on transformations on data, could be defined for a generalized data representation
    * Core elements are goals and plans (Oatley and Johnson-Laird, 1987, p. 30)
      · Goals → symbolic representations of possible environment states to achieve
      · Plans → sequences from the current environment state to a goal, can include instinctive and highly practised ones (i.e. automatic)
    * Emotions as a mechanism for managing cognitive resources and goal priorities (Johnson-Laird and Oatley, 1992, p. 207–208), and responding to models—including social ones for cooperation and competitive planning—that are proven invalid in the moment (Johnson-Laird and Oatley, 1992, p. 205–206)
      · Triggered when smoothly flowing action is interrupted, detects significant change in goal or plan outcomes, typically at plan junctures (Oatley, 1992, p. 46, 48; Oatley and Johnson-Laird, 1987, p. 35–36)
      · Cause the system to enter an "emotion mode" that inhibits other "emotion modes" or oscillates between multiple "modes" (Oatley and Johnson-Laird, 1987, p. 34) → comparable to other system state changes
      · "Modes" associated with different goal priorities, possible actions, and skills (Oatley and Johnson-Laird, 1987, p. 37)
    → Does not necessarily imply a Belief-Desire-Intention (BDI) architecture
  - Assumes a two-pathway system (Oatley and Johnson-Laird, 1987, p. 32–34)
    * Reactive → propagates a global "signal" to setup an emotion "mode"
    * Deliberative → invoke individual functions, reason about system state for planning
    → Does not depend on specific architecture features, assume that "planning" does not have to be formal
    * Can naturally cause temporal shifts in emotion quality as different processes add meaning (influenced by individual and cultural factors) to a goal/plan change (Oatley and Johnson-Laird, 1987, p. 47)

C.3.2 Flexibility: Choosing Which CME Tasks to Use (RF2)

Appraisal theories are assumed to need some minimum number of processes for emotion generation. Therefore, they are evaluated on the ability to call them individually as needed. It is assumed that a game designer can choose when to call the emotion generation as a complete process.

- **Frijda** (☆)
  - Core emotion process is interdependent (Frijda, 1986, p. 454) → unrealistic to allow its components to be called out of turn
  - Possible to skip and/or interrupt processes (Frijda, 1986, p. 461–463)
    * Direct implementation would require theory knowledge → violates *Hiding the Complexity of Emotion Generation* requirement (RE1)
    * Could build interrupts over the emotion process, temporarily bypassing it (i.e. automatic responses) → emotion process continues at its current pace and updates emotion state when it finishes

  - Task choice difficult to realize within the process, can implement interrupts that bypass the system and act like automatic responses

- **Lazarus** (☆)
  - Emotion process is interdependent (Lazarus, 1991, p. 39, 208–211) → unrealistic to allow its components to be called out of turn
  - No obvious mention of ways to skip or interrupt tasks
  - Define separate processing levels for societal, psychological, and physiological tasks (Lazarus, 1991, p. 211) → could turn whole levels on/off as needed
  - Create switches/input points for designers to allow internal processes (i.e. emotion-based coping) to influence the appraisal process and outcomes (Lazarus, 1991, p. 210)
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → make available to advanced users

- **Scherer** (☆☆☆)
  - Monitoring system triggers appraisal cycles based on relevance (Scherer, 2001, p. 99) → choose when to start and stop reappraisals and/or update appraisal registers
  - Check individual appraisal units (SEC) to update systems and when to see what the current action tendency is (Scherer, 2001, p. 104, 106) → requires caution because it could cause cascading changes in interdependent modules, which also changes the current appraisal
  - Define separate processing levels for different types of information (i.e. sensory-motor, schematic, conceptual) (Scherer, 2001, p. 102–103) → could turn whole levels on/off as needed

- **Roseman** (–)
  - Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81) → does not touch on the emotion process itself

- **OCC** (☆☆)
  - Emotion structure built with three distinct branches → could choose a subset of branches
    * Some emotions only possible if multiple branches active (e.g. *Anger* requires event and attribution branches) (Ortony et al., 2022, p. 29; Ortony, 2002, p. 195; Steunebrink et al., 2009, p. 7)
    * Each branch requires at least one evaluated variable to proceed, additional variables can retain neutral values (Ortony et al., 2022, p. 71, 95, 98) → could choose which tasks to run based on required values
    * Insufficient information could mean that the process will not produce a result

- **Smith & Kirby** (☆☆)
  - Builds on Smith and Lazarus (1990) (Smith and Kirby, 2001, p. 122) ∴ assume that its core emotion process is also interdependent and it is unrealistic to allow its components to be called out of turn

- Control over sources of appraisal inputs (Smith and Kirby, 2000a, p. 93–94, 100; Smith and Kirby, 2001, p. 129–130)
    * Sources interact and their disparate information integrated before appraisal
    * Can control when sources provide information, when to integrate, and how to integrate them → control emotion generation at the triggering stage
    → Potential to choose tasks that provide and integrate inputs, controlling the emotion generation process
    * No obvious information about how to integrate information sources

- **Oatley & Johnson-Laird** (☆☆)
  - Base elements are goals and plans → can decide which plan junctures to call emotion generation at
  - Emotion "modes" have a basic meaning that deliberative processes can build on (Oatley and Johnson-Laird, 1987, p. 35, 43), definition of two pathways that can propagate to the whole system (i.e. reactive) or invoke individual functions (i.e. deliberative) (Oatley and Johnson-Laird, 1987, p. 32–34)
    * Freedom to choose which tasks to call when additional information is needed to add nuance to emotion states
    * Game developer would need to provide all additional tasks → does *not* violate *Hiding the Complexity of Emotion Generation* (RE1) because of its partial basis on an intuitive, "folk" understanding of emotion embedded in language (Oatley, 1992, p. 74–75, 86–87)

C.3.3 Flexibility: Customizing Existing Task Parameters (RF3)

Differing from when game designers call emotion generation tasks is the ability to control their functionality, such as variable sensitivity and activation thresholds. Ideally, EMgine should allow game designers to manipulate as many system parameters as possible to maximize customizability, effectively creating "individual differences" with each change.

- **Frijda** (☆☆☆)
  - Notes many potential elements that can be parameterized, one hypothesized source of individual differences (Frijda, 1986, p. 456–458)
    * Each phase in the core emotion process can be influenced individually by both internal and external inputs
    * Different and variable sensitivity levels/thresholds/concern priorities for matching inputs with satisfaction conditions
    * Variable acceptance conditions for connecting a generated meaning structure with action readiness modes/emotions
    * Open ended parameters → allow designers to customize additional parameters to influence emotion generation
  - Potential to implement some parameters implicitly from system states

- **Lazarus** (–)
  - Discussion of appraisal styles implies that emotion process dispositions are part of an encoding process, not the appraisal itself (Lazarus, 1991, p. 138)
    - Some individual differences contained in the structure and organization of goals (Lazarus, 1991, p. 99) → outside EMgine's scope
    - Personality defined as goal commitments, beliefs, and knowledge as an input to emotion generation (Lazarus, 1991, p. 209) → outside EMgine's scope
  - → No explicit mention of "tuning" the emotion generation process directly
- **Scherer** (☆☆)
  - Parameters associated with appraisal registers (Scherer, 2001, p. 105–106)
    - Individual variables combined with weighted functions that change with the "confidence" in the data → mechanize as a user-defined task parameter
    - Action tendency activation "strength" tied to appraisal profile and degree of "definiteness" of individual checks → potential for parameterized activation thresholds based on strength and confidence in appraisal check accuracy
- **Roseman** (–)
  - Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, the structure of emotions (Roseman, 2001, p. 68, 81), and empirical validation of appraisal dimension influence on resulting emotion (Roseman et al., 1996, p. 242, 244) → does not touch on the emotion process itself
- **OCC** (☆☆)
  - Parameterization of emotion intensity and activation thresholds → change how easily and intensely emotions are produced (Ortony et al., 2022, p. 220–221)
    - Variable weights on emotion intensity function
    - Modulation of emotion thresholds → changes how strong the emotion is before it manifests
  - Elicitation rule conflict resolution not addressed (Ortony et al., 2022, p. 228) → allow customization of rule priority
  - Handling "mixed emotions", coexisting positive and negative emotions from the same appraisal (Ortony et al., 2022, p. 63–64) → implement customizable mechanism to determine which to express at any given moment
  - Suggest varying parameters on emotion generation mechanisms (Ortony, 2002, p. 203) → process not well defined, limits ability to implement it
  - If multiple processing levels are implemented, can parameterize the thresholds for control and interrupt thresholds from each one (Ortony et al., 2005, p. 185)
  - Few guidelines about how these work → risk of reducing psychological validity
- **Smith & Kirby** (☆☆)
  - Builds on Smith and Lazarus (1990) (Smith and Kirby, 2001, p. 122) ∴ assume that its core emotion process prevents direct "tuning" too

  - Control over appraisal input sources (Smith and Kirby, 2000a, p. 93–94, 100)
    * Sources interact and their separate information integrated before appraisal → control degrees of interaction and weights during information integration
    * Can control when sources provide information → "sensitivity" or activation thresholds
    * No obvious information about how to integrate information sources

- **Oatley & Johnson-Laird** (☆☆)
  - Emotions elicited by relative changes in success probabilities at plan junctions (Oatley, 1992, p. 98) → candidate for implementing sensitivity thresholds
  - Mentions temporal differences in emotion intensity, variable emotion decay rates of emotion, replacement with other emotions elicited by the same scenario (Oatley, 1992, p. 22–23) → candidates for customizing how emotion quality and intensity varies over time and context
  - Few guidelines about how to define parameters → low risk of violating psychological validity due to its partial basis on an intuitive, "folk" understanding of emotion embedded in language (Oatley, 1992, p. 74–75, 86–87)

C.3.4 Flexibility: Allowing the Integration of New Components (RF4)

When included, the appraisal theories tend to define other affective types relative to emotion. This implies that integrating them requires no additional structures in favour of building on top of existing features. This makes them ideally suited for *Allowing the Integration of New Components* (RF4) in this respect.

Although integrating non-affective components should be theory-agnostic, how easily this can be done varies between appraisal theories. Therefore, the analysis examines their ability to integrate both affective and non-affective components.

- **Frijda** (☆☆☆)
  - Proposes that adding, removing, and/or modifying the components of emotion creates different types of affect (Frijda, 1986, p. 253) → does not require changes to emotion generation, definitions built on top of existing emotion definitions and functions
    * Later refinement for an implemented version of the theory related mood, personality, and sentiments to emotion by their focus and duration (Figure C.1)
    * Could derive core affect from emotion process via the *valence* and *demand character* appraisal dimensions and Arousal value (Frijda, 1986, p. 207, 454)
  - Inclusion of a "Regulation Processes" block that can affect nearly all parts of the emotion process (Frijda, 1986, p. 545)
    * Multiple points to introduce new components and processes → easy to add non-affective components
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) if users can access points directly → create an interface to hide entry points, make it easier to use and understand

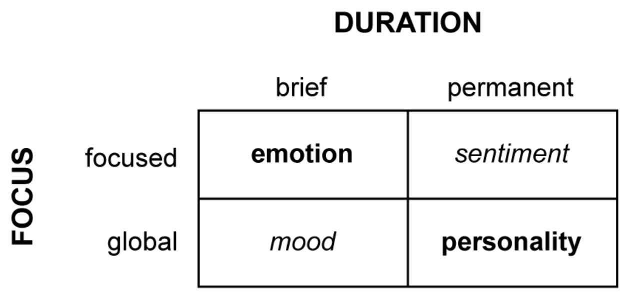


Figure C.1: Proposed Relation Between Emotion and Other Affective Types based on Frijda (Adapted from Moffat (1997, p. 136))

- **Lazarus** (☆)
  - Personality not seen as a set of innate traits that manifest in appraisal and coping (Lazarus, 1991, p. 316), defined as a collection of goals, needs, commitments, knowledge, attitudes, and beliefs that influence how an event is perceived and how the individual acts on the resulting action tendency (Smith and Lazarus, 1990, p. 623–624, 628) → implicitly defined
    - ∗ Affords flexibility (i.e. not limited to a set of values) → supports creative freedom, definitions of individual characters based on their goals and knowledge rather than numerical values
    - ∗ More difficult to define personality quickly (e.g. have to decide what beliefs a character with a desired personality would have)
  - Mood is "an existential state or condition of life" that is appraisal-dependent, related to subjective well-being (Lazarus, 1991, p. 266–267)
    - ∗ Could define as a state that aggregates appraisal results into a "satisfaction/dissatisfaction" value
  - Equates affect to subjective experience (Lazarus, 1991, p. 57)
    - ∗ Could define core affect using *goal congruence* as Valence
    - ∗ Arousal is part of an action tendency, tied to the emotion's core relational theme (Lazarus, 1991, p. 58–59, 150) → not explicitly defined
  - Potential interface points for external processes part of input generation/output manipulation (Lazarus, 1991, p. 210) → does not have to integrate with emotion generation processes, trivial to add non-affective components
- **Scherer** (☆)
  - Proposes definitions for mood and personality (Scherer, 2000, p. 140–141), but are not accounted for in the working theory (Scherer, 2001, p. 93, 119)
    - ∗ Personality could be defined as sensitivities in appraisal dimension and register functions, mood as temporary sensitivities caused by previous appraisals → potential to violate psychological validity
  - No clear connection to core affect

  - Potential to integrate non-affective components during the information processing and appraisal objective steps (Scherer, 2001, p. 104) → might require knowledge of how those components work, violating *Hiding the Complexity of Emotion Generation* (RE1)

- **Roseman** (☆)
  - Suggests that mood and personality are tied to emotion generation (Roseman, 2001, p. 81–83), ways to describe appraisal styles for individual or families of emotion (Roseman, 2001, p. 88–89) → implicitly defined
    - Affords flexibility (i.e. not limited to a set of values) → supports creative freedom, definitions of individual characters based on their goals and knowledge rather than numerical values
    - More difficult to define quickly (e.g. have to decide what appraisal dispositions a character with a desired personality would have)
    - Could be extended to represent cultural influences on emotion generation
  - No clear connection to core affect
    - Could define core affect using *situational state* and *motivational state* as Valence
    - No obvious component for Arousal
  - Focus on the relationship between appraisal values and emotions (Roseman, 2001, p. 81) → does not focus on other parts of the generation process, no obvious place to integrate non-affective processes

- **OCC** (☆☆☆)
  - Proposes that personality is a unique parameter profile defining how emotion generation behaves within and between process levels (Ortony et al., 2005, p. 189–190)
    - Tuning emotion generation for each NPC → personality implicitly supported by *Customizing Existing CME Task Parameters* (RF3)
    - Could implement personality inventories as parameter profiles (Ortony et al., 2005, p. 191–192) → does not provide explicit definitions, potential to violate psychological validity if done incorrectly, might not matter if the profiles do what the developer expects
  - Moods described as free-floating, object-less affective states that can influence emotion but can also arise from sources independently of emotion (Clore and Ortony, 2002, p. 27) → could be linked to personality "parameter profiles" by treating it as an initial condition
    - Defined as temporally-driven parameter changes (Ortony et al., 2022, p. 221–222, 228) → implicitly supported by *Customizing Existing CME Task Parameters* (RF3)
  - Potential to represent core affect
    - Arousal is a global intensity variable, roughly proportional to base emotion intensity or perhaps even only parts of this (i.e. subjective importance of the situation) (Ortony et al., 2022, p. 80–83) → other factors can influence it and has a slow rate of decay, supports *Customizing Existing CME Task Parameters* (RF3)
    - It follows that Valence might be approximated as sum of the absolute signed values of the same variables (i.e. is the overall feeling positive or negative?)
  - Two potential ways to integrate non-affective components

    * As part of the input generation process → designer-driven, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)
    * As a method for controlling task parameters → implicitly supported by *Customizing Existing CME Task Parameters* (RF3)

- **Smith & Kirby** (☆)
  - No clear definitions for personality, mood, or core affect
    * Potential correlation between *emotion-focused coping potential* and some personality traits (Smith and Kirby, 2009a, p. 1366–1368, 1369) → suggests that personality traits are parameters on the emotion generation process
    * Core affect could be constructed from *motivational congruence* (as Valence) and *motivational relevance* (as Arousal) → not necessarily empirically supported, potential to violate psychological validity
  - Appraisal registers synthesize information from multiple sources and levels of processing (Smith and Kirby, 2001, p. 130)
    * Multiple points to introduce new components and processes → easy to add non-affective components
    * Integrating non-affective components would require manipulating the detector mechanisms, potential to violate *Hiding the Complexity of Emotion Generation* (RE1) if users can access points directly → create an interface to hide entry points, make it easier to use and understand

- **Oatley & Johnson-Laird** (☆☆☆)
  - Emotions often have moods and sentiments associated with them (Oatley, 2000, p. 87) → implies that adding these affective types would be an extension of existing emotion structures
  - Temperaments (i.e. personality traits) hypothesized to be enduring predispositions towards emotion "modes" (Oatley and Johnson-Laird, 1987, p. 34; Oatley, 1992, p. 61)
    * Also defines sentiments—enduring emotional dispositions about something, typically other individuals (Oatley, 2000, p. 81) → potential to define two sets of personality traits (general and target-specific), affords more creative freedom
  - Moods defined directly in the theory as control signals that persist after the cause of an emotion passes/no longer associated with semantic content and keeps the system in a particular state (Oatley and Johnson-Laird, 1987, p. 32; Oatley, 1992, p. 64)
    * Could be realized as temporary predispositions towards emotion "modes" or a longer lasting, low intensity emotion state (Oatley and Johnson-Laird, 1987, p. 34–35) → potential to allow both, give user the choice of which to use, affording more creative freedom
  - Potential to define core affect based on how a goal is affected (positive or negative) for Valence, emotion intensity as Arousal → no explicit definitions given, potential to violate psychological validity if done incorrectly, might not matter if the profiles do what the developer expects
  - Assume that the cognitive system is modular and asynchronous (Oatley and Johnson-Laird, 1987, p. 31) → implies that adding non-affective processes is feasible, should not require knowledge of the inner workings of emotion generation

C.3.5 Flexibility: Choosing NPC Emotions (RF5)

Like the discrete theories, the appraisal theories tend to define emotions as categories to group different aspects of a response together. In this sense, excluding predefined emotions is trivial. Once again, *adding* new ones is unclear and there are no obvious "rules" to follow. EMgine can still take advantage of them because new emotions need only make sense to the developer so that they can use them. Therefore, the appraisal theories are evaluated for what a developer would need to do and how easy it is to realize.

