MAPS: REAL-WORLD TO VIRTUAL

GENERATING PLAYER-TRAVERSABLE PATHS FOR CYCLESCAPE FROM REAL-WORLD DATA

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Abstract

Children undergoing Dialysis spend a lot of time on self-care, including three hospital visits a week, three to five hours in length, accounting for 30% of their after-school time. As a result, many of these children lack the time to lead an active life, and combined with their ailing health, leads to deteriorating quality of life. As a result, many of these children lack confidence in their capabilities and cannot answer questions such as "Can I bike to school?". Cyclescape, an exercise VR game, aims to provide entertainment to patients undergoing dialysis, improve their quality of life, and help them answer such questions. This thesis explores converting real-world data into a personal game level, consisting of a path in a game that players (patients) can traverse on a stationary bike while undergoing dialysis. We will explore the different types of real-world map data available and how they are used in video games. We will then derive different goals the map should address to improve the player's condition and then design Cyclescape to meet them. Lastly, we will analyze how successful Cyclescape was in meeting these goals.

To my parents and partner who believed I could

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Chapter 1

Introduction

Children with serious medical conditions spend a lot of time on self-care. Children with end-stage renal disease, in particular, spend three hospital visits 3-5h in length per week on hemodialysis or peritoneal dialysis treatment, accounting for 30% of their after-school time. These children have difficulties finding time for activities such as sports, social events, and general entertainment. As a result, these children are often less physically able than their peers, as well as have poorer mental health, such as reduced optimism and self-confidence.

As a result, **Cyclescape is a Virtual Reality video game developed to test a hypothesis: for kids undergoing dialysis treatment, can we both improve their physical and mental state by having them escape to a virtual-reality world**, of which they navigate through by pedalling on a stationary bike in the real world. The map of the game plays a non-trivial aspect; while we do not need to make the map's visuals accurate to life, the effort required to travel it should be. This brings us to our next question: How can we simulate this effort and personalize it for various players?

The obvious solution is to recreate real-world physical data into a video game "map" that reflects parts of reality; including the distance and effort). Attempting to recreate a substantial enough world size for a player to transverse, however, especially a unique one for each player is unrealistic. So, what physical aspects of the real world contribute to the physical exertion required to transverse a path? That would be the distance travelled, the path's elevation, physical conditions (paved roads, forest, dirt, etc.), and the climate. The latter two are much more difficult data to obtain and can change frequently. The distance and elevation, however, can be easily obtained from real-world geo data. Cyclescape will combine this map data with map generation to create a unique and customizable map for each player.

Note that this thesis will focus on map generation in regards to Cyclescape. The thesis ”Purpose Built Exergame Design” [6] by Ethan Chan, who was the co-developer of Cyclescape, will cover more of the game design aspects of Cyclescape.

1.1 Problem Statement

Cyclescapes is being designed to examine whether an AR/VR game played on a stationary bike while wearing a VR headset can improve physical and mental health (although we do not touch much on the latter, nor are able to test it in the scope of this thesis) of kids undergoing dialysis treatment. The game should encourage physical exercise and provide an interesting and believable experience to help them forget their current physical environment. Furthermore, can we integrate existing real-world data into a pedalling-based game to effectively simulate the home-to-school (and back) trip on a bike while catering to kids who are not (yet) able to? To address the goals above, we will dynamically create a personalized map using real-world geographic data (in the form of a GPS map route) to create a personalized game map for the current player. Lastly, We will then analyze how the generated map meets the following goals (which we will derive in 3.1.1):

- Provide replayability
- Encourage the player to cycle
- Provide a meaningful experience
- Improve the player’s mental well-being
- Avoid causing excessive motion sickness

1.2 Outline

This thesis consists of 10 chapters, excluding this introduction. Chapter 2 will present the pre-requisite knowledge required to understand the rest of the thesis. Chapter 3 will define the goals of Cyclescape, the constraints, and major viewpoints. Chapter 4 will give examples of previously existing real-world data usage in video games, then Chapter 5 will explain the different types of geographic data available, and how the correct one was picked for cyclescape. Chapter 6 will explain the stakeholders, the deployment environment, and anticipated users, as well as both the functional and non-functional requirements.

Chapter 7 will extend the previous by deriving map-design goals that we will use in the evaluation. Chapter 8 covers the architecture of Cyclescape, and chapter 9 explains its design and implementation. Chapter 10 evaluates how the implementation of Cyclescape met the goals designed in chapter 7, and chapter 10 concludes what we learned, the results, and future changes.

1.3 Contributions

The contributions found in this thesis are:

- An overview of how real-world data is used in video games
- A brief overview at available open geographic data
- The design, architecture and implementation of Cyclescape, a VR cycling game for kids undergoing Dialysis
- Design a methodology for transforming real world data into a virtual video game map
- Derive goals that can be used to measure how well a generated map can positively influence a child undergoing dialysis

1.4 Covid-19 Disclaimer

The official start date for research and development of Cyclescape began in September 2019 and revolved around in-person development and multiple rounds of live testing. Unfortunately covid-19 hindered much of our development and testing phase and affected the following:

- We were unable to procure equipment for our expected deployment environment due to supply issues
- Our original testing was going to be multiple rounds: The first round would be informal and with adult peers, friends, and acquaintances. The second round would be informal, with the expected audience - children on Dialysis and their caretakers, to receive initial feedback on their thoughts of Cyclescape. Lastly, there would be a more formal and structured testing round with the children on Dialysis and their caretakers to assess the goals we would define in 3.1.1. Throughout the development and research of Cyclescape, we expected that rounds two and three would eventually come around, however, that never came to be, and the evaluation ended up being done with only the first round of testing, and

we could only try our best to make an educated guess on how the target audience would've reacted to Cyclescape.

Chapter 2

Prerequisite Knowledge

This section will cover briefly the background knowledge required to understand the contents of this paper.

2.1 Geographical Map Data

In the context of this paper, Geographical Map Data will refer to the digital representation of real-world Geographic attributes such as location, spatial relationships, and environmental data. Geographical Data is generally available in two formats: Vector Data and Raster Data [8].

2.1.1 Vector Data

Vector data is a set of XY coordinates corresponding to points(commonly in longitude and latitude), lines, and polygons. Lines are used to describe features that are too narrow to have an area such as a road. Polygons is a set of coordinates forming a closed boundary to represent features that have an area such as a property boundary. Vector data is useful for storing data that has discrete boundaries, property borders, streets, and physical objects. An example that uses Vector Data is the standard Google Map View.

2.1.2 Raster Data

Raster data is made from a set of squares (also called pixels, cells or grids). Each of these squares stores data for a given parameter that the raster map is representing. As a result, they are good for continuously changing attributes, such as temperature, elevation, or contamination. An example of raster data would be Google's Satellite view.

2.2 Video Game Map

This refers to both the setting and virtual *physical* environment on which a video game takes place.

2.3 Dialysis

A medical treatment for people with late-stage kidney failure [[2]]. With kidney failure, waste and toxins build up in the bloodstream and need to be filtered through dialysis. There are two types of Dialysis - hemodialysis and peritoneal dialysis. Peritoneal dialysis occurs through a dialysis solution implanted into the body. The target audience undergoing dialysys in this paper however is going through hemodialysis - where a machine removes blood from the body, filters it and returns it to the body over a period of 3-5 hours, 3 times a week. The machine entry and exit point may take place through the chest area, or arm.

2.4 VR

VR is an acronym for Virtual Reality. VR refers to a computer-generated environment that simulates a user's experience in that world to be real. This is generally accomplished through virtual reality equipment such as a head-mounted display, some means of control or movement (such as turning head, or hand controllers), as well as audio and video feedback resulting from the user's interaction in the environment.

2.5 Stationary Bike

A stationary bike, also called an exercise bike, is a device where a person sits either upright or recumbent (laid back) and pedals in a stationary area.

Chapter 3

Cyclescape Project Overview

3.1 Project Description

3.1.1 Project Goals

This chapter will give an overview of the goals of Cyclescape, the constraints that must be met, as well as the target participants.