- **Frijda** (☆)
  - Emotions as descriptions of action readiness in response to different combinations of events, or by the nature of the emotional object (Frijda, 1986, p. 72–74) → defining new emotions requires defining new action tendencies
    * Requires modifications to the emotion generation process (i.e. defining appraisal patterns) → violates *Hiding the Complexity of Emotion Generation* (RE1)
    * Some "non-basic" emotions are blends, can define a limited set of additional emotions → limited flexibility
    * Define emotions by pairing existing ones with an event or object type and assigning it a new name → similar to scripting, event-coding
- **Lazarus** (☆)
  - Emotions associated with themes that can coexist (Lazarus, 1991, p. 229)
    * Potential to allow developers to create named combinations representing "new" emotions → necessarily create more complicated emotions
    * Defining emotions that are not combinations would require new appraisal pattern definitions (i.e. modify the emotion generation process) → violates *Hiding the Complexity of Emotion Generation* (RE1)
- **Scherer** (☆☆)
  - "Emotions" defined as the net effect of continuous, fluctuating changes in subsystems (Scherer, 2001, p. 106, 108)
    * Adding new emotions requires identification and naming of a set of subsystem changes (i.e. requires an understanding of how emotions are generated) → violates *Hiding the Complexity of Emotion Generation* (RE1)
  - "Innate" emotions[5] (e.g. *Joy*) attributed to common adaptational issues that produce consistent system effects (Scherer, 2001, p. 108, 113) → range of known emotions are products of mixtures and/or blends of "innate" ones
    * Some emotion profiles have "open" entries that can accept any value for that dimension → potential to define emotion family "members" by providing specific values for "open" entries, potential to violate *Hiding the Complexity of Emotion Generation* (RE1)
    * Intensity differences can also differentiate otherwise identical emotions → define new emotions by intensity class, external to the emotion generation process so no violation of *Hiding the Complexity of Emotion Generation* (RE1)

[5]Scherer calls them *modal* emotions.

- **Roseman** (☆☆)
  - Proposes that more than one emotion can be experienced simultaneously due to different evaluations (Roseman, 2001, p. 81)
    - Definition of new emotions as mixtures → external to the generation process, so no clear violation of *Hiding the Complexity of Emotion Generation* (RE1)
    - Emotions logically grouped by response strategy (e.g. *attack*, *exclude*) → potential for a design tool to guide the process of defining new emotions?
- **OCC** (☆☆)
  - Emotions necessarily tied to cognitive abilities that build on four basic affective states (Ortony et al., 2005, p. 183–184) implies that adding "new" emotions is about adding meaning → dependent on what is available for inputs, designer-driven, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)
  - Proposed a smaller emotion structure for believable agents, collapsing 22 emotions into five positive and five negative ones (Ortony, 2002, p. 193–194)
    - Potential to add "new" emotions as more cognitive processes are added → dependent on what is available for inputs, designer-driven, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)
  - *Surprise* as a special case, can be added with the *unexpectedness* appraisal variable (Ortony, 2022, p. 13–14, 16–17)
  - "New" emotions can be defined as differences in intensity/elicitation thresholds (e.g. *Pleased* for low intensity and *Ecstatic* for high) (Ortony et al., 2022, p. 220–221)
    - External to the emotion generation process → no violation of *Hiding the Complexity of Emotion Generation* (RE1)
- **Smith & Kirby** (☆)
  - Unclear how to define additional emotions
  - Hypothesizes that emotion categories are likely dense clusters in dimensional space (Smith and Scott, 1997, p. 245–246)
    - Potential to combine with V-A or PAD Space, define new emotion categories from existing data clusters → would require some understanding of source material, potential violation of *Hiding the Complexity of Emotion Generation* (RE1)
    - Developers could collect their own data to find affective "clusters" in a dimensional space → time consuming, error-prone, potential violation of *Hiding the Complexity of Emotion Generation* (RE1)
- **Oatley & Johnson-Laird** (☆☆☆)
  - How people describe emotions in everyday language indicates underlying cognitive meanings (Johnson-Laird and Oatley, 1992, p. 210) → can build on a layperson's understanding of emotions, supports *Hiding the Complexity of Emotion Generation* (RE1)
  - Emotion "modes" are not absolute definitions, only have heuristic properties that capture general classes of events (Oatley, 2000, p. 87) → potential to create more refined emotions by constraining the classes

    - "New"/"adult" emotions are based on emotion "modes", deliberative processes attach more meaning to them (Oatley and Johnson-Laird, 1987, p. 35, 43; Oatley, 1992, p. 76–78)
    - Can also be defined at junctions of mutual plans with one or more other agents, requires a self-model (Oatley and Johnson-Laird, 1987, p. 44, 46, 48) → way to integrate cultural differences due to the impact on models and reasoning processes (Oatley and Johnson-Laird, 1987, p. 47)
  - Emotions that have different semantic contents can exist simultaneously (Oatley, 1992, p. 104) → potential to define emotion "mixtures"
    - External to the emotion generation process → no violation of *Hiding the Complexity of Emotion Generation* (RE1)

C.3.6 Flexibility: Allowing Developers to Specify How to Use CME Outputs (RF6)

There is a clear difference between reflexes and emotions: one is very difficult to control how one reacts and the other has a range of them to pick from (Fellous, 2004, p. 45). The idea of emotion *components* also suggests that there is flexibility in which system aspects emotion affects and how (Hudlicka, 2019, p. 133; Scherer, 2001, p. 108; Roseman, 2011, p. 436). This implies that *any* appraisal theory should be able to strongly support this requirement. The question is now how well each theory defines what this means.

- **Frijda** (☆☆☆)
  - Set the output boundary of EMgine at the action proposer (i.e. action tendency), relevance and control precedence signals, and physiological change generator (i.e. Arousal) points (Frijda, 1986, p. 455)
    - Would also allow for another layer to group these into emotion categories (Frijda, 1986, p. 72)
    - Can feed the outputs back into EMgine → provide an interface so that this is a matter of "flipping a switch", supported by *Customizing Existing CME Task Parameters* (RF3)
    - → Allows maximum flexibility for defining what to do with outputs that is agnostic to how "action" is defined
- **Lazarus** (☆☆☆)
  - Set the output boundary of EMgine at the appraisal outcome (i.e. action tendency, subjective experience, physiological response), would also allow for labelling the output with emotion categories (Lazarus, 1991, p. 209–210)
    - Excludes coping process integral to the theory → could be added as an external component, supported by *Allowing the Integration of New CME Components* (RF4)
    - Resulting NPC actions would impact their interpretation of the environment → implicitly supports the reappraisal process (Lazarus, 1991, p. 134)
    - Can feed the outputs back into EMgine → provide an interface so that this is a matter of "flipping a switch", supported by *Customizing Existing CME Task Parameters* (RF3)

→ Allows maximum flexibility for defining what to do with outputs that is agnostic to how "action" is defined

- **Scherer** (☆☆☆)
  - Set the output boundary of EMgine at the action tendency level, would also allow for labelling the output with emotion categories (Scherer, 2001, p. 107, 113) → allows maximum flexibility for defining what to do with outputs that is agnostic to how "action" is defined
  - Allow users to access individual appraisal registers (Scherer, 2001, p. 104) → affords more flexibility
    - ∗ Each part of the appraisal process makes changes to different subsystems, creates continuously changing outputs (Scherer, 2001, p. 107) → appraisal "history" encoded in unique pattern caused by subsystem changes, values update frequently
    - ∗ Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → make available for advanced users
    - ∗ Potential to violate psychological validity → how a user uses the values should be external to EMgine, so its internal psychological validity would remain intact
- **Roseman** (☆☆☆)
  - Set the output boundary of EMgine at the "response strategy", the typical physiological, phenomenological, expressive, behavioural, and motivational emotion contents (Roseman, 2013, p. 141; Roseman, 2001, p. 75; Roseman, 2018, p. 146–148, 151–152)
    - ∗ Potential to connect components directly to existing game modules (e.g. "expressive" as an input to NPC animation, "motivation" to planning) → user chooses which ones to use, supported by *Choosing Which CME Tasks to Use* (RF2)
    - ∗ Differentiates between "action tendency" and what action is actually taken, informed by emotion intensity (Roseman, 2011, p. 436) → input to the behaviour/expression selection process, explicitly built-in support for *Allowing Developers to Specify How to Use CME Outputs* (RF6)
    - ∗ Also notes that there is consistency in what types of responses that each emotion elicits (Roseman, 2011) → creates consistent behaviour necessary for believability (Ortony, 2002, p. 200)

  → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large
- **OCC** (☆☆☆)
  - Set the output boundary of EMgine at the evaluation of emotion categories and intensities (Ortony et al., 2022, p. 29, 72, 84)
    - ∗ Propose that action tendencies are not necessary or sufficient to define emotion because some emotions might lack a "characteristic" action tendency as defined as voluntary actions following emotion (Ortony et al., 2022, p. 14) → allows the generation of emotions that lack one, removes constraint from user
    - ∗ Claims "action tendency" is a set of components that emotions constrain themselves to but might not use all components (Ortony, 2002, p. 198, 201) → creates consistent behaviour necessary for believability (Ortony, 2002, p. 200)

  → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large

- **Smith & Kirby** (☆☆☆)
  - Set the output boundary of EMgine at "emotional response", contains appraisal outcome (e.g. emotion category and dimensions, intensity), physiological activity (e.g. Arousal, facial expressions), and action tendencies (Smith and Kirby, 2001, p. 123, 130)
    - ∗ Users can separate components and send them to different system processes
    - ∗ Can also send components back into appraisal processes via appraisal sources → potential for different interpretations due to processing in appraisal source (Smith and Kirby, 2000a, p. 99)
    - → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large
- **Oatley & Johnson-Laird** (☆☆☆)
  - Set the output boundary of EMgine at control signals, labelled with an emotion category (Oatley, 1992, p. 50, 54)
  - Control signals are global entities or "alarms" that change the system "mode" when a goal is impacted by an active plan, bringing it into focus (Oatley, 1992, p. 62–63)
    - ∗ Users can choose which system components are receptive to the signal and to what degree → supported by *Choosing Which CME Tasks to Use* (RF2) and *Customizing Existing CME Task Parameters* (RF3)
    - → Allows maximum flexibility for defining what to do with outputs that is agnostic to the system at large

C.3.7 Flexibility: Ability to Operate on Different Levels of NPC Complexity (RF7)

Due to the assumed role of cognition in emotion processes (Gratch and Marsella, 2015, p. 55; Broekens, 2021, p. 354), there is also an assumed level of NPC complexity needed for an appraisal-based CME to properly function. Therefore, the appraisal theories evaluation is concerned with how much cognitive processing it requires to produce results.

- **Frijda** (☆)
  - Requires encoded categories for events and rules for inputs, action structures for evaluating coping, process to evaluate event/action implications, definition of concern structures (Frijda, 1986, p. 457) → effort to create likely to linearly increase with respect to game complexity
    - ∗ Some can be implicitly evaluated in EMgine → relieves some of the authorial burden from game designers
  - Can add regulation processes as needed, not mandated in the core emotion process (Frijda, 1986, p. 454, 456) → can potentially adapt to increases in NPC/game complexity
    - ∗ Path in process to add planning if needed, but not critical to function (Frijda, 1986, p. 462)

  - Requires a monitoring process (i.e. blackboard structure) to continuously update situational meaning (Frijda, 1986, p. 459) → space requirements increases with information sources

- **Lazarus** (☆☆☆)
  - Purpose of appraisal is to "integrate the two [personal interests with environmental realities] as effectively as possible" (Lazarus, 1991, p. 135) → complexity controlled by EMgine, can be made relatively simple
  - Complexity in individual factors and environmental condition evaluations that get passed to appraisal (Lazarus, 1991, p. 209–210) → designer controlled, can define to match game complexity
    - ∗ Minimally requires definitions for goals, "ego type", event causes, predictions about the impact of actions and future events (Lazarus, 1991, p. 149–150)
    - → Could connect to hard-coded data/processes for low-complexity games (e.g. *Pac-Man* (Namco, 1980)), increase complexity with game
  - Implication of a central data structure to store appraisal values as they become available (Lazarus, 1991, p. 134, 151, 189, 210–211)
    - ∗ Stores outputs of appraisal evaluations, not the inputs
    - → Complexity likely to be constant or linearly increase with respect to the number and complexity of inputs

- **Scherer** (☆☆☆)
  - Built-in support for variable NPC complexity
    - ∗ Appraisal dimension groupings (SECs) can be as complex as the information processing system allows, often a continuous or graded scalar or multidimensional evaluation (Scherer, 2001, p. 94) → numerical values easier to manipulate
    - ∗ Assumes three levels of processing (sensory-motor, schematic, conceptual) that interact (Scherer, 2001, p. 102–103) → potential to derive some information in EMgine implicitly from inputs
      - · Provide option to turn these tasks off or configure them → support for *Choosing Which CME Tasks to Use* (RF2) and *Customizing Existing Task Parameters* (RF3)
  - Reappraisals run until a monitoring system signals termination or adjustment, appraisal components updated by reappraisals (Scherer, 2001, p. 99) → game designer can decide when to terminate appraisal cycles based on game needs, support of *Customizing Existing Task Parameters* (RF3) and *Be Efficient and Scalable* (RF8)
  - Appraisal registers updated as new information becomes available, central structure, can control relative importance of each value using a weighted function to represent "goodness" of data (Scherer, 2001, p. 105);
    - ∗ Implies a temporal and confidence value for each register (Scherer, 2001, p. 106) → game designer can decide when to evaluate emotion state based on these values, support of *Customizing Existing Task Parameters* (RF3)