These are the goals as defined by the research proposal for Cyclescape [14]

1. Project Goal 1: Determine the **short** and **long term** effects of VR-based exercise on wellbeing of children undergoing dialysis
2. Project Goal 2: Determine the dialysis efficiency which will be measured from pre and post dialysis blood samples
3. Project Goal 3: Determine the fitness of the participant, defined as maximal volume of oxygen uptake
4. Project Goal 4: Utilize VR technology to deliver physical and emotional stimulus in a meaningful and engaging format

The following goals regarding map generation can be derived from the project goals:

1. From Project-goal-1, we must make sure that Cyclescape's in-game map has to provide **replayability** to observe long-term effects.
2. From Project-goal-2 and Project-goal-3, the map must encourage the player to cycle, and improve their physical fitness.
3. From Project-goal-4, the map generated must provide an experience that is impactful to either the user, the caretaker, or the parent. (through the accomplishment of some goal)

4. From Project-goal-4, the map generated must encourage them to accomplish some goal that improves their mental well-being (self-confidence, optimism)
5. From Project-goal-1, due to the player being on Dialysis (and being in a weakened state), the generated map should avoid causing motion sickness.

3.2 Mandated Constraints

3.2.1 Implementation Environment of the Current System

The game will use the following constraints as the foundation for development. Constraints 1, 2, and 4 are directly enforced by the project proposal, which can be seen in appendix A. Constraints 3 was derived through the requirements of the project.

1. Must use virtual reality technology
2. Must use pedalling from a stationary bike as the main source of video game control
3. Players will be patients undergoing dialysis
4. The system must be a game

3.2.2 Viewpoint overview

Cyclescape is a video game designed for two distinct participants: the player using the VR headset and stationary bike to engage with the game and a medical practitioner or caretaker overseeing the player's activity. The primary task for the player is to complete the game challenges designed to encourage physical exertion. The caretaker's task is to monitor the player's well-being through tracked biometrics to ensure the player's safety and manage Cyclescape configuration settings for the player. Both the player's and caretaker's viewpoints will be analyzed below.

Player's Viewpoint

Cyclescape, a VR (Virtual Reality) video game, centers around cycling on a stationary bike. This activity is augmented by an attached trainer, a device capable of modifying resistance and tracking rotations. The game will be session-based, similar to an arcade game, and last until the map is successfully traversed, or the time limit set by the caretaker is met. The player can select from different themes and difficulties that best appeal to them.

To make the maps more personalized and impactful experience to the player, the cycling paths will be based on real-world geographic data, replicating the real-world effort to bike along said path through the bike trainer. The goals for the players (at least, those old enough) will be to improve their stamina and boost their self-confidence through feats such as "I can bike to school!".

Caretaker's Viewpoint

The caretakers will focus on the configuration and setup of the video game and real-world data, as well as the monitoring and tracking of their health throughout their treatment. For game management, the caretaker will be able to add/remove players and customize the level with aspects such as the theme of the map and the difficulty/intensity of that level. They will also select the map data to be used for Cyclescape. The selected map will help the caretaker teach their patient(player) their current stamina and provide information such as whether the patient is strong enough to do things such as bike to school. The game will track and record the player's heartbeat using a heartbeat monitor for the bio-metrics data. It will record data such as peak, average, and starting heart rate - and provide safety features such as pausing the game if the maximum heartbeat threshold is reached. The player's distance travelled during the duration, along with their top and average speed, will also be tracked and recorded by the bike trainer for statistical purposes.

Chapter 4

Real-world Data in Games

Using real-world data in Video Games is not a new concept. Rather, real-world data is widely used in video games - just rarely in the scenario that will be covered in this paper. The following section discusses the different types of data being used and some examples that use said data.

4.1 Real-World Setting

This is the most popular type of real-world data being used in video games, where developers attempt to recreate an entire real-world location as a setting for the game. Due to size restrictions, most of these result in a slightly condensed and modified version of the actual city, but often with efforts to preserve the most well-known streets and landmarks. Some notable examples include Sleeping Dogs [23], which recreated Hong Kong, Watch Dogs [22] - Chicago, and Spider-Man [13] - Manhattan.

4.2 Real-World Landmarks

Generally, the overall world in these games is fictional, but famous landmarks are added. This is a subset of the Real-world Locations above and is generally used to convince the player that a certain in-game location is, in fact, a real-world location. A game franchise that makes constant use of this is Assassin's Creed - Unity [21] has a faithful recreation of Notre Dame in their version of Paris, and Brotherhood [20] includes the Coliseum (Rome). Some other examples are the Statue of Liberty - numerous superhero games use this to tell the players that the setting is New York, or Shibuya Crossing, featured in Persona [4], World End's with You [18], and many other games that feature Tokyo.

4.3 Satellite Imaging

Satellite imaging in games refers to grafting satellite images as a texture in a game. This has been available since the mid-2000s in games such as Microsoft Flight Sim X [16] or XPlane [15], which allowed players to put in custom terrain files generated from real geographic data. While these early implementations are not much more than a flat low-resolution image being used as a backdrop, and generally for a smaller, fixed area, satellite imaging in games in modern times has improved drastically. One such example is the newer Microsoft Flight Simulator 2020, which reportedly claims to feature all cities, airports, roads, and mountains [1] amounting to around 2 petabytes of data from Bing Satellite imagery. Microsoft Flight 2020 then uses Microsoft Azure's Artificial intelligence to render the visuals, enhance them (simulate 3D), and fill in the missing gaps.

4.4 Terrain Data

This refers to the recreation of a geographic location being recreated through geographical data input. While no officially released games with this feature exist, two notable examples will be discussed below.

4.4.1 Minecraft Terra 1-1 Mod

This is a fan-made mod for Minecraft, a survival sandbox featuring a procedurally generated world made of various blocks. Created by YouTuber PippenFTS, Terra 1-1 Mod [17] is a recreation of the earth as a whole. The mod reads in open source data from multiple sources. OpenStreetMap for elevation, road, water data, and ArcGIS REST TreeCover for tree data. Climate Data, including rain and temperature, is obtained from The University of Delaware Center for Climatic Research's Climate Data Archive, and soil suborder data is from USDA Natural Resources Conservation Service's Global Soil Region Map. With these datasets, Terra 1-1 Mod is a to-scale recreation of planet Earth, complete with all-natural geographic data, with man-made structures being ignored.

4.4.2 Freeciv Map Generation based on Open Data

This is also a custom mod made for and discussed in "Balanced Civilization Map Generation Based on Open Data [5]" by Julian Togelius and Gabriella Barros for the open-source game FreeCiv. FreeCiv itself is a fan-made, open-source game heavily inspired by Sid Meier's Civilization - a turn-based strategy game series where the player leads a civilization from the Stone Age to modern times and beyond through acquiring resources, research, and military conquest. The settings for these games are either procedurally generated from a game seed or a hand-crafted map such as “Earth” or “Pangaea”. Barros and Togelius argue that many procedurally generated maps result in an unbalanced or uninteresting map, while hand-crafted maps are time-consuming and difficult to keep up with the increasingly diverse player base’s demands.

In this mod, terrain information is obtained from OpenStreetMap (OSM), an open-source, community-based alternative to Google Maps, which is then imported into a Java application using JMap viewer. Resource locations are obtained through Google with search terms like “oil deposit + maps”. An interactive tool was then created to guide the user through importing and selecting both terrain resource maps and generating a FreeCiv map.

4.5 Data Games

We will refer to a series of papers and games written and developed by Togelius and Friberger. They state that while real-world data being used in video games is not unheard of; they claim that the “real-world data has passed through a manual filter where human game designers select and reshape data to be suitable for the game in terms of e.g. challenge and overall aesthetics”[11]. As a result, Togelis and Friberger describe data games as “games where gameplay and/or game content is based on real-world data external to the game, and where gameplay supports the exploration of and learning from this data”[11]. These games require two main resources: open data, which refers to publicly accessible data on the web from governments, companies, and other organizations, and procedural generation (PCD), which is the automatic generation of content through some algorithm.