- **Roseman** (☆☆)
  - Suggestion that there are different versions of appraisal mechanisms of variable complexity triggered as time allows (Roseman, 2001, p. 77), influenced by emotion intensity (Roseman, 2011, p. 440)
    - ∗ Can specify different appraisal mechanisms → game designers can build on top of input API, choose how information is synthesized into EMgine inputs
  - Still requires empirical data to determine the minimum cognitive requirements for appraisals (Roseman, 2001, p. 87–88)
    - ∗ Lowest level involves fixed action patterns (Clore and Ortony, 2002, p. 32) → correspondence with core EMgine tasks, direct match between generated emotion and game designer-assigned behaviours
    - ∗ With no defined process, do not know how to integrate cognitive processes into EMgine
- **OCC** (☆☆)
  - Has three levels of processing (reactive, routine, reflective) (Ortony et al., 2005, p. 175–177, 179)
    - ∗ OCC proper part of the highest processing level, "reflective", does not interact with external environment → requires cognitive/high-level processes, inputs from other two levels
    - ∗ Number of potential emotions restricted in reactive (no emotions) and routine (four emotions) levels → violates *Choosing NPC Emotions* (RF5)
    - ∗ Assumptions make it unlikely to be applicable to architectures that are simpler than adult humans (Sloman et al., 2005, p. 220)
  - Produce a simpler, less rigorous architecture with one processing level
    - ∗ Complexity might lie in variable evaluations and representations of goals/standards/attitudes, coding of rules appears relatively simple (Ortony et al., 2022, p. 220–227)
    - ∗ Could allow for user-defined evaluations and representations → support as a Domain-Specific Language (DSL) to avoid violating *Hiding the Complexity of Emotion Generation* (RE1)
- **Smith & Kirby** (☆☆☆)
  - Potential to design multiple appraisal mechanisms that rely on different functions (e.g. planning, expectation evaluation) → clear distinction between available functions and EMgine's abilities
    - ∗ Number of appraisal variables determines types of emotion available (Yih et al., 2016a; Yih et al., 2016b; Yih et al., 2020, p. 488–492)
    - → Number of potential emotion categories tied to NPC complexity
    - ∗ Potential to violate *Choosing NPC Emotions* (RF5) → assuming that NPC complexity and what emotions the game designer wants them to have are directly proportional, this is unlikely to be a concern

- **Oatley & Johnson-Laird** (☆☆)
  - Distinguishing emotion types changes based on cognitive abilities (Oatley and Johnson-Laird, 1987, p. 40–41), possible goal and plan representations (Oatley, 1992, p. 57–58)
    * Emotion "modes" as "base classes" of emotion
    → Number of potential emotion categories tied to NPC complexity
    * Potential to violate *Choosing NPC Emotions* (RF5) → assuming that NPC complexity and what emotions the game designer wants them to have are directly proportional, this is unlikely to be a concern

C.3.8 Flexibility: Be Efficient and Scalable (RF8)

The main concern for the efficiency and scalability of the appraisal theories is how they evaluate inputs. However, this complexity seems to lie in input creation. Since this precedes their transformation into emotions, action tendencies, and other components, it passes a lot of this burden to the game developer. Ideally, EMgine would handle more of these tasks. However, this also allows developers to choose how they want to generate inputs. Ultimately this gives them more freedom and allows EMgine to merge more easily into different games and underlying architectures. What EMgine focuses on, then, is helping game developers manage different evaluation processes.

- **Frijda** (☆☆)
  - Uses 17–24 appraisal dimensions to create unique profiles for emotions, not all dimensions needed for each emotion (Frijda, 1986, p. 205–219; Frijda, 1987, p. 121–124)
    * Efficiency might be hindered if unnecessary dimensions are evaluated
    * Give developers choice of appraisal dimensions → compromises *Hiding the Complexity of Emotion Generation* (RE1)
  - Scalability mostly driven by complexity of inputs and externally-defined regulation processes → depends on complexity of evaluations to generate inputs, designer-driven
- **Lazarus** (☆☆☆)
  - Dependent on knowledge (Lazarus, 1991, p. 145), knowledge evaluation mechanisms → depends on designer chosen architecture
  - Appraisal process appears to be of a fixed complexity once inputs are given (Lazarus, 1991, p. 210), implies that scalability depends on complexity of knowledge processes and inputs → depends on complexity of evaluations to generate inputs, designer-driven
- **Scherer** (☆☆)
  - Uses 16 appraisal dimensions divided into four groups (Scherer, 2001, p. 114–115) → minimum set of appraisal dimensions necessary to differentiate emotion families (Scherer, 2001, p. 94)
  - Evaluates groups to avoid using unneeded expensive processes (Scherer, 2001, p. 99–100, 102–103)
    * Does not exclude potential to begin getting partial results by running the four components in parallel

    - Groups can have more than one associated process → lower level processes for each group first, higher level processes only used if they do not return results
    - Can add a central controller to allow integration of additional processes similar to Smith & Kirby appraisal detector (Scherer, 2001, p. 103–105)
  - → Efficiency tied to the complexity of inputs, partially designer-driven
  - → Mechanisms for scalability built-in, but requires more overhead to manage, might conflict with *Ability to Operate on Different Levels of NPC Complexity* (RF7)

- **Roseman** (☆)
  - Suggests that there are different versions of appraisal mechanisms of variable complexity triggered as time allows (Roseman, 2001, p. 77) → potential for scalability, efficiency
  - Focuses on the structure of emotions and appraisal dimensions (Roseman, 2001, p. 68, 81) → no further information given

- **OCC** (☆☆)
  - Uses 3–14 variables to differentiate emotion families, not all variables needed for each emotion (Ortony et al., 2022, p. 29, 72, 84) → can prevent evaluation of some variables based on the active branch
  - Efficiency tied to complexity of inputs (Ortony et al., 2022, p. 220–227) → tied to evaluation mechanisms, designer-driven
  - Can introduce mechanisms such that lower-complexity processes run first and call higher-complexity processes if they cannot produce a result (Ortony et al., 2005, p. 179) → more control of efficiency and scalability
  - Can have two parallel emotion-elicitation mechanisms → can produce conflicting results (Clore and Ortony, 2002, p. 37–39, 54)
    - Memory-based heuristics, which is faster and more error-prone → improved efficiency, could run into memory-related scalability issues
    - Deliberative processing, which is slower and less error-prone → reduced efficiency, more scale-friendly
    - → Could create a more believable result, but might conflict with *Ability to Operate on Different Levels of NPC Complexity* (RF7)

- **Smith & Kirby** (☆☆☆)
  - Uses 7–16 variables to create unique profiles for emotions, not all dimensions needed for each emotion (Yih et al., 2020, p. 489; Yih et al., 2016a)
    - Efficiency might be hindered if unnecessary dimensions are evaluated
    - Give developers choice of appraisal dimensions → compromises *Hiding the Complexity of Emotion Generation* (RE1)
  - A few variables could be evaluated by EMgine (e.g. *motivational relevance*) → efficiency and scalability controlled by EMgine
  - Some evaluation processes produce inputs *for* EMgine → designer-driven, architecture dependent

    * Appraisal detector continuously monitors for changes in variables, combines information and called appraisal process (Smith and Kirby, 2001, p. 129–130) → implicitly enforces scalability as developers add and remove processes
        · Detector must only require minimal resources to function well (Smith and Kirby, 2000a, p. 90–91) → acknowledges that efficiency is essential
    * Support for multiple, parallel user-defined processes that could have variable complexity levels (Smith and Kirby, 2000a, p. 91–92) → create a mechanism for developers to define when complex processes activate

- **Oatley & Johnson-Laird** (☆☆☆)
  - Assumes a system that coordinates multiple plans and goals under time and resource constraints (e.g. plans only work 1–2 steps ahead) (Oatley and Johnson-Laird, 1987, p. 31, 36) → property of the architecture, designer-driven
  - Goals and plans associated with emotion has their own monitoring mechanisms (Oatley, 1992, p. 50) → can decide which ones to associate with EMgine, built-in scalability
    * Mechanism would work on goal and plan information → can be made efficient
  - Emotions can be given more complex meanings by evaluating more information via selective function calls (Oatley and Johnson-Laird, 1987, p. 32–34) → designer-dependent and ties scalability, efficiency scaled to the needs of the game, supports *Ability to Operate on Different Levels of NPC Complexity* (RF7)

C.3.9 Ease-of-Use: Hiding the Complexity of Emotion Generation (RE1)

The appraisal theories generally have strong support for this requirement. Designers do not need to know what is done with the inputs they provide, so the processing of those inputs can be hidden from them.

- **Frijda** (☆☆☆)
  - System arranged so that information can be supplied at any point to black box processes, tracked by an internal monitor/situational meaning blackboard structure (Frijda, 1986, p. 455–456, 459) → do not need to know how the process uses information
- **Lazarus** (☆☆☆)
  - Appraisal assigns personal meaning to knowledge (Lazarus, 1991, p. 145) → do not need to know how the process uses information
  - Six appraisal dimensions, reappraisal accounts for changes to input values (Lazarus, 1991, p. 134, 149–150) → can incorporate changing information as a queue of input values
- **Scherer** (☆☆☆)
  - Inputs combined into registers (Scherer, 2001, p. 105), patterns of register values matched to emotions (Scherer, 2001, p. 114–115) → do not need to know how this is done
    * Some dimensions are pure information (e.g. *intrinsic pleasantness*) (Lazarus, 1991, p. 146) → inherently hides process complexity

    * Appraisal dimension groupings (SECs) can be divided into hard-wired and deliberative units (Scherer, 2001, p. 102) → do not need to know which ones are deliberative or not
  - Changes in SECs can cause continuously changing outputs (Scherer, 2001, p. 107) → need only query if there has been a change, do not need to know if the generation process was triggered

- **Roseman** (☆☆)
  - Inputs pattern-matched to emotion families (Roseman, 2001, p. 70–71, 81) → do not need to know what the patterns are
  - Focus on the relationship between appraisal values and emotions (Roseman, 2001, p. 81) → does not focus on other parts of the generation process

- **OCC** (☆☆)
  - Inputs pattern-matched to emotions, combined into intensity values and compared to threshold rules (Ortony et al., 2022, p. 84, 227–228) → do not need to know how this is done
  - Need to know patterns of variables to support *Choosing NPC Emotions* (RF5) → potential to expose variable patterns, but not how the variables are combined or compared to threshold rules

- **Smith & Kirby** (☆☆)
  - Inputs combined into single unit by appraisal register, triggers generation process (Smith and Kirby, 2001, p. 130) → do not need to know how this is done
  - Need to know patterns of variables to support *Choosing NPC Emotions* (RF5) (Yih et al., 2020, p. 489; Yih et al., 2016a) → potential to expose variable patterns, but not how they are used

- **Oatley & Johnson-Laird** (☆☆)
  - Emotions as products of interpretations of goals and plans (Oatley and Johnson-Laird, 1987, p. 30) → do not need to know how they are interpreted
  - Need to provide additional information to support *Choosing NPC Emotions* (RF5)
    * Add contextual information to generated emotion (Oatley, 1992, p. 76–78) → does not require knowledge of how the emotion was produced
    * Tied to "folk" understanding of emotions, their consequences, and antecedents (Johnson-Laird and Oatley, 1992, p. 214–215) → minimizes potential to violate this requirement

C.3.10 Ease-of-Use: Having a Clear API (Input) (RE2)

It is not enough for an appraisal theory to be clear in what it requires for appraisal. It must also be clear in what it does with those inputs to produce an unambiguous output. Therefore, the theories are analyzed for both their necessary inputs, how those could be realized as an input interface, and how those inputs map to appraisal outputs.

- **Frijda** (☆☆)
  - Minimally requires definition of concerns (which include goal definitions), environment states/events, action (tendency) structures (Frijda, 1986, p. 454, 457) → generally do not know how to define inputs (Roseman, 2001, p. 86–87)
  - At least 20 variables listed (Frijda, 1986, p. 205–216), smaller list of 14 variables have preliminary empirical validation (Frijda, 1987, p. 128–131) → potential to overwhelm users with the full list
    - Some variables describe knowledge (e.g. *valence* (Frijda, 1986, p. 207)) → cannot remove from input variable list
    - Some variables could be derived from knowledge (e.g. *change* derived from previous and current state, implicit in definition of "event" (Frijda, 1986, p. 209–210)) → exchange variables for knowledge in input list
      - Might be able to reduce the required input list if there are overlaps in required knowledge for many variables
      - Replace variable names with knowledge that is generally understood (e.g. states, goals) → supports *Hiding the Complexity of Emotion Generation* (RE1)
    - Some variables might be encoded implicitly in others (e.g. *presence/absence*, *urgency* (Frijda, 1986, p. 208–209, 455)) → do not have to be exposed to user, reduce required input list in API
    - Unique profiles for some emotions (Frijda, 1986, p. 217–219), empirical validation of some patterns (Frijda, 1987, p. 122–123) showing that each emotion uses a subset of variables → might be able to define subsets of variables if some emotions are not needed
  - → Options error-prone, require careful design of EMgine
    - Do not know how to define some of these inputs (Roseman, 2001, p. 86–87)
- **Lazarus** (–)
  - Minimally requires local and global "ego-identity" goals, causal agents and their control over an event, coping potential, predictions about future prospects (Lazarus, 1991, p. 102, 149–150) → generally do not know how to define inputs (Roseman, 2001, p. 86–87)
    - Correlated with five appraisal dimensions
    - Written in natural/familiar language, conceptualized as entities and values → supports *Hiding the Complexity of Emotion Generation* (RE1)
  - Appraisal patterns are not clearly unique (e.g. *Anxiety* and *Disgust* only differ in ego-involvement, but what is the difference between "protection against existential threats" and "being at risk of a poisonous idea"? (Lazarus, 1991, p. 237, 261)) → prone to assumption biases, threatening psychological validity

- **Scherer** (☆☆)
  - Minimally requires goals, events and their properties (e.g. *predictability*, *intrinsic pleasantness*), causality, predictions about events, time constraints on goals, predictions about the controllability over potential outcomes, ability to influence and/or adapt to potential outcomes, and information about the agent's conception of self-ideal and social norms
  - 15 appraisal variables divided into four groups internally for organization and flow (Scherer, 2001, p. 94) → potential to overwhelm users with the full list
    - Some variables describe knowledge (e.g. *intrinsic pleasantness*) (Scherer, 2001, p. 95) → cannot remove from input variable list
    - Some variables could be derived from knowledge (e.g. *discrepancy from expectation* derived from current state prediction about current state from previous ones (Scherer, 2001, p. 96)) → exchange variables for knowledge in input list
      - Might be able to reduce the required input list if there are many variables require the same knowledge
      - Replace variable names with knowledge that is generally understood (e.g. probabilities, goals) → supports *Hiding the Complexity of Emotion Generation* (RE1)
    - Unique profiles for some emotions that have some empirical support (Scherer, 2001, p. 114–117) showing that each emotion uses a subset of variables → might be able to define subsets of variables if some emotions are not needed
  - → Options error-prone, require careful design of EMgine
    - Do not know how to define some of these inputs (Roseman, 2001, p. 86–87)
- **Roseman** (☆☆)
  - Minimally requires goals, current environment states, causal agents, predictions and confidence values about future events, coping potential, if a problem is intrinsic or instrumental
  - Seven appraisal variables create 17 emotion categories, accounts for all variable combinations (Roseman, 2001, p. 68–69) → empirically validated and compared with dimensions from other appraisal theories (Roseman et al., 1996, p. 256, 260,267), revised as new data is collected (Roseman, 2001, p. 72, 75)
  - Generally do not know how to define these inputs (Roseman, 2001, p. 86–87) → hypothesize that appraisal variables influence each other, some might be inputs to the evaluations of others (Roseman et al., 1996, p. 271)
- **OCC** (☆)
  - Clear distinctions between events, agents, and objects (Ortony et al., 2022, p. 69–70) → minimally requires goals, changes to goals, agents, standards, and preferences
  - At least four global variables and ten local variables to distinguish emotion families (Ortony et al., 2022, p. 98) → potential to overwhelm users with the full list
    - Reduce the list by using some variables to calculate others (e.g. *arousal* is evaluated from other variables (Ortony et al., 2022, p. 83)) → applies to few variables, might violate *Ability to Operate on Different Levels of NPC Complexity* (RF7)
    - Reduce the list by ignoring some variables → unclear how to choose which or how many variables to keep

    * Limit the variables to the six variables that distinguish events, agent, and object-related emotions → unable to differentiate emotions in the same branch
    * Generally do not know how to define these inputs (Roseman, 2001, p. 86–87)