In their other paper, “Generating Game Content from Open Data”[9], they described the three main dimensions that data games could be categorized into:

1. Underlying Genre - the foundation for the data game design.
2. Source of Data used in the Game:
   (a) Data types - numbers, text, images, etc
   (b) Data Topic - where the data originated from, for example, geographic data, political data and so on
3. How data is transformed into game content - where content refers to various artifacts in the game, including maps, levels, items, and quests.

Togelius and Friberger also have a few other papers focusing on specific data games that they have generated which include the following:

1. Bar Chart Ball, A Data Game [19] describes an arcade-like game where players indirectly control a ball by modifying a bar chart under the ball, which in itself displays real-world demographic data from the UK.
2. Open Trumps, A Data Game [12] describes a modified version of the card game Top Trumps, where the decks are procedurally generated from a specified Open Data source instead. In the paper, the data set utilized is countries and details such as GDP, mortality rates, or Tomato Production.
3. Generating Interesting Monopoly Boards from Open Data [10] describes a modified version of the popular board game Monopoly. This version of Monopoly uses economic and social indicator data from the local UK government as input, along with user input for options such as weightings for data and criteria for street selection to procedurally generate a custom Monopoly playing board.

4.6 Real-World Data in Cyclescape

Cyclescape aims to provide a impactful and relevant experience to the player through the use of map data and answer questions such as “Can I bike to school”? Cyclescape will implement features described in Terrain Data to accomplish this. In contrast, Cyclescape will not attempt to recreate our planet like Terra 1-1 or an entire map like FreeCiv. Instead, Cyclescape will look at a map route, specifically the longitude, latitude, and altitude coordinates from one location to another. Using this data, Cyclescape will attempt to simulate the real-world distance and effort (from the distance and altitude) to transverse the path virtually.

Chapter 5

Geographic Data

In section 3, pre-requisite knowledge, we covered what geographical data is and the formats that it is available in. This paper will focus on the usage of Elevation data due its usage in the CycleScape project as introduced in chapter 2, however, we will briefly explore other types of geographic data to familiarize ourselves with alternatives and future works. Lastly, we will explain the different methods by which elevation data can be obtained.

5.1 Types of Geographic Data

The types of open geographic data include (but are not limited to) the following (Christine, Homuth, personal communication, 2020):

1. Land Cover - the physical elements of Earth's surface, such as forests, swamps, and deserts.
2. Boundaries - human-defined land boundaries - such as property borders
3. Hydrography = data on water locations such as rivers, lakes, and oceans.
4. Temperature - this can refer to one of 2 things:
    (a) The temperature across an area at a certain time
    (b) The varying temperature over a time period at a specific location
5. Transportation - the transportation routes, such as bike trails, bus routes, train routes
6. Elevation - the height data of geographic locations. This is available in one of two formats:
    (a) Vector Data in the form of Contour Lines (think of elevation lines drawn on topographic maps)

   (b) Raster data where a map is formed from a surface of pixels - where each pixel has a corresponding elevation value.

7. Orthoimagery - satellite imagery or aerial view of a geographic location where the scale is uniform among all areas.

Some of these types of data are obtainable through both Vector and Raster Data (i.e. Elevation), while some, such as temperature, are normally associated with Raster Data and Boundaries with Vector Data.

5.2 Type of Data to be chosen

We will primarily use elevation data, due to its usage in the CycleScape project as introduced in chapter 2. We will traits that make it an ideal candidate for map generation, specifically with direct mappings, and also see if any other geographical data types meet the same criteria. Firstly, a bounded derivative implies the change is within a limit, and does not change too drastically - such as jumping immediately from min to max values. A bounded derivative in a direct mapping will result in a gradual slope, which will be more aesthetically pleasing, and the smaller slopes will make it easier to add other level elements, and easier to plan around where the player is expected to be. Secondly, the data being in the form of a vector is also ideal. This would mean that when one moves along one axis, the other one to two axis will also change accordingly - which allows for easy direct mapping to a path in map generation.

5.3 Choosing and Obtaining Elevation Data

As was briefly mentioned above, elevation data is available in two different formats - Vector data and Raster data. Vector data is in the form of Contour lines, such as in Topographic maps, or DEM - Digital Elevation Model. The alternative is Raster data, where a map is made up of a surface of pixels, and each pixel, located at a specific longitude and latitude has a corresponding altitude. Vector data is more useful for acquiring the overall elevation of a 3D area, whereas raster data is more useful when you need specific points on a map only. In the CycleScape project, the player will upload a map file in the form of a GPX or KML file, containing a set of longitude and latitude points. As such, raster data comes in a form that requires less processing as the coordinates can simply be used to obtain the corresponding altitude. In Vector data, we would have to process the 3D area for the actual points (and this is generally slightly less accurate).

There is much more available open geographic data available in Vector form due to its ease of storing a lot of information, and versatility for usage. Raster data generally seems to be available through different API queries, where you would send in a request containing a longitude and latitude pair and get a corresponding altitude response. The main free option is available through **Open-Elevation**, but at the cost of long and unreliably query responses. The alternative, and what is used for the CycleScape project is **Google-Elevation-API**. Google-Elevation-API allows for the query of a series of coordinates, such as multiple longitude-latitude pairs as would be seen in a path, and provides fast and reliable response times. It is however a paid resource upon each query, amounting to 0.5 cents USD per query.

Chapter 6

Project Requirements

This chapter will cover

- Stakeholders
- Project environment
- Required hardware and software
- Anticipated Users
- Functional Requirements
- Non-functional Requirements

6.1 Project Stakeholders

The primary stakeholders of the Cyclescape Project are as follow:

- Dr. Obeid, Joyce - Hospital Researcher, Non-technical Cyclescape Project Manager
- Dr. Carette, Jacques - My MASc Supervisor, and Cyclescape Consultant

- Trandinh, Thien - Cyclescape Developer
- Chan, Ethan - Cyclescape Developer
- Patients under Dialysis Treatment - Primary Audience of the project
- Parents of the Patients under Dialysis Treatment
- The caretaker overseeing the patient undergoing Dialysis Treatment - Secondary target audience of the project

6.2 Project Environment

6.2.1 Hardware

The expected deployment unit for the release of Cyclescape will include:

- VR (Virtual Reality) Headset (HTC Vive and HTC Cosmos were used for development and testing, other headsets may or may not work) - This will be the main display for the player
- ANT+ Bike Trainer - which will be used to track bike pedal rotations as well as alter the resistance in the pedalling
- A stationary bike that can have a bike trainer be connected to
- ANT+ Compatable Heart Rate monitor - used to record the player's heart rate
- A desktop consisting of the hardware-defined in the table below
- A standard mouse, keyboard and monitor for the caretaker

Component	Specification
CPU	i5-9600kf
GPU	MSI GTX 1660
PSU	Corsair CX 550W
Motherboard	ASrock Z390
Memory (RAM)	2x8GB 3200MHz DDR4
Storage	500GB SSD

Table 6.1: Specifications for desktop used for Cyclescape Testing Environment

Figure 6.1: The VR headset to be used

Figure 6.2: Stationary Bike and Trainer setup for Development

6.2.2 Software

The required software will all be free and easily accessible and include the following:

- Unity Game Engine - The majority of Cyclescape will be developed and run on the Unity Game Engine, and developed Mono C# and Unity's XR Library for handling VR
- VR Drivers - this will either be headset-specific drivers (i.e., Vive drivers), or SteamVR, which works for all headsets; however requires a Steam account and for you to be signed in
- Any mapping software that can export a path from one point to another as a KML or GPX file. Google Earth is the suggested option.

6.2.3 Other

This includes anticipated equipment for a deployment unit, however, the Cyclescape project will be expected to work without it. This includes:

- Dialysis Unit - the players playing the game are expected to undergo Dialysis Treatment. This will restrict the player's movement to one arm or hand.

6.3 Anticipated Users and their Use Cases

This section will cover the use cases of the two expected users for Cyclescape, split into the setup and playing phases (taking into account but ignoring responsibilities related to Dialysis treatment).