- **Smith & Kirby** (☆☆)
  - Minimally requires goals, environment states/events, agent actions and their confidence in their efficacy, agent dispositional traits, event causality, agent responsibility, and predictions about the desirability of future environment states
    * Inputs required for three of seven appraisal dimensions empirically tested (Smith and Kirby, 2009a, p. 1357, 1361–1362, 1367)
    * A fourth variable might be dependent on one of the three tested variables (Smith and Kirby, 2001, p. 138) → observed tendency, not examined directly
    * Other dimensions have yet to be tested (Smith and Kirby, 2009a, p. 1369)
  - Sixteen appraisal variables (seven "core" variables (Smith and Kirby, 2001, p. 123), approximately nine additional ones derived from empirical data (Yih et al., 2020, p. 489; Yih et al., 2016a)) make unique patterns for 20 emotions → not all patterns accounted for, potential to overwhelm users with the full list
    * Some variables appear to describe knowledge (e.g. *likeability* (Yih et al., 2016a)) → cannot remove from input variable list
    * Some variables derived from knowledge (e.g. *motivational relevance* derived from goals and environment states (Smith and Kirby, 2009a, p. 1361)) → exchange variables for knowledge in input list
      · Might be able to reduce the required input list if there are many variables require the same knowledge
      · Replace variable names with knowledge that is generally understood (e.g. probabilities, goals) → supports *Hiding the Complexity of Emotion Generation* (RE1)
    * Emotion appraisal profiles show that each emotion uses a subset of variables (Yih et al., 2020, p. 489; Yih et al., 2016a) → might be able to define subsets of variables if some emotions are not needed

    → Options error-prone, require careful design of EMgine

- **Oatley & Johnson-Laird** (☆☆☆)
  - Emotions elicited at plan junctions where probabilities of goal success changes (Oatley, 1992, p. 98) → minimally requires information about current state of plans and goals
  - Goals as symbolic representations of environments states, plans as transformations between the current environment state and a goal (Oatley and Johnson-Laird, 1987, p. 30)
    * Goals → active/dormant, achievement status, type (e.g. self-preservation, gustatory), known conflicts with other goals
    * Plans → active/dormant, priority

    → Little to no additional information required

C.3.11 Ease-of-Use: Having a Clear API (Output) (RE2)

Many appraisal theories output emotion as a series of components rather than explicit categories. This has the potential to clutter the output API, and potentially violating requirements like *Hiding the Complexity of Emotion Generation* (RE1) and *Traceable CME Outputs* (RE4). However, the componential outputs lend themselves well to supporting *Allowing Developers to Specify How to Use CME Outputs* (RF6) as this would allow users to only use the parts relevant to their design. Fortunately, most of the examined theories relate output component groups with a named emotion. This allows EMgine to create output "packages" labelled with an emotion category and intensity that can be unpacked by advanced users. This creates a small output API while supporting *Hiding the Complexity of Emotion Generation* (RE1), *Traceable CME Outputs* (RE4), and *Allowing Developers to Specify How to Use CME Outputs* (RF6).

- **Frijda** (☆☆)
  - Outputs three data "packages": an Arousal value, relevance and control precedence signals, and action tendencies (Frijda, 1986, p. 454–455) → provides "how strong", "what priority", and an abstracted "how to behave"
  - → Supports *Hiding the Complexity of Emotion Generation* (RE1)
  - Arousal and action tendency "packages" might not be immediately understandable
    - Can associate action tendencies with emotion words (Frijda, 1986, p. 72) to improve understandability
    - Give Arousal a more recognizable name and/or made into an optional or hidden output
- **Lazarus** (☆☆☆)
  - Outputs one data "package" tagged with an emotion label and core theme, containing two "sub-packages": physiological response and action tendencies (Lazarus, 1991, p. 209–210)
    - Also includes subjective experience components, which requires reasoning about the emotion process → skip in design
    - Do not have to manage "sub-packages" directly → supports *Allowing Developers to Specify How to Use CME Outputs* (RF6) and *Hiding the Complexity of Emotion Generation* (RE1)
- **Scherer** (☆)
  - No direct output → emotions emergent, related to a series of subsystem changes (Scherer, 2001, p. 113)
    - Might not be immediately clear what the information means or what can be done with it → violates *Traceable CME Outputs* (RE4), potential violation of *Hiding the Complexity of Emotion Generation* (RE1)
  - Could output an emotion term and associated action tendency when the changes match a known pattern (Scherer, 2001, p. 117)
    - Support *Hiding the Complexity of Emotion Generation* (RE1) and *Traceable CME Outputs* (RE4)

    * Advanced users could examine the changes directly → supports *Allowing Developers to Specify How to Use CME Outputs* (RF6)
    * Potential to have subsystem changes that do not match any known patterns → EMgine might appear to be non-functional

- **Roseman** (☆☆☆)
  - Outputs a "package" labelled with an emotion category containing "sub-packages" for typical physiological, phenomenological, expressive, behavioural, and motivational contents (Roseman, 2001, p. 75)
    * "Package" contents represents coordinating systems for a coping strategy (Roseman, 2013, p. 141)
    * Designed to impose categorical distinctions on continuous appraisal dimensions (Roseman, 2001, p. 75, 80), might explain why laypeople see emotions as discrete entities (Roseman, 2013, p. 147) → achieves understandability of discrete theories, supports *Hiding the Complexity of Emotion Generation* (RE1)
    * Differentiates reward seeking and punishment avoidance (Roseman et al., 1990, p. 910) → easier to distinguish emotion states
    * Do not have to manage "sub-packages" directly → supports *Hiding the Complexity of Emotion Generation* (RE1) and *Allowing Developers to Specify How to Use CME Outputs* (RF6)

- **OCC** (☆☆)
  - Outputs two fields: emotion category and intensity (Ortony et al., 2022, p. 220–2212) → simple presentation of "what" and "how strong", achieves understandability of discrete theories
  - Supports *Hiding the Complexity of Emotion Generation* (RE1)

- **Smith & Kirby** (☆☆☆)
  - Outputs a "package" labelled with an emotion category, core relational theme, and intensity, wrapped around appraisal dimension values (Smith and Kirby, 2001, p. 123, 125)
    * Do not have to manage appraisal dimensions directly → supports *Hiding the Complexity of Emotion Generation* (RE1) and *Allowing Developers to Specify How to Use CME Outputs* (RF6)
    * Include a "sub-packages" of facial muscle movements using FACS and physiological changes (Smith and Kirby, 2001, p. 133–135), motivational goals and coping strategies (Yih et al., 2016a; Yih et al., 2016b, Yih et al., 2020, p. 488–492) derived from appraisal values → additional suggestions for advanced use cases

- **Oatley & Johnson-Laird** (☆☆☆)
  - Basic emotion "modes" are psychologically and physiologically distinct (Oatley and Johnson-Laird, 1987, p. 48), assigned labels are not strict definitions (Johnson-Laird and Oatley, 1992, p. 217) and rely on intuitions about emotions from experience and language (Oatley, 1992, p. 69–71, 74–75, 82, 86–87) → generally understandable

  - Outputs an emotion "signal" rather than a concrete state (Johnson-Laird and Oatley, 1992, p. 214) → affords flexibility for both state-based and stateless emotion definitions
    * Potential to connect both definitions to expressive and action-based mechanisms (Oatley and Johnson-Laird, 1987, p. 31)
    * As signals, only have a small number (five) (Oatley and Johnson-Laird, 1987, p. 33) → requires a small signal recognition process to pick up signal emissions
  - Supports *Hiding the Complexity of Emotion Generation* (RE1) and *Allowing Developers to Specify How to Use CME Outputs* (RF6)

C.3.12 Ease-of-Use: Traceable CME Outputs (RE4)

Generally, the process view afforded by appraisal theories also allows for traceability between inputs and outputs, supporting testing and debugging. The appraisal theories also produce, or connect their outputs to, emotion categories which supports *Hiding the Complexity of Emotion Generation* (RE1) and *Having a Clear API (Output)* (RE2).

- **Frijda** (☆☆☆)
  - "Blackboard" structure as central information hub, retains history of evaluation (Frijda, 1986, p. 459) → built-in traceability tool
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language
- **Lazarus** (☆☆☆)
  - Appraisal patterns shown as a decision tree (Lazarus, 1991, p. 222) → visualization of appraisal showing where inputs are used
    * Six appraisal dimensions → tree is a manageable size
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could design to use everyday language and avoid psychology jargon
  - Appraisals are not sequential (Lazarus, 1991, p. 151), has multiple mechanisms (Lazarus, 1991, p. 189), is transactional and temporal in nature (Lazarus, 1991, p. 210–211), reappraisal as a key process (Lazarus, 1991, p. 134) → implies a central data structure, like a blackboard, to store information as it becomes available
    * Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could design to use everyday language and avoid psychology jargon
- **Scherer** (☆)
  - Suggested system representation is a neural network (Scherer, 2001, p. 105) → might not produce traceable/explainable results
  - Each appraisal unit (SEC) changes different subsystems → creates a continuously changing outputs, "history" of the appraisal (Scherer, 2001, p. 107) that is helpful for debugging
    * Many possible combinations → difficult to have consistent outputs for testing

- **Roseman** (☆☆☆)
  - Appraisal as a selection mechanism in a system (Roseman, 2001, p. 76, 81–83) → requires decision rules, potential to provide trace as a decision tree
    - Seven appraisal dimensions → tree is a manageable size
    - Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could design to use everyday language and avoid psychology jargon
- **OCC** (☆☆☆)
  - Eliciting conditions written to reflect how they are talked about in everyday language, how people tend to experience them (Clore and Ortony, 2002, p. 25–26) → connection between inputs and outputs (emotion category/intensity pair) generally understandable
    - Could include a trace function showing effects of input variables and values, changes in expression thresholds → make as an advanced system function to maintain *Hiding the Complexity of Emotion Generation* (RE1)
- **Smith & Kirby** (☆☆☆)
  - Two potential points for tracing (Smith and Kirby, 2001, p. 130)
    - Appraisal detector output where it merges information into one unit before appraisal → show trace of how information is combined
      - Converting disparate inputs that developers know of into aggregated values → unlikely to violate *Hiding the Complexity of Emotion Generation* (RE1)
      - Would require a customizable detector to support EMgine's flexibility → supported by *Customizing Existing CME Task Parameters* (RF3)
    - After converting appraisal unit into an emotion → can show trace of appraisal pattern as a decision tree
      - Sixteen appraisal dimensions (Yih et al., 2020, p. 489; Yih et al., 2016a) → unmanageable tree size
      - Could reduce tree size by removing dimensions that are not relevant to the elicited emotion → provides information about unused variables
      - Potential to violate *Hiding the Complexity of Emotion Generation* (RE1) → could be designed to avoid psychology jargon, use everyday language
- **Oatley & Johnson-Laird** (☆☆☆)
  - Connection of emotion "mode" triggers with plans and goals (Oatley and Johnson-Laird, 1987, p. 36)
    - Create a trace function that presents goal and plan information used to produce outputs
    - Leverage computational knowledge
  - Adding cognitive meanings to an emotion "mode" could explain language and cultural differences (Johnson-Laird and Oatley, 1992, p. 218) → can trace the impact of cognitive processes on the elicitation of new emotions

C.3.13 Ease-of-Use: Providing Examples of Novel Game Experiences (RE7)

Each theory presents different ways to create novel game mechanics and interactions due to their differing focuses. The role of the self and culture is commonly discussed, suggesting new ways that NPCs can develop and interact with players. However, in all cases, realizing these requires additional components or relies on a particular type of NPC functionality. Consequently, all of the theories are only good (☆☆) candidates for satisfying this requirement.

- **Frijda** (☆☆)
  - Incorporate additional components as needed to make finer distinctions between emotion states (Frijda, 1986, p. 216)
  - → Potential for social and cultural based mechanics
- **Lazarus** (☆☆)
  - Coping as part of variable NPC responses (Lazarus, 1991, p. 112–115) → part of action generation, outside the scope of EMgine
  - Role of biological and social variables in the development of the emotion process (Lazarus, 1991, p. 39) → varying EMgine parameters based on NPC "age" to alter processing
  - Core relation themes and the stages of the emotion process (Lazarus, 1991, p. 106, 121) → potential to relate to narrative drama
- **Scherer** (☆☆)
  - Normative significance evaluation accounts for the role of self-esteem/self-concept, social, and cultural influences in emotion generation (Scherer, 2001, p. 98)
  - → Potential for social and cultural based mechanics
- **Roseman** (☆☆)
  - Ties response strategies to appraisal dimensions (Roseman, 2013, p. 144) → emotions differentiated by strategy (Roseman, 2013, p. 148; Roseman, 2001, p. 76)
    - Subjective interpretation of emotion state → closer to emotion recognition in real life
    - Requires knowledge about dimensions → violates *Hiding the Complexity of Emotion Generation* requirement (RE1)
    - → Unideal, available for advanced users
  - Proposed connected between different bases of racism (Roseman, 2001, p. 84–85) → potential for a social intervention mechanics
- **OCC** (☆☆)
  - Implement NPC curiosity when no other emotion processes are active (i.e. resting state) (Ortony et al., 2005, p. 194) → enhance believability
    - Make the state slightly positive instead of zero → engages in exploratory behaviour
    - Requires expectations to know when things are different and might warrant action
  - Define mood as repeated emotion elicitations (Ortony et al., 2022, p. 228) → dynamic and potentially player-unique game sessions

- **Smith & Kirby** (☆☆)
  - Proposed connection between appraisal dimensions and individual facial movements, physiological activities (Smith and Scott, 1997, p. 237–240, 242–243)
    → Connection to non-human (e.g. alien, animal) and non-humanoid (e.g. computer, city) representations for emotion expression

- **Oatley & Johnson-Laird** (☆☆)
  - English names for basic emotions imply behaviours of social creatures (Johnson-Laird and Oatley, 1992, p. 209) → social role of emotions
  - Group dynamics using communication between agents at plan junctions via emotion, modelling "contagious" emotions, mutual plans between NPCs (Oatley and Johnson-Laird, 1987, p. 31, 40–44) → requires a model of the self (i.e. NPC models itself)
    * Potential to model computationally as a system → recursively defined, informed by language and culture
    → Maintenance and propagation of cultural values and norms via learning and guidance
    → Learning new ways to handle plan junctions can lead to evolving abilities to represent individual and cultural differences
  - Sentiments → model influence of social emotions on NPC relationships (Oatley, 2000, p. 78, 80–86)
    * Connection to social goals: affiliation, protection, dominance → potential to overlay onto PAD Space?
  - Narrative planning (Oatley, 1992, p. 6–7, 107–108, 225)
    * Mental simulation of personal plans to understand potential reactions in advance, simulation of others' plans to understand their emotions → directly tied to narratives and can account to responses to stories and films
    → Integration into narrative planning to elicit specific emotions from different NPCs
  - Reliance on plans → partial violation of *Independence From an Agent Architecture* requirement (RF1)

C.3.14 Examining the Remaining Requirements

The appraisal theories are sufficiently different and satisfy most of the requirements in different ways. However, they are also relatively sparse for certain aspects of the emotion process (e.g. emotion decay, intensity) and have comparable information for two ease-of-use high-level requirements.

- *Ease-Of-Use: Allowing the Automatic Storage and Decay of the Emotion State (RE5)*
  - Frijda, Lazarus, Scherer, OCC, Smith & Kirby, Oatley & Johnson-Laird (☆☆)
    * No explicit description about how to store or decay emotion states
    * Time-dependent process approach (Frijda, 1986, p. 453; Lazarus, 1991, p. 39, 209; Ortony et al., 2022, p. 220–228; Oatley, 1992, p. 22–23; Smith and Kirby, 2000a, p. 85) → could support its design
    * Could be integrated via existing processes like reappraisal (Scherer, 2001, p. 99) and monitoring (Smith and Kirby, 2001, p. 129–130)

    * Supports *Customizing Existing CME Task Parameters* (RF3) → include parameters to turn automation off, change entire decay functions or only some of their variables, allow for multiple context-dependent decay functions

  - Roseman (–)
    * Focus on the relationship between appraisal values and emotions, how those emotions impact different systems in response, and the structure of emotions (Roseman, 2001, p. 68, 81), empirical validation of appraisal dimension influence on resulting emotion (Roseman et al., 1996, p. 242, 244) → does not touch on the emotion process itself

- *Ease-Of-Use: Showing that Emotions Improve the Player Experience (RE6)*
  - Scherer (☆☆☆)
    * Associates each emotion with action tendencies (Scherer, 2001, p. 108) → could be applied to many actions and expressions that an NPC might need
    → Design studies around behaviour classes that players evaluate with respect to their experience
    → Some cross-cultural validation, connected to FACS-coded facial expressions (Scherer, 2001, p. 116–118)
  - Frijda, Lazarus, Roseman, and Smith & Kirby (☆☆)
    * Associates each emotion with action tendencies (Frijda, 1986, p. 88; Lazarus, 1991, p. 87, 122; Roseman, 2013, p. 143; Yih et al., 2016a; Yih et al., 2016b; Yih et al., 2020, p. 488–492) → could be applied to many actions and expressions that an NPC might need
    → Design studies around behaviour classes that players evaluate with respect to their experience
  - Oatley & Johnson-Laird (☆☆)
    * Associates each emotion with action tendencies (Oatley, 1992, p. 55, 108, 192, 212) → could be applied to many actions and expressions that an NPC might need
    → Design studies around behaviour classes that players evaluate with respect to their experience
    * Focus on the connection between emotion and plans and goals in narrative and language (Oatley, 1992, p. 70–71) → suggest that it is especially amenable to studies of NPC intentionality and believability
  - OCC (☆)
    * Provides an emotion and intensity as output → gives only a few guidelines about action tendency associations (Ortony, 2002, p. 197).