6.3.1 Player

Player Characteristics:

- **Age:** 6-18
- **Physical Capabilities:** Completely Sedentary to Low
- **Virtual Reality Experience:** None to High
- **Gaming Experience:** None to High

Cyclescape's players are patients (children) undergoing hemodialysis - the treatment of blood externally through a machine - inserted through either the chest or arm. Before Cyclescape, these patients would be doing stationary activities such as watching TV, playing video games, or interacting with their cellphones.

Player - Setup:

- Climb up onto the Stationary Bike
- Change the bike's seat settings to fit the current Player
- Attach a heart-rate monitor to the Player's arm
- Put on the Virtual Reality (VR) headset and adjust it so it sits firmly on the Player's head

After these steps, the Player would see a waiting room on the headset, waiting for the game to start.

Player's Use Case:

Cyclescape aims to replace those stationary activities done during dialysis with a VR exercise game that is more physically and mentally beneficial for the player. Cyclescape will provide a virtual world for the player to be in, displayed to the user through the use of a VR Headset. The physical length of the game level - will be based on a real-world route that is uniquely generated for each player. This, as well as challenges, provides a means of mental stimuli encouraging the player to pedal.

Cyclescape will read in 3 main input from the user:

- VR Headset Position - The game will track the user's headset direction relative to the starting calibrated view and display to the user as if they turned their heads in real life.
- Bike Pedal Velocity - Trainers will be attached to the stationary bike, which will track the velocity and acceleration of the bike pedals - which will then be translated into movement in-game, displayed to the player
- Heart Rate - Through the use of a heart-rate monitor, the player's live heart rate will be read and displayed to the caretaker

The player will be presented with numerous challenges in-game that will require different velocities of pedalling to complete successfully,

6.3.2 Caretaker

- **Technical familiarity:** Low to High
- **Virtual Reality Experience:** None to High
- **Gaming Experience:** None to High

The caretaker is the caregiver overseeing the patient's dialysis treatment. The caretaker will be responsible for the setup, execution, and monitoring of Cyclescape, including software and physical responsibilities.

Caretaker's Use Case

Regarding software, the caretaker will be responsible for setting up the game for the player. This includes importing a real-world map route into the game and customizing the map options for the current player. Once the game has started, the caretaker will also have to continuously monitor the player's heart rate and be able to stop the game.

The caretaker will also be responsible for caring for the patient outside of Cyclescape's software. This includes sanitation between sessions, helping the patient get on the stationary bike, putting on the headset, and assisting with attaching the heart rate monitor to the patient's arm.

6.3.3 Hardware

6.4 Functional Requirements

FR-HW-1
Description: The system must receive data originating from ANT+ bike trainer device.
Rationale: Cyclescape must use bike pedalling as its main source of control.
Fit Criterion: When the user pedals on a deployed system (with connected trainer, pedal, and game), the pedal data is recorded and parsed by the system.
Relevant Stakeholders: Joyce

FR-HW-2 ***Description:*** The system must receive data originating from ANT+ heart rate monitoring device.
Rationale: The caretaker must be able to monitor the patient and adjust the game accordingly for player safety.
Fit Criterion: In a deployed system, the patient's live heart rate is recorded and displayed to the caretaker.
Relevant Stakeholders: Joyce

FR-HW-3 ***Description:*** The system will map forward pedalling intensity recorded by the bike trainer into a forward velocity in-game.
Rationale: The forward motion of a pedal would move the bike forward in the real world, and the game world should mimic the same logic.