Key Points

- These notes guided the score assignments in Tables 7.4, 7.5, 7.6, and 7.7
- Scoring is, in part, subjective based on interpretations of the requirements and understanding of emotion literature

Appendix D

EMgine's Emotion Profiles for Examining Animated Characters

Every game has its rules. We just need to know how to break them.

Maeve Millay, *Westworld*

These are the emotion profiles created during the acceptance test case specification process (Chapters 11 and 12). The profile of *Sadness* does not appear here because it serves as the example in Chapter 11.2. A reminder that the FACS scores are only suggestions because an individual untrained in FACS made the code assignments.

D.1 Joy

Joy and its variants are enjoyable emotions, which are critically understudied because they are not typically problematic (Ekman, 2007, p. 191, 199–200). They are essential to survival because they motivate individuals to engage in activities that: are good for them; build confidence, social responsiveness, and connections to things that reduce negative mental states (Izard, 1977, p. 244, 246); and achieve personal goals (Ortony et al., 2022, p. 50, 102). Cognitively, *Joy* broadens attention and thinking and builds personal skills and resources through play (Fredrickson, 2009). However, it also lowers the experience thresholds for negative emotions as the perceptual system appears to "see more" and might decrease productivity by delaying uncomfortable situations (Izard, 1977, p. 256–257). To combat this, *Joy* encourages the cognitive system to have higher tolerances for stimuli and lower the importance of unsolved problems. To others, *Joy* can communicate the individual's evaluation of their subjective well-being—how well-off they are and that they expect their good fortune to continue.

A low arousal state and subjective, self-aware feelings of calmness and tranquility characterize *Serenity*, a low intensity *Joy* (Sunddararajan, 2009). The intensity of the arousal state grows to match the intensity of *Joy* and *Ecstasy* while simultaneously reducing feelings of calmness. Although not explicitly mentioned, the elapsed time since making the last progression towards goal achievement and how much progress they made also appears to define the strength of the initial *Joy* appraisal. For example, a reunion with a loved one is more intense if the last reunion was some time ago and, presumably, the individual achieves the goal of being with them in full. The intensity of *Joy* is also often inversely proportional to the perceived chances of achieving a goal, such as meeting with an admired person that the individual never thought was possible.

Signs of *Joy* *Joy* is a relatively intense, long-lasting emotion (Scherer and Wallbott, 1994, p. 321, 324). Its expression is rarely controlled or regulated, marked by highly-expressive verbal and non-verbal behaviours in addition to strong approach behaviours. A socially attractive emotion, *Joy* predisposes individuals towards actions that manifest a sense of pleasure and security in the world including sharing and approaching behaviours (Lazarus, 1991, p. 268–269). This can manifest as expansiveness, generosity, and outgoingness. In social situations, a happy individual is more likely to initial a conversation and observers will enjoy their company.

The voice is more likely to distinguish *Joy* from other enjoyment-related emotions than the face (Ekman, 2007, p. 204). Laughter is a unique non-verbal signature (Scherer and Wallbott, 1994, p. 322). Energy conservation is not important as it is needed to enable approach behaviours associated with *Joy*, which can involve physical and mental labour, indicated by an elevated body temperature.

Characteristic Facial Expression The lower face and eyelids convey *Joy* (Ekman and Friesen, 2003, p. 103, 105, 107, 112; Izard, 1977, p. 241) and is easy to spot (Tables D.1, D.2, and D.3). Changes in the eyebrows and forehead are not essential for its identification.

The "Duchenne smile", simultaneously affecting the eyelids and lower face, is the most reliable indicator of an "enjoyment smile" (Frank and Ekman, 1993, p. 12–13, 18, 21; Frank et al., 1993, p. 92). There are different kinds of smile, a movement drawing the corners of the lips back and up, but the "Duchenne smile" specifically activates:

- The *zygomaticus major* muscles in the cheeks, revealing the nasolabial folds[1], and
- The *orbicularis oculi* muscles around the eyes causing "crow's feet" to appear in the outer corners, which become more apparent with age.

As the intensity of *Joy* increases, the smile becomes broader and the lips part to reveal the teeth. The cheeks rise higher, deepening the nasolabial folds and pushing the lower eyelids up, narrowing the eyes. This also causes more pronounced "crow's feet" and creasing below the lower eyelids.

While the cheek muscles are easy to move voluntarily, it is much more difficult to move the *orbicularis oculi* muscles circling the eyes (Ekman, 2007, p. 206) which pulls the eye cover fold[2] down. This produces the "eyes sparkling with happiness" effect, which is difficult to replicate voluntarily. This helps disambiguate a *Joy* smile from other kinds.

Examples Jasmine from Disney's *Aladdin* (Clements and Musker, 1992) has been pressured by her father to marry according to criteria defined in the law, which she feels severely limits her agency in the decision. Thus far, Jasmine has been unable to find someone that she connects to from the line of suitors that she has been presented with and she has no say in who she meets.

She clearly illustrates different intensities of *Joy* through her eyes and mouth (Figure D.1). In *Serenity*, she has a general lack of tension in her face, a slight smile, and lowered eyelids conveying a sense of calm. As the intensity of the emotion increases, her smile broadens and her cheeks rise which pushes her lower eyelids up. Animators often choose not to illustrate the nasolabial folds or "crow's feet", likely to reduce the amount of work required per frame and to create a more aesthetically pleasing image. Instead, they rely on the broadness of the smile and changes in the lower eyelids.

[1]The creases running from the nose to the space beyond the lip corners on the cheeks.

[2]The skin between the eyelid and eyebrow.

Joy00 *Neutral*

Joy01 *Serenity*

Joy02 *Joy*

Joy03 *Ecstasy*

Figure D.1: Examples of *Joy* in Jasmine's Facial Expressions

Joy01: After returning from an illicit date with her suitor and choosing him as her betrothed, Jasmine experiences *serenity* because:

- She has chosen a prince, which will both please her father for following the law and herself for choosing someone she cares for

Jasmine signals her *Serenity* via overall calmness and apparent reflection as she hums the song she sang with Prince Ali to herself while brushing her hair.

Joy02: Seeing her father's reaction to her choice of suitor is *joyful* for Jasmine because:

- She has made the choice for herself
- The choice follows the law, which pleases her doting father
- Her father personally approves of her choice

She expresses her *Joy* by maintaining physical contact with her suitor while maintaining eye contact with her father and nodding her confirmation of his statements. Her shoulders appear to rise towards her ears rather than relaxing, implying a higher than normal energy expenditure.

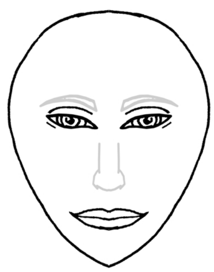
Joy03: During a quiet moment with her father and love interest, Jasmine becomes *ecstatic* when:

- Her father relaxes the conditions of the law, previously thought impossible, giving her complete control of her choice of suitor
- She has made the choice for herself

- Her father personally approves of her choice

Her excitement is shown by her hopping on the spot then running to her betrothed to jump into his arms, both indicative of a high energy expenditure, and her verbal confirmation that she chooses him.

Table D.1: Facial Sketches of *Serenity* with Suggested FACS Codes

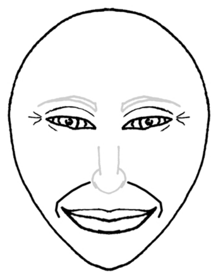


Label	Serenity
Intensity	Low

Description	**FACS Codes**
Smooth forehead skin	–
No tension in upper eyelids	–
No tension in the lower eyelids	–
Corners of the lips are slightly drawn back and up	AU 12
Mouth closed	–

AU 12 describes zygomaticus major muscle movement

Table D.2: Facial Sketches of *Joy* with Suggested FACS Codes

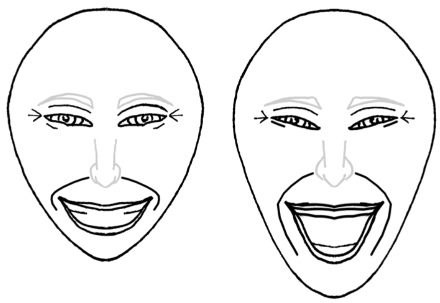


Label Joy
Intensity Medium

Description	**FACS Codes**
Smooth forehead skin	–
Slightly lowered eyebrows/upper eyelids	AU 6*
Eyes might appear to have a "sparkling" effect	AU 6*
Crow's feet in outer corners of eyes	AU 6+12*
Raised cheeks pushing the lower eyelids upwards	AU 6
The eyes might appear narrower due to the raised lower eyelids	AU 6+12*
Obvious nasolabial folds	AU 6+12*
Corners of the lips are drawn back and up towards the ears	AU 12
Mouth might open to reveal the teeth	AU 25

* *Indirect effect of AU*
AU 6 describes orbicularis oculi muscle movement
AU 12 describes zygomaticus major muscle movement

Table D.3: Facial Sketches of *Ecstasy* with Suggested FACS Codes



Label Ecstasy
Intensity High

Description	**FACS Codes**
Smooth forehead skin	–
Slightly lowered eyebrows/upper eyelids	AU 6*
Eyes might appear to have a "sparkling" effect	AU 6*
Crow's feet in the outer corners of eyes	AU 6+12*
Raised cheeks pushing the lower eyelids upwards	AU 6
The eyes might appear narrower due to the raised lower eyelids	AU 6+12*
Obvious nasolabial folds	AU 6+12*
Corners of the lips are drawn back and up towards the ears	AU 12
Upper lip appears tense	AU 12*
Mouth open to reveal the teeth	AU 25
Jaw might stretch, parting the teeth (e.g. laughing)	AU 27

* *Indirect effect of AU*
AU 6 describes orbicularis oculi muscle movement
AU 12 describes zygomaticus major muscle movement

D.2 Fear

This is the most researched emotion primarily because it is easy to elicit in animals (Ekman, 2007, p. 152) and there is an increase in the number of fear-inducing scenarios in contemporary civilizations (Izard, 1977, p. 355). The primary purpose of *Fear* is to ensure survival by either avoiding or escaping potentially harmful situations (Lazarus, 1991, p. 235–236; Ekman, 2007, p. 152). Stimuli causing *Fear* often leave strong impressions in memory, making them easier to recall (Izard, 1977, p. 355). It also influences perception, reducing the individuals information intake and increasing uncertainty, and reduces the number of behavioural alternatives. Thinking slows, becoming narrow and rigid, paving the way for immobilization and helplessness in the most intense scenarios. The individual also experiences the subjective feeling of insecurity, helplessness, and looming imminent danger.

As the intensity of *Fear* increases, individuals experience more extreme physical and cognitive changes (Izard, 1977, p. 365). They become functionally blind to all but the triggering stimulus, experience high tension that can hinder movement, and cannot think beyond the concept of escape. Attempting to manage *Fear* can counteracted it, but becomes less feasible as its intensity grows. If "flight" is not possible and the perceived harm is great, the intensity of *Fear* greatly increases and the individual is more like to become immobilized and helpless.

Signs of *Fear* Compared to the other emotions, *Fear* has few outward expressions and have nearly no verbal expressions (Scherer and Wallbott, 1994, p. 323–324) which matches with the tendency to immobilize the body. How someone behaviourally reacts to *Fear* depends on their past experiences, but follows the same tendencies of avoidance and escape: immobilization to avoid detection followed by either "flight" to escape or attributing blame to become *Angry* in an attempt to physically remove the threat (Ekman, 2007, p. 153–154). Other behaviours aside from "flight" that organisms might use in the interest of protection include warily watching the source of *Fear* to increase awareness, action inhibition, trembling, cowering, hiding, and seeking the company of others. The action tendency associated with *Fear* is avoidance or escape, which is reflected in the common connection of "flight".

Fear accumulates a high energy expenditure and body tension, but the body temperature is low (Scherer and Wallbott, 1994, p. 321–322, 324, 326). This matches the "flight" response where the body redirects blood flow to the chest and abdomen in preparation for fast movement. This causes an increase in muscle tension, which appears as trembling. As the intensity of *Fear* increases, trembling goes from slow and loose movements to faster and stiffer ones. Heart acceleration also increases at a linearly proportional rate to the intensity of *Fear*. Perspiration is another physical indicator of *Fear* that prepares the body to prepare to run. *Fear* is a relatively short-lived emotion (Scherer and Wallbott, 1994, p. 320), possibly because of the high strain on body and mind.

Characteristic Facial Expression All major facial areas convey *Fear* (Tables D.4, D.5, and D.6), but how many areas it engages depends on the emotion's intensity (Ekman and Friesen, 2003, p. 50, 55, 63; Izard, 1977, p. 364–365). If only one area has characteristic changes, it implies a low intensity *Fear*[3]. Changes in all facial areas and a high level of facial muscle tension indicates high intensity *Fear*: *Terror*.

[3]Ekman refers to both *Worry* and *Apprehension* as mild versions of *Fear*, which this profile takes as synonymous to *Apprehension*.

People often confuse the facial expressions of *Fear* and *Surprise*, but changes in the upper face reliably distinguish them. In *Fear*, the lower eyelids tense and the upper eyelids rise, exposing the sclera. This causes the illusion that the eyeballs are popping out of their sockets. This is further emphasized by raised eyebrows with the inner corners drawn together such that they appear to be straight. This can also cause horizontal wrinkles to appear in the middle of the forehead.

Tensed lips pulled back towards the ears is another indicator of *Fear*. As the intensity grows, the mouth opens and exposes the teeth which might be clenched.

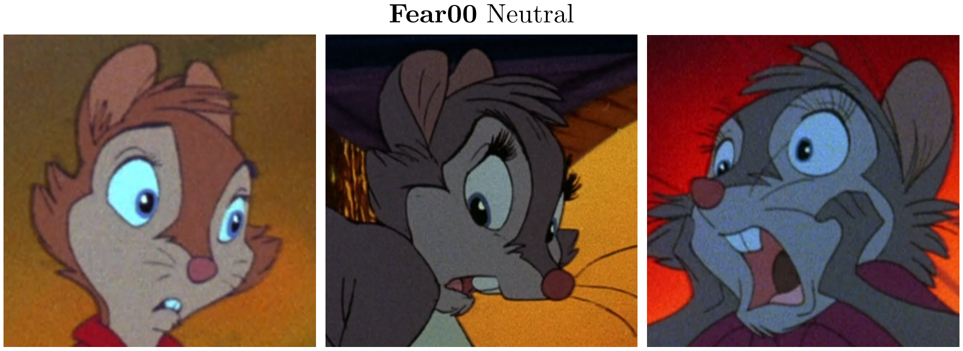
Examples Mrs. Brisby, a field mouse in Don Bluth's *The Secret of NIMH* (Bluth, 1982), is a good example of the primary purpose of *Fear*: self-preservation. She knows that she is small and is an easy target for larger predators like cats and owls.

While the facial expressions vary in the jaw and lips, Mrs. Brisby clearly shows *Fear* through her eyelids and eyebrows (Figure D.2). As its intensity rises, her upper eyelids rise and her lower eyelids tense. Her shrinking iris and pupil emphasizes this, creating the illusion that she is exposing more of her sclera. She has raised her eyebrows and they appear to be straight, albeit angled due to the perspective of the images. The tension in Mrs. Brisby's lips increases with the intensity of *Fear* and exposes her teeth, with her jaw dropping in *Terror*. The animators chose not to include forehead and cheek creases in these expressions.

Fear01: A friend urged Mrs. Brisby to visit the Great Owl, a wise animal of the forest who is likely to be able to help her solve a problem threatening her family. Despite knowing that the Great Owl is no ordinary animal, and after being told by the Owl to come inside his house or leave, Mrs. Brisby still feels *apprehensive* because:

- Her physical safety is at imminent risk because he might choose to eat her instead of talk

Fear00 Neutral



Fear01 *Apprehension* **Fear02** *Fear* **Fear03** *Terror*

Figure D.2: Examples of *Fear* in Mrs. Brisby's Facial Expressions

("owls EAT mice!")

- She cannot defend herself against a predator and escape is uncertain because the Great Owl's house is a hollow high in a tree

Mrs. Brisby also displays *Apprehension* by wearily watching her surroundings and slowly proceeding into the Great Owl's hollow.

Fear02: To help her family, Mrs. Brisby volunteers to put a sleeping drug in the farm cat's food dish, which is only accessible after crossing the large, open kitchen inside the farmer's house. She is *fearful* because:

- The kitchen is empty but there is a high potential for change, as the immediate risks—the cat and the farmer's wife—are both at the front door and will return to the kitchen shortly
- She cannot be certain how long they will be gone for

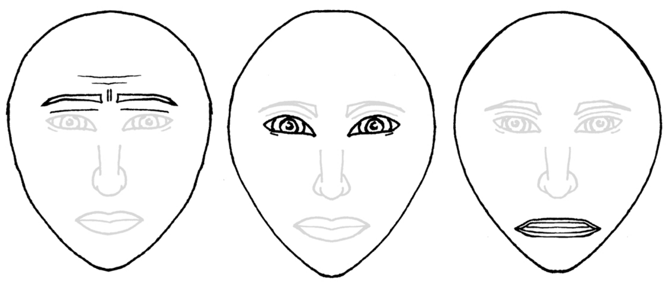
Her *Fear* is apparent in her loose trembling and her reluctance to move from her current location (i.e. freezing).

Fear03: In the process of helping her friend, Mrs. Brisby comes within a few feet of the farm cat whom has seen her. She experiences *Terror* because:

- There is an immediate and severe risk to her physical safety, as an encounter with the cat will certainly kill her

Her trembling is quick and sharp as she freezes in place, staring at the cat who is climbing the rest of the way onto the log she is standing on.

Table D.4: Facial Sketches of *Apprehension* with Suggested FACS Codes

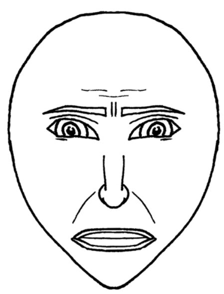


Label Apprehension
Intensity Low

Description	**FACS Codes**
At least one of:	
Raised, straightened eyebrows pulled together; Wrinkles might appear in the centre of the forehead	AU 1+2; AU 1+2+5*
Raised upper eye lids exposing the sclera, tensed lower eye lids; Lower eyelids might be covering part of the iris; Eyes fixated on one point	AU 5+7; AU 7*; 69
Lips pulled back towards the ears; Open mouth exposing the teeth; Jaw clenched	AU 20; AU 25; AU 31

* *Causes change indirectly*

Table D.5: Facial Sketches of *Fear* with Suggested FACS Codes

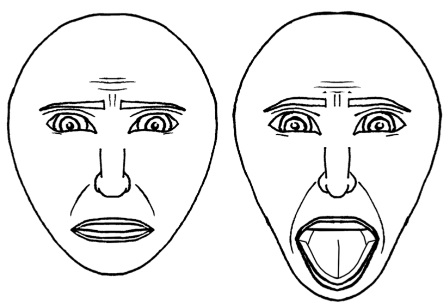


Label Fear
Intensity Medium

Description	**FACS Codes**
Raised, straightened eyebrows pulled together	AU 1+2
Wrinkles might appear in the centre of the forehead	AU 1+2+5*
Raised upper eye lids exposing the sclera, tensed lower eye lids	AU 5+7
Lower eyelids might be covering part of the iris	AU 7*
Eyes fixated on one point	69
Lips pulled back towards the ears	AU 20
Open mouth exposing the teeth	AU 25
Jaw clenched	AU 31

* *Causes change indirectly*

Table D.6: Facial Sketches of *Terror* with Suggested FACS Codes



Label	Terror
Intensity	High

Description	**FACS Codes**
Raised, straightened eyebrows pulled together	AU 1+2
Wrinkles might appear in the centre of the forehead	AU 1+2+5*
Raised upper eye lids exposing the sclera, tensed lower eye lids	AU 5+7
Lower eyelids might be covering part of the iris	AU 7*
Eyes fixated on one point	69
Lips pulled back towards the ears	AU 20
Open mouth exposing the teeth	AU 25
Jaw clenched OR Stretched open	AU 31 OR AU 27
Chin might appear drawn back	AU 27*

* *Causes change indirectly*

D.3 Anger

Anger is a high energy, negative emotion that commonly arises in response to unwanted or harmful situations, mobilizing the individual to remove or attack the offensive person or object (Kuppens, 2009). It is rarely felt alone for long, with emotions like *Fear* and *Disgust* commonly preceding or following it (Ekman, 2007, p. 113). *Anger* predisposes the individual to attack a target that they believe is preventing them from achieving a goal and/or caused offence (Ekman, 2007, p. 114; Izard, 1977, p. 329–330; Lazarus, 1991, p. 226). This impulse is usually tightly controlled due to potential consequences for social relations, cultural expectations, long-term self-interest, and personal values. To this end, coping strategies and the importance of other goals affected by the consequences of expressing *Anger* play a significant role in altering the individual's reaction to experiencing it. Subjectively, people often describe *Anger* as an unpleasant feeling.

The intensity of *Anger* heavily depends on personality, with some people unable to feel anything stronger than *Annoyance* and others having short tempers, easily flying into *Rage* (Ekman and Friesen, 2003, p. 81). The ability to control the action tendencies and expression of *Anger* becomes more difficult as the emotion's intensity increases. Frustration is an early warning sign that something is preventing a goal's completion.

Signs of *Anger* The tendency to attack or remove obstacles usually appears as agitation or aggression. As intensity increases, the individual becomes more energetic and impulsive in order to prepare them for physical altercations (Izard, 1977, p. 331). This emotion tends to make people more extroverted to try to sustain a high-level of focused and directed activity to unblock progression towards goals. Although *Anger* is a highly expressive and rarely well-controlled emotion, both verbally and non-verbally, many cultures condemn it (Ekman, 2007, p. 120; Scherer and Wallbott, 1994, p. 320, 323–324). Therefore, there might be signs that an individual is trying to control their *Anger* instead of acting on it.

An increase in energy expenditure and high tension often accompany *Anger* (Scherer and Wallbott, 1994, p. 321–322, 324, 326). In preparation for "fight", the body increases its heart rate to send more blood through the body, raising its temperature while increasing its tension. The increased energy primes individuals for some measure of violence, either physical or verbal, presumably to remove a perceived obstacle (Ekman, 2007, p. 110, 125) or source of blame (Lazarus, 1991, p. 223, 225).

Characteristic Facial Expression *Anger* registers on all facial areas (Ekman and Friesen, 2003, p. 82, 88, 92, 95, 97; Izard, 1977, p. 330). Changes in all areas must appear for the expression to be unambiguous (Tables D.7, D.8, and D.9).

In *Anger*, the eyebrows draw together and lower. This can make them look like they are pointing down towards the nose. The eyebrow movement typically causes the upper eyelids to lower as well. Combined with tensed lower eyelids, which appear to rise with the intensity of *Anger*, the eyes appear penetrating or as if the individual has a hard, fixed stare.

The mouth can have two forms depending on the individual's intended action. If the individual is engaging verbally, then the lips form a squared shape around the teeth. If they are trying not to speak or are preparing for a physical altercation, the lips are firmly pressed together which might make them appear thinner. Thinning of the lips is one of the earliest observable signs of *Anger* in the face. It can happen alone, likely because it is a hard action to inhibit. This sign usually occurs before a person becomes aware of their *Anger*.

Examples Beast from Disney's *Beauty and the Beast* (Trousdale and Wise, 1991) is a natural choice to demonstrate *Anger* due to his angry disposition. He is the castle's master, which comes with the ultimate level of control over its affairs and castle staff.

Beast's angled eyebrows, lowered upper eyelids, tensed lower eyelids, and penetrating stare become more apparent as the intensity of his *Anger* increases (Figure D.3). Animators also exaggerated changes in the pupil size and mouth, making them more reliable indicators of intensity compared to the eyebrows. Despite its importance, thinning lips are not a reliable sign of *Anger* in animation because many animated characters lack explicitly drawn lips. A line implies the mouth and sometimes animators add a second line to indicate where the bottom of the lower lip is. Instead, changes in the mouth shape imply changes in the lips. Beast demonstrates the possible mouth shapes: the flat line of his mouth implies that his lips are pressed together to avoid speaking in *Annoyance*; a square shape is formed by the mouth line when preparing for a fight in *Anger* to show the increased tension in the cheeks; and in *Rage*, the square shape of the mouth line is significantly larger to convey the act of yelling, which also exposes more of Beast's teeth.

Anger01: Beast wants to make a good impression on Belle and expects that moving her out of the dungeon and into a proper room will help. He becomes *annoyed* with her after she:

- Questions his authority, which he perceives as harmful to his image as the castle's master
- She chose to speak from a sitting position rather than following silently

His sweeping gestures to the dungeon and demanding to know if the girl wants to stay in the dungeon are other indicators of *Annoyance*.

Anger02: The villagers are attacking the castle and Beast knows that he is physically powerful and can match his attacker. He becomes *Angry* because:

Anger00 *Neutral*

Anger01 *Annoyance*

Anger02 *Anger*

Anger03 *Rage*

Figure D.3: Examples of *Anger* in Beast's Facial Expressions

- The aggressor is attacking Beast in his home, with the intent to kill, putting him in immediate danger of mortal harm
- The attacker made it clear that he premeditated the decision

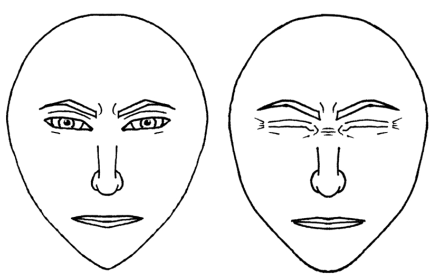
Beast's decision to physically retaliate, including intimidation via loud roars, is evidence of his *Anger*.

Anger03: Beast has locked himself away in his castle because he believes himself to be hideous. When a traveller arrives at the castle, Beast experiences *Rage* because he:

- Believes the traveller is mocking him because he is no longer "handsome", which is an integral aspect of his self-image
- Interprets the man's inability to look away as a conscious decision to stare rather than *Fear*

Leaping to block doors and forcefully speaking to the traveller are all signs of Beast's *Rage*.

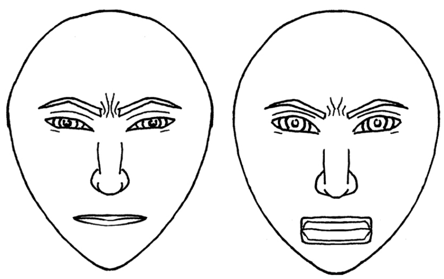
Table D.7: Facial Sketches of *Annoyance* with Suggested FACS Codes



Label Annoyance
Intensity Low

Description	FACS Codes
Lowered eyebrows that are close together and angled downwards towards the nose causing vertical wrinkles to appear between them	AU 4
Narrowed OR tensed, closed eyes	AU 7 OR AU 7+43
Thinned lips that are pressed together	AU 17+24

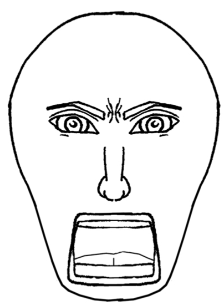
Table D.8: Facial Sketches of *Anger* with Suggested FACS Codes



Label	Anger
Intensity	Medium

Description	FACS Codes
Lowered eyebrows that are close together and angled downwards towards the nose causing vertical wrinkles to appear between them	AU 4
Narrowed OR glaring eyes (raised upper eyelids, tensed lower eyelids) that might appear to be bulging	AU 7 OR AU 5+7
Might have flared nostrils	AU 38
Thinned lips that are pressed together OR Exposed teeth with tensed, rectangular shape mouth	AU 17+24 OR AU 20+23+25
Tightly clenched jaw, possibly jutting forward	AU 31+29
Possibly red-faced	–

Table D.9: Facial Sketches of *Rage* with Suggested FACS Codes



Label Rage
Intensity High

Description	**FACS Codes**
Lowered eyebrows that are close together and angled downwards towards the nose causing vertical wrinkles to appear between them	AU 4
Glaring eyes (raised upper eyelids, tensed lower eyelids) with constricted pupil that might appear to be bulging OR Eyes squeezed shut, especially if yelling	AU 5+7 OR AU 7+43
Flared nostrils	AU 38
Thinned lips	AU 24
Tightly clenched jaw that might be jutting forward OR yelling, exposing teeth	AU 31+29 OR AU 27
Usually red-faced	–

D.4 Disgust

A low-intensity emotion, *Disgust* is the feeling of aversion and rejection, usually involving some type of removal or avoidance strategy. People experience it when they encounter something revolting, contaminated, deteriorating, or spoiled (Izard, 1977, p. 336; Ekman, 2007, p. 172–174; Lazarus, 1991, p. 259). Cognitively, *Disgust* motivates individuals to redirect their attention to avoid dealing with the object of revulsion, an impulse which can manifest as nausea, or change it if possible (Izard, 1977, p. 336–337). If the offensive object cannot be avoided and cannot be changed, the individual will attempt to eject it in a manner comparable to vomiting (Lazarus, 1991, p. 262). Subjectively, people describe *Boredom*—taken as low intensity *Disgust*—as unpleasant, marked by a strong desire to shut out or ignore the situation (Smith and Ellsworth, 1985, p. 832–833, 835). *Disgust* is similar, but feels like it requires more effort than *Boredom*.

The intensity of *Disgust* is directly proportional to the level of revulsion and avoidance the individual feels. The weakest level of aversion, *Boredom*, is an understudied emotion. Some work conducted on *Boredom* found it to be an emotion of its own (van Tilburg and Igou, 2017, p. 317). *Boredom* is a desire to abandon the current situation for a more stimulating one (Bench and Lench, 2013, p. 468; van Tilburg and Igou, 2012, p. 192). Framed as low intensity *Disgust*, *Boredom* is like a weak aversion to an event with an avoidance strategy aimed at finding a more interesting one or withdrawing attention from the current activity (Rozin et al., 1999, p. 430). Unlike *Disgust*, *Boredom* can be a positive experience, prompting a search for stimulation (Vodanovich and Kass, 1990, p. 118, 120) and interest (Smith et al., 2009, p. 157).

Although bodily function is intimately tied to *Disgust*, it evolved to include ideational and social aspects (Rozin et al., 1999, p. 431). *Disgust* towards others effectively dehumanizes them and enables the condoning of their persecution (Ekman, 2007, p. 178–179; Miller, 1997, p. 8–9, 50, 133–134). Tolerance for *Disgust* triggers increases when dealing with intimate relationships, such as caring for a sick family member. This suggests that *Disgust*, or having a higher tolerance for triggers, also serves as a mark of personal commitment and further cements its importance as a social emotion.

Signs of *Disgust* *Disgust* predisposes individuals to avoid contact with the offending object. This is different from *Fear* in that the object of *Disgust* might still capture the individual's attention and prompt them to observe it from afar (Rozin et al., 1999, p. 111–113). As the intensity increases, the experience of *Disgust* is no longer positive and the individual's aversion increases. At the most intense, *Loathing*, individuals can feel physically nauseous (Ekman and Friesen, 2003, p. 66) and employ more extreme avoidance strategies that have higher costs than they would normally be willing to pay, such as refusing to eat. In the most extreme case, the individual cannot look at the object at all because the nausea is overwhelming and potentially vomiting in response. If the object of *Disgust* is related to sanitation or hygiene, it is more likely that the individual will change the situation rather than avoiding it altogether to increase the probability of survival.

Disgust uses a significantly lower amount of energy compared to *Anger*, and it consequently passes quickly and with little expressiveness (Scherer and Wallbott, 1994, p. 319, 323–324, 326). This is coupled with a decelerated heart rate, likely tied to parasympathetic activation such as salivation and gastrointestinal activation which causes heart activity to slow. Short, verbal expressions such as exclamations often accompany *Disgust*.

Characteristic Facial Expression The nose and upper lips primarily drive the facial expressions of *Disgust* (Tables D.10, D.11, and D.12), which affect the surrounding facial areas (Ekman and Friesen, 2003, p. 68, 71, 76; Izard, 1977, p. 336). The eyebrows are not critical to this facial expression, but can distinguish *Disgust* from *Anger* as the inner eyebrows do not draw together.

Wrinkling the nose or raising and pushing the upper lip out signals *Disgust*. While these features can occur individually, it is more common to observe them together. As the intensity of *Disgust* increases, these movements become more pronounced. The wrinkling of the nose causes other wrinkles to appear on and around it, which pulls the upper lip and cheeks upwards and the eyebrows down. In turn, this lowers the upper eyelid. These effects can make *Disgust* difficult to distinguish from *Anger* because it appears that the eyelids are tensing due to wrinkles formed by the raised cheeks.

It is common to observe a gaping mouth, potentially with a visible or protruding tongue, as if to physically reject the offending stimulus.

Examples Never wanting for anything in his life and being Emperor, Kuzco from Disney's *The Emperor's New Groove* (Dindal, 2000) is self-absorbed and has difficulty changing his habits.

Kuzco provides examples of the different levels of *Disgust* in his expressions (Figure D.4). The changes are weak in *Boredom*, but he still displays a protruding upper lip and lowered upper eyelids. *Disgust* is easier to identify with prominent wrinkles around his nose, a raised and jutting upper lip, lowered eyebrows, pushed up lower eyelids due to his rising cheek muscles, and lowered upper eyelids. *Loathing* sees these aspects further exaggerated and punctuated with a protruding tongue.

Disgust01: Kuzco quickly becomes *bored* at a dinner because:

- His hosts are not entertaining him despite his need to constantly do something interesting

Disgust00 *Neutral*

Disgust01 *Boredom*

Disgust02 *Disgust*

Disgust03 *Loathing*

Figure D.4: Examples of *Disgust* in Kuzco's Facial Expressions

- He can leave without consequence at any time

Kuzco's *Boredom* is apparent from his body language—slouching forward and leaning his elbows on the table—and his attempts to find a distraction by playing with his fork and then by trying to start a conversation with his hostess.

Disgust02: Seeing his companion eating a questionable meal fills Kuzco with *Disgust* because:

- He finds the meal repulsive
- He does not have to eat it too

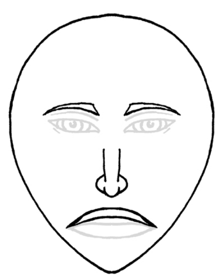
Kuzco makes his emotions clear non-verbally with several utterances of "ewww", shaking his head, and leaning away from the table. He is also fixated on the event rather than averting his eyes, suggesting some level of morbid interest.

Disgust03: As he continues to watch his companion eat, Kuzco's emotion intensifies to *loathing*:

- He notices that his companion is enjoying his meal
- He cannot change his companion's behaviour or thoughts

The same signals as *Disgust* mark his *loathing*, but following his facial expression and his obvious attempt to avoid vomiting further supports this.

Table D.10: Facial Sketches of *Boredom* with Suggested FACS Codes

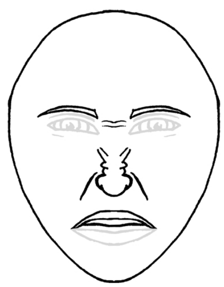


Label Boredom
Intensity Low

Description	**FACS Codes**
Slightly lowered eyebrows which lowers the upper eyelids	AU 9*
Inner eyebrows might be raised	AU 1
No tension in the eyelids	–
No tension in the cheeks	–
Slightly raised upper lip that juts out	AU 9
Lips might be parted	AU 25

* *Causes change indirectly*

Table D.11: Facial Sketches of *Disgust* with Suggested FACS Codes



Label	Disgust
Intensity	Medium

Description	**FACS Codes**
Eyebrows might be lowered causing the upper eyelids to lower	AU 9*
Inner eyebrows might be raised	AU 1
No tension in the eyelids	–
Raised cheeks causing the lower eyelids to rise	AU 9*
Nose wrinkled and drawn upwards causing wrinkles to appear beside and on the nose bridge	AU 9
Raised upper lip that juts out	AU 9
Corners of the lips are drawn down and back	AU 15

* *Causes change indirectly*

Table D.12: Facial Sketches of *Loathing* with Suggested FACS Codes

Label	Loathing
Intensity	High

Description	**FACS Codes**
Eyebrows might be lowered causing the upper eyelids to lower	AU 9*
Inner eyebrows might be raised	AU 1
No tension in the eyelids	–
Crow's feet might appear beside the eyes	AU 9*
Raised cheeks causing the lower eyelids to rise	AU 9*
Nose wrinkled and drawn upwards causing deep wrinkles to appear beside and on the nose bridge	AU 9
Fully raised upper lip that juts out	AU 9
Tongue might be visible or protruding from the mouth	AD 19

* *Causes change indirectly*

D.5 Acceptance

Trust, or low intensity *Acceptance*, is an elementary component in social and economic life referring to a subclass of decisions under risk (Fehr and Zehnder, 2009). It is a general expectation about a subjective probability that an individual assigns to a potential future event where they are willing to accept risk by relying on another (Misztal, 1996, p. 18–19, 24; Rousseau et al., 1998, p. 395, 399; Nooteboom, 2002, p. 48). Although there is a clear sociocultural element, "social emotions" use some of the same brain functioning areas as the other agreed-on primary emotions (Immordino-Yang et al., 2009, p. 8024–8025). The emotional element of *Trust*, or "affective trust", builds on past experiences with, feelings of security, confidence, and satisfaction towards, and the perceived level of selfless concern demonstrated by a partner regardless of what the future holds (Rempel et al., 1985, p. 96, 109). In these relationships, the individual takes risks when disclosing information, accepting promises, and sacrificing immediate rewards for future gains. It is necessary for coping with the volume and complexity of information for decision-making because *Trust* reduces the number of outcomes to consider, effectively narrowing the selection space. This makes it easier to accept risk when some factors are unknown (Misztal, 1996, p. 19–20; Nooteboom, 2002, p. 79–81). Memory is a key component in this as it allows the individual to use previous experiences to predict how likely their partner will act in a manner sensitive to the individual's goals.

At the least intense, *Acceptance*, the individual does not require a personal relationship, likely because of the implicit agreement that others respect and adhere to established values, norms, and behaviours or habits in addition to internalized norms or values of ethical conduct (Misztal, 1996, p. 21–23; Nooteboom, 2002, p. 11, 67). As the relationship becomes personal and intensity increases to *Trust*, the individual begins to take their partner's qualities and past actions into account. In *Admiration*, the individual weighs their partner's actions and qualities less in favour of believing that their partner has their best interests at heart more (Rempel et al., 1985, p. 97), reducing the overall cognitive load of risk assessment. *Admiration* is also a positive response to extraordinary displays of skill, talent, and achievement (Haidt and Seder, 2009; Algoe and Haidt, 2009, p. 107–108). This might be due to a belief that the admired will do what is best in the imagined fictional relationship, especially in the absence of past experience with them.

Signs of *Acceptance* The general action tendencies in *Trust* are to approach, interact, and sometimes touch another to convey that they are valued and secure in the relationship (Lazarus, 1991, p. 278–279). This often includes gestures of warmth, tenderness, interest, and concern for the other. As the intensity grows to *Admiration*, individuals increase the risk they are willing to make for the other (Rempel et al., 1985, p. 111) and focus more on the positive aspects that they could emulate in themselves (Smith, 2000, p. 185–186). This energizes the self and motivates both relationship and skill building with the other (Algoe and Haidt, 2009, p. 111), advancing learning via mimicry, and the pursuit of other personal goals.

Creating a closer relationship enables individuals to learn more from the admired while also increasing and sharing in their prestige[4] through praise. This speeds cultural learning by allowing information transmission between individuals and creating a common knowledge base. Some contradictory studies have found that *Admiration*, while inspiring to individuals, might not motivate them to action (van de Ven et al., 2011, p. 790–791). Instead, individuals happily surrender to the admired, potentially due to the difficulty of self-improvement compared to praising someone else for completing a task that they believe they could do themselves if they wanted to.

[4]Researchers consider prestige to be fundamentally different from dominance because it evolved to improve human cultural capacity through social learning where deference is given freely rather than under threat (Henrich and Gil-White, 2001, p. 167, 170).

Physiologically, the body often feels warm and has an elevated heart rate when experiencing *Trust* (Algoe and Haidt, 2009, p. 115). However, at the highest intensity *Admiration* there might be chills instead. Reminiscent of the "flight" *Fear* response, this tends to happen when the individual is not familiar with the admired individual and have no evidence that there will not be an altercation that they believe themselves ill-equipped to handle. There might also be "tears in the eyes" and/or a lump in the throat at high intensities (Algoe and Haidt, 2009, p. 110).

Characteristic Facial Expression There are no known, empirically supported facial expressions for *Acceptance*, *Trust*, or *Admiration*. These sketches (Tables D.13, D.14, and D.15) rely on the definition of each emotion and facial movements of *Joy*, which motivates individuals to engage in beneficial activities. They also draw from evidence about the meanings of individual facial features, such as a smile and briefly raised eyebrows encouraging social contact (Oatley, 1992, p. 93; Smith and Scott, 1997, p. 248–249).

- A near complete relaxation of all muscles into a neutral or calm expression could be *Acceptance*, conveying that the other is following an expectation about a known routine. It might appear to have a slight smile, shown by lifting the corners of the mouth.
- A confident, inviting expression could convey *Trust*. Raised eyebrows and a closed-mouth smile while maintaining eye contact with the other could convey this intent.
- The face could convey *Admiration* with a small, possibly open-mouthed, smile and widened eyes with raised, curved eyebrows angled upwards in the middle, conveying the child-like wonder and happiness that typically accompanies this emotion. A "sparkling" effect in the eyes describing excitement or happiness with another might be present[5].

Examples Tiana from Disney's *The Princess and the Frog* (Clements and Musker, 2009) has built her life around the belief that working hard is the key to making your dreams come true. For Tiana, that wish is to own a restaurant.

Tiana has slightly upturned lip corners and an otherwise neutral expression in *Acceptance*, a happy expression with raised eyebrows in *Trust*, and a more pronounced expression of *Trust* with her eyes sparkling in *Admiration* (Figure D.5).

Trust01: Tiana has regular shifts at the diner where she serves customers. Due to the established server-customer routine that has a significant social element, she experiences *acceptance*:

- As a waitress, Tiana puts herself at social risk while attending customers because she has limited avenues to handle them should they behave poorly
- In return for her services, she expects her customers to treat her courteously, both socially and when paying their bill

This is shown through Tiana's calm and confident approach of customers and general appearance of ease.

Trust02: Tiana's friend suddenly leans in close and whispers loudly to her while Tiana's mother reads them a fairy tale, causing her to experience *trust*:

- Her friend is excitable and has a deep love of fairy tales

[5] In addition to descriptions of *Admiration*, this was inspired by artistic representations of the emotion such as those of Charles Le Brun (Le Brun, 1760).

Trust00 *Neutral*

Trust01 *Acceptance*

Trust02 *Trust*

Trust03 *Admiration*

Figure D.5: Examples of *Trust* in Tiana's Facial Expressions

- Tiana has an established, positive relationship with her friend
- She values her friend's interests

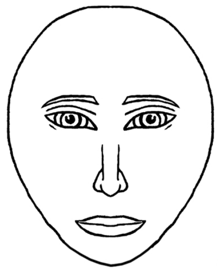
Tiana shows care for her friend by being physically close to them. Her head and eye movement also indicate that she is giving her friend her complete attention.

Trust03: Tiana openly *admires* her hard-working father when he tells her that she can wish on stars, but she must also work hard for what she wants:

- Tiana has a strongly established, positive relationship with her father
- She feels energized to work hard with her father to open a restaurant together

Leaning towards her father, giving him her full attention, and her relaxed posture all indicate Tiana's *Admiration*.

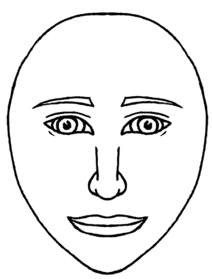
Table D.13: Facial Sketches of *Acceptance* with Suggested FACS Codes



Label Acceptance
Intensity Low

Description	**FACS Codes**
Eyebrows might be slightly raised	AU 1+2
No tension in the eyelids	–
Corners of the mouth might be lifted	AU 12

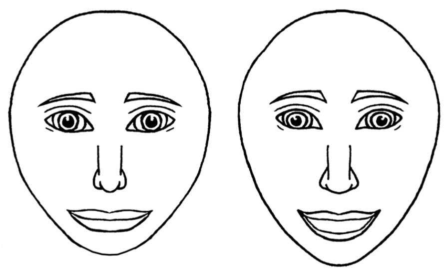
Table D.14: Facial Sketches of *Trust* with Suggested FACS Codes



Label Trust
Intensity Medium

Description	**FACS Codes**
Smooth forehead skin	–
Eyebrows raised	AU 1+2
Neutral eyelids	–
Eye contact with subject of interest	69
Corners of the lips are drawn back and up	AU 12
Closed mouth	–

Table D.15: Facial Sketches of *Admiration* with Suggested FACS Codes



Label Admiration
Intensity High

Description	**FACS Codes**
Smooth forehead skin	–
Raised, curved eyebrows with the inner corners angled upwards	AU 1+2
Raised upper eyelids	AU 5
Relaxed lower eyelids	–
Eyes might appear to have a "sparkling" effect	63*+AU 5*
Gaze might be cast upwards	63
Eye pupils might be dilated	–
Corners of the lips are drawn back and up	AU 12
The jaw might be slack, allowing the mouth to open slightly	AU 25+26

* *Causes change indirectly*

D.6 Interest

Interest motivates individuals to achieve goals by enabling sustained periods of attention on a single object or thought (Tomkins, 2008, p. 186, 188–189, 191; Izard, 1977, p. 212, 236–238) and explains how organisms are able to select a manageable number of stimuli to attend to from a never-ending stream of internal and external stimuli sources (Izard, 1971, p. 321). As the most prevalent emotion in healthy individuals, *Interest* motivates long-term commitment and effort which are necessary in interpersonal relationships, self-development, creativity, and the motivation to search for approaching and exploring new experiences (Silvia, 2008, p. 58). The more stimulation an object or thought brings, the more likely that *Interest* will arise. What provides the necessary stimulation to arouse this emotion differs by personality. *Interest* critically involves attention, supported by an increase in energy expenditure, to increase physical or symbolic interaction with an object via fine tuning and stretching of the relevant sensory-perceptual-cognitive mechanisms (Izard, 1971, p. 238–239). *Interest* can potentially increase predictive processes, consequently affecting decision-making and stress levels. Subjectively, people tend to describe *Interest* as pleasant, marked by devotional attention (Smith and Ellsworth, 1985, p. 832) but it becomes stressful as intensity rises (Warm et al., 2008, p. 438).

At the most intense, *Vigilance*, an organism sustains its attention while waiting for a stimulus to appear at an unknown time (Warm et al., 2008, p. 433, 435) to heighten their ability to protect themselves from danger, identify self-benefits, and clarify changes in the environment (Whalen, 2009). Therefore, *Anticipation* is assumed to be a milder form of *Vigilance* where organisms have made a prediction about some future event and are waiting for it to occur.

Researchers contest *Interest*'s status as an emotion because of its ties to the orientation reflex, an involuntary biological survival mechanism for rapidly directing attention towards immediate changes in the environment that are novel or threatening before the organism evaluates them (Friedman et al., 2009, p. 1144). However, empirical, physiological evidence collected from individuals who had a lack of interest in their daily lives strengthen its status as an emotion. Forcing themselves to work out of necessity, duty, or pride while *Interest* was absent led to apathy and excessive physical fatigue. Researchers suggest that the physical symptoms of the apathetic state are due to a reduction of glucose usage by the body, regardless of how much is present (Rennie and Howard, 1942, p. 281), a type of "vegetative state" where the body subconsciously prepares the body for rest even though it is working (Alexander and Portis, 1944, p. 205). This suggests that *Interest* serves another purpose: conserving an individual's energy when there is nothing worthwhile attending to so that there is ample energy available when a pressing event arises.

Signs of *Interest* In *Interest*, an individual focuses on certain aspects of their environment and knowledge to gather information they believe is necessary to accurately appraise their current situation (Izard, 1977, p. 213, 225). Another emotion typically follows an *Interest*-driven appraisal once the individual has gathered the information that they want. Head and eye tracking might accompany this emotion to maintain the individual's focus.

Attention is usually maintained for short periods of time unless the current activity demands a prolonged arousal state (Tomkins, 2008, p. 190). Maintaining attention and the continuous use of cognitive processes makes *Interest* mentally and physically draining. This results in increased stress levels, which could trigger other negative emotions. This makes it difficult to remain highly-attentive for long periods of time, an effect known as the vigilance decrement (Warm et al., 2008, p. 434–435). Training can improve this effect but it worsens with age.

Characteristic Facial Expression Researchers have described and empirically tested a facial expression for *Interest* (Izard, 1977, p. 215; Tomkins, 2008, p. 185, 187; Silvia, 2008, p. 57), but no descriptions were found for *Anticipation* or *Vigilance*. However, the expression for *Anger* is ambiguous if changes are not observed in all three facial areas—eyebrows, eyes, and lower face (Ekman and Friesen, 2003, p. 83). If only the eyebrows change, the individual might be intently concentrating on something instead of experiencing *Anger*, which aligns with the integral role of attention in *Anticipation* and *Vigilance*. The eyes have a similar description when they alone change, as well as the mouth when the lips press together. Therefore, the assumption is that the expressions for *Anticipation* and *Vigilance* involve similar facial changes as *Anger* and the surrounding context differentiate between them when there are changes in all three facial areas.

Interest is shown in the face primarily by the eyes, which fixate on a target (Tables D.16, D.17, and D.18). The lower eyelids might rise to further sharpen vision. If reverie or reflective problem solving caused *Interest*, the eyes tend to have a "faraway" look indicating that the person is not in the present moment. There might be minor variances of eyebrow height in either direction of movement. As the intensity increases to *Anticipation*, there are similar changes in the eyes that become more exaggerated as the eyebrows change. Directing more attention to a single source in *Vigilance*, the eyes either widen, as in *Interest*, or squint to temporarily improve the eye's focus like a pinhole camera. The eyes might cycle between widening and squinting to reduce stress on the underlying facial muscles. The inner corners of the eyebrows are likely further drawn together due to the amount of effort exerted, possibly exaggerated due to stress. If the individual is imagining a scenario, their eyes might close.

The lower face is not essential to the expression of *Interest* because individuals tend to have quirks, such as biting their lip. Generally, a slackness in the jaw and mouth marks *Interest* which can persist as intensity increases. Alternatively, the lips might press together and the jaw might clench in an attempt to contain energy or stress. If the jaw is not clenched, it is likely slack as in *Interest*. With a further increase in intensity, the mouth and jaw further clench together, often accompanied by a twisting of the mouth to one side.

Examples Elastigirl from Pixar's *The Incredibles 2* (Bird, 2018) is a superhero and parent, both of which demand her attention to do well.

She displays *Interest* through her raised eyebrows, maintenance of eye contact, and slackness in her jaw shown by her slightly parted lips (Figure D.6). As the intensity grows to *Anticipation*, Elastigirl's eyebrows come together and lower, forcing her upper eyelids to lower as well, focusing her vision. Her jaw is tighter, but her lips are still slightly parted. At the highest intensity, her furrowed brow and narrowed eyes are more prominent. She is clenching her jaw with lips pressed together with one side twisted up in a display of extreme concentration.

Interest01: Elastigirl's husband says that there is a note and package for her, but does not tell her what it says. She focuses her attention on him in *Interest* while he hands her the note because:

- The note came with a mysterious package from work, so it is likely related to a work goal
- The package excites her husband, so she tries to gather more information from him about it

Elastigirl's *Interest* is shown by tracking her husband's face with her head and eyes. Her posture also conveys *Interest* by being relaxed and still while she listens to him.

Interest02: A police scanner picks up a conversation about potential criminal activity around the opening ceremony for a new train. Elastigirl experiences *Anticipation* because:

- Her work tasked her with the city's protection and suspicious activity could negatively affect it

Interest00 *Neutral*

Interest01 *Interest* **Interest02** *Anticipation* **Interest03** *Vigilance*

Figure D.6: Examples of *Interest* in Elastigirl's Facial Expressions

- Listening to the police scanner should provide critical details about the location and severity of the threat, helping her decide if they need her

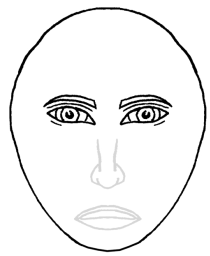
Her *Anticipation* is apparent via her increased attention to the police scanner, evident by her stillness, and her eyes that appear alert but do not seem to be focusing on anything.

Interest03: Elastigirl's instincts say that her assigned case is not closed and she arrested the wrong person. She becomes *vigilant* when an oddity appears in her suit's camera footage because:

- With the criminal still potentially free in the city, her goal to protect the city is at risk
- Reviewing the footage could reveal critical information, reducing her uncertainty regarding the case's status

Elastigirl's tense posture, leaning towards the screen, and eye fixation is evidence of her *Vigilance.*

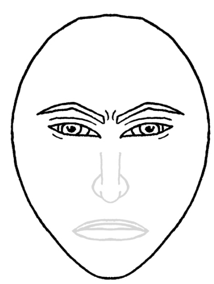
Table D.16: Facial Sketches of *Interest* with Suggested FACS Codes



Label Interest
Intensity Low

Description	**FACS Codes**
Eyebrows are marginally lifted or lowered	AU 4
Upper eyelids might be raised	AU 5
Lower eyelids might be tensed	AU 7
Eyes are fixed on a target	69, M69
Jaw might be slightly slack	AU 26
Lips might be parted	AU 25

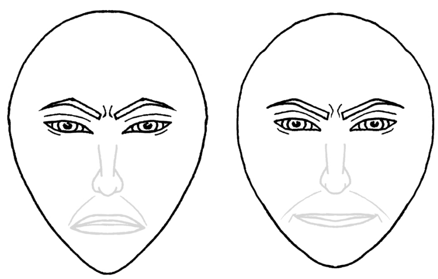
Table D.17: Facial Sketches of *Anticipation* with Suggested FACS Codes



Label Anticipation
Intensity Medium

Description	**FACS Codes**
Eyebrows lowered	AU 4
Upper eyelids are raised OR lowered	AU 5 OR AU 7
Lower eyelids might be tensed	AU 7
Eyes are fixed on a target	69, M69
Jaw is slack or clenched	AU 26 OR AU 31
Lips might be parted	AU 25

Table D.18: Facial Sketches of *Vigilance* with Suggested FACS Codes



Label	Vigilance
Intensity	High

Description	**FACS Codes**
Eyebrows are lowered and the inner corners are brought together	AU 4
Upper eyelids are lowered (squinting) or raised	AU 7 OR AU 5
Lower eyelids be tensed	AU 7
Eyes are fixed on a target	69, M69
Jaw is slack or clenched	AU 26 OR AU 31
Lips might be parted	AU 25

D.7 Surprise

Surprise is a response to sudden and unexpected events that an individual is ill-prepared for (Ekman, 2007, p. 149; Ortony et al., 2022, p. 144–146; Izard, 1977, p. 277). It is not possible to feel *Surprise* when the individual makes a correct prediction about something (Ekman, 2007, p. 151). The main function of *Surprise* is to prepare the individual so that they can effectively handle rapidly changing scenarios and their consequences (Izard, 1971, p. 291). It forces the clearing ongoing cognitive activities to make way for the immediately following, likely more appropriate, emotion (Izard, 1977, p. 281). *Surprise* itself is not pleasant or unpleasant, but might subjectively feel like it. People often consider *Surprise* as pleasant because it typically leads to a pleasant or interesting event (Smith and Ellsworth, 1985, p. 832, 836). When unpleasant emotions follow *Surprise*, it is usually because the individual was caught off-guard when they wanted to be prepared and they subsequently feel overexposed.

For this profile, differing degrees of certainty with respect to what individuals should do differentiate *Surprise* intensity. At the lowest level, *Distraction*, individuals are entirely focused on one task and are effectively blind to everything else. By the middle level, *Surprise*, the uncertainty has grown such that the individual's mind has gone blank, but is still cognitively aware enough for other processes to activate and produce a more appropriate emotion for the event—the brief pause needed to effectively evaluate the situation. In *Amazement*, the uncertainty is so severe that the individual does not know what to do and they are simply focused on taking in as much information about the unexpected person, object, or event as possible.

Surprise is the briefest of emotions—lasting mere seconds—and lacks some of the characteristics of the other emotions ((Ekman, 2007, p. 150–151); Izard, 1977, p. 280–281). This often results in its re-evaluation to determine if it is an emotion at all. There is further evidence against its candidacy because it is often confused with *Fear* in preliterate cultures (Ekman, 2007, p. 10) whereas literate cultures do not, potentially due to their exposure to expressions portrayed in the media (Ekman et al., 1987, p. 714, 716) and since *Fear* and *Surprise* are both caused by extreme changes in stimulation. This might be due to the tendency for individuals to interchange *Surprise* and the startle reflex, a motor response which protects vulnerable body areas and enables escape in sudden encounters. This reflex is part of the startle response defence mechanism underlying the mostly unconscious response to sudden, intense stimuli (Davis, 1984, p. 288). *Surprise* serves its own functional purpose (Ortony et al., 2022, p. 146; Izard, 1977, p. 281) and its briefness distinguishes it from other emotions and involuntary physical reactions such as startling.

Signs of *Surprise* During *Surprise*, the individual's mind goes blank and they are unsure of what to do (Izard, 1977, p. 278–279). Their muscles contract in preparation of movement if needed with a tension level comparable to *Interest*. This might look like the freeze response of *Fear*, which can account for its confusion with it. This, effectively, gives individuals a moment to figure out what is going on (Ekman, 2007, p. 148–149). *Surprise* is difficult to manage due to its unexpectedness and sudden onset, but its short duration does not necessitate this need under typical circumstances.

Characteristic Facial Expression Ekman proposes that there are four types of *Surprise* with distinct facial expressions (Ekman and Friesen, 2003, p. 42–43). Plutchik's *Surprise* seems to be the type requiring changes in all three facial areas. The other types only need two out of the three facial areas, becoming an expression of *Surprise* when the last area changes. However, Plutchik describes *Distraction* and *Amazement* as different intensities of *Surprise*, implying that there are changes in all facial areas that become more exaggerated with intensity. Expressions of *Surprise* here use this approach.

Surprise registers on all three facial areas (Tables D.19, D.20, and D.21) and there must be changes in all of them for the expression to be unambiguous due to this emotion's closeness to *Fear* (Ekman and Friesen, 2003, p. 37, 45). In general, the face has less tension when expressing *Surprise* than *Fear*.

The eyebrows rise and curve, causing more skin to show between the eyes and eyebrows. This movement sometimes causes horizontal wrinkles to appear on the forehead, especially in older adults. The eyes open wide and the upper eyelids rise to show more of the sclera in both *Surprise* and *Fear*. The relaxed lower eyelids distinguish between the expressions because there is little or no tension in them when expressing *Surprise*.

The jaw also lacks the tension that *Fear* causes, simply dropping open. This can also indicate the intensity of *Surprise*, with the jaw dropping more as the intensity increases.

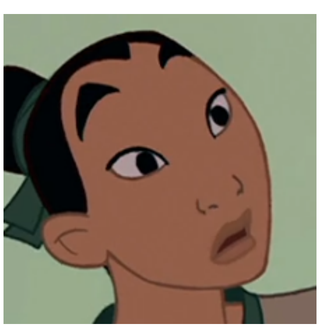
Examples The title character in Disney's *Mulan* (Cook and Bancroft, 1998) disguises herself to enter a military training camp, which is full of people and experiences that are completely different from what she has been exposed to her entire life.

The intensity of Mulan's *Surprise* are in expressions during her first day at a military camp (Figure D.7). Her eyebrows rise and curve making it seem that there is more skin between her eyes and eyebrows. Her eyes are wide and expose her sclera, but show no tension in the lower lids as they still appear to have the same shape as her neutral expression. Her jaw has dropped, parting her lips. These changes become more exaggerated with each intensity level.

Surprise01: Mulan is *distracted* at the start of her first fighting lesson:

- Her captain threw several staffs to the recruits quickly without warning, but Mulan knew that she would be practising with one that day

Surprise00 *Neutral*



Surprise01 *Distraction* **Surprise02** *Surprise* **Surprise03** *Amazement*

Figure D.7: Examples of *Surprise* in Mulan's Facial Expressions

- Mulan had a few seconds to adjust to the situation as others caught their staff

She reacts by fixating her eyes and head orientation towards the staff as it approaches and remaining still with one arm out to catch it.

Surprise02: Mulan was so engrossed by the conversation with her friend that she is *surprised* when she almost collides with another group of recruits—one of which has just loudly told others to "Look!" at his chest tattoo:

- She was not paying attention to her surroundings and had been keeping her distance from others, so being that close to other people was unexpected
- The talking was loud and close to her, contrasting with her other quiet conversation

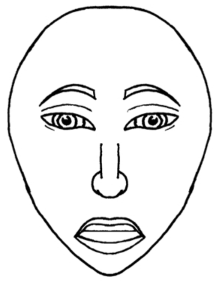
Her *surprise* is apparent when she immediately stops her conversation and movement, fixating her eyes on the people in front of her, suggesting that Mulan is trying to understand the situation. Her straightened posture also suggests *surprise* when she reflexively draws her shoulders and head back.

Surprise03: Mulan and the recruits are *amazed* by their captain's precise and graceful handling of the staff which they are only being introduced to:

- Mulan likely assumed that her captain would be showing them basic movements with the staff
- The captain had only briefly taken a resting stance before suddenly launching into a display of his skill
- Compared to the recruits, the difference in skill is unparalleled

Mulan's *amazement* is shown through her body language: an inability to move and the relaxation of her shoulders and hands as her staff slowly leans away from her while fixating her eyes on her captain. This suggests that she is diverting all of her attention to him.

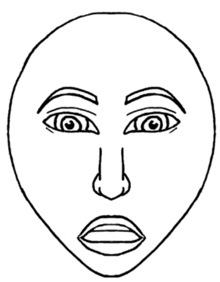
Table D.19: Facial Sketches of *Distraction* with Suggested FACS Codes



Label	Distraction
Intensity	Low

Description	**FACS Codes**
Raised, curved eyebrows that might produce wrinkles on the forehead	AU 1+2
Upper eyelids might be raised	AU 5
Slack jaw causing the lips and teeth to part	AU 25+26
No tension in the mouth	–

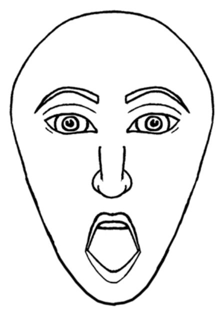
Table D.20: Facial Sketches of *Surprise* with Suggested FACS Codes



Label	Surprise
Intensity	Medium

Description	**FACS Codes**
Raised, curved eyebrows that might produce wrinkles on the forehead	AU 1+2
Raised upper eyelids OR blinking, revealing the sclera above the iris	AU 5 OR AU 45
Lower eyelids are relaxed	–
Slack jaw causing the lips and teeth to part	AU 25+26
No tension in the mouth	–

Table D.21: Facial Sketches of *Amazement* with Suggested FACS Codes



Label Amazement
Intensity High

Description	**FACS Codes**
Raised, curved eyebrows that might produce wrinkles on the forehead	AU 1+2
Raised upper eyelids OR blinking, revealing the sclera above the iris	AU 5 OR AU 45
Lower eyelids are relaxed	–
Slack jaw causing the lips and teeth to part	AU 25+26
No tension in the mouth	–

Black Yoshi