Fit Criterion: When a player pedals forward, the player's position in-game will also move forward relative to the intensity pedalled.
Relevant Stakeholders: Joyce, Thien, Ethan, Carette

FR-HW-4 ***Description:*** The system will map zero or backward pedalling to a zero acceleration in-game.
Rationale: The game will slow down the player's movement relative to the real world.
Fit Criterion: The player stops pedalling, and the player's acceleration in-game becomes 0.
Relevant Stakeholders: Thien, Ethan

FR-HW-5 ***Description:*** The bike trainer should be able to modify the resistance according to the map data provided.
Rationale: The bike trainer should be able to produce resistance mimicking the real-life effort of biking up or down an incline or decline in real life.
Fit Criterion: When the map data shows an incline, the trainer's resistance should increase accordingly.
Relevant Stakeholders: Joyce, Thien

FR-HW-6 ***Description:*** The VR headset should interpret and map the movement and orientation of the player's head.
Rationale: The VR headset should be able to imitate the vision available in the real world.
Fit Criterion: When the player turns 60 degrees to the right, the camera view in-game will also rotate 60 degrees to the right.
Relevant Stakeholders: Thien, Ethan, Carette

FR-HW-7 ***Description:*** The system should provide the means to calibrate the player's current orientation before the game starts.
Rationale: Cyclescape was created to be portable, and the patient's position and orientation while playing the game may change between sessions.
Fit Criterion: In the map setup page, the caretaker can select a button that checks the user's current orientation and sets that orientation as "looking straight".
Relevant Stakeholders: Thien, Ethan, Carette

6.4.1 Gameplay

FR-GP-1
Description: The system should be able to generate challenges for the player

to complete.
Rationale: Challenges will be the main motivation for Cyclescape to encourage physical activity for the player.
Fit Criterion: Challenges are generated in the game during a game session.

FR-GP-2
Description: The system should notify the player when a challenge has been generated into the world.
Rationale: The player should know when the challenge is present to attempt it
Fit Criterion: The challenge will be visible to the player's VR headset view.

FR-GP-3
Description: The game must be able to model and track the player's performance relative to the session and challenges presented.
Rationale: The game needs to accurately track how the player's actions relate to their performance in playing Cyclescape.
Fit Criterion: The metrics used to record the player's performance changes predictably relative to the player's actions.

FR-GP-4
Description: The system will parse in real-world data and store it as a height map.
Rationale: Cyclescape must store real-world data to emulate real-world effort in-game accurately.
Fit Criterion: The system reads in a map file, queries for elevation data, and stores the real-world data in-game.

FR-GP-5
Description: The system will be able to track a player's relative position on a path when playing the game.
Rationale: Player position needs to be tracked to notify both the player and caretaker of the player's current progress and whether or not the path is completed.
Fit Criterion: The player's position on the path updates live relative to the player's pedalling in the real world.

FR-GP-6
Description: The system will provide information to the player on their in-game performance.
Rationale: Knowing their progress will provide feedback and help motivate the player to continue their actions.

Fit Criterion: During a Cyclescape session, the player's current score will be visible to the user and updated live.

FR-GP-7
Description: The system will acknowledge when a player completes a challenge within the game.
Rationale: In order to update and evaluate the player's performance - the system needs to update when the player's actions influence performance.
Fit Criterion: Upon completion of a challenge, the player's performance metric will change accordingly.

FR-GP-8
Description: The system will allow the enabling and disabling of certain interactive challenges.
Rationale: The game should be customizable to various player preferences for both gameplay and exercise level.
Fit Criterion: In the game-setup page, the caretaker enables/disables a challenge, and the game's launch will reflect those changes.

FR-GP-9
Description: The caretaker shall be able to adjust the the length of one session duration.
Rationale: Different players will have different endurance levels that must be accommodated.
Fit Criterion: The game session will reach an ending state once the specified time is reached.

FR-GP-10
Description: The game will allow the caretaker to stop or pause the game.
Rationale: The patients' physical health may be poor, and they should allow the caretaker to pause or stop the game if they feel the player's safety is threatened.
Fit Criterion: While the game session is running, the caretaker clicks a button that stops the session.

FR-GP-11
Description: The game shall adjust the game's challenge difficulty automatically depending on the player's heart rate and performance.
Rationale: The player's health and safety is a stakeholder priority.
Fit Criterion: The game can track the player's current performance and heart rate.

6.4.2 Data

FR-D-1
Description: The system can save session data for future use.
Rationale: Session data should be stored to be re-used for future sessions.
Fit Criterion: Upon parsing and creating a path from an imported map file, the data will be saved to the system.

FR-D-2
Description: The system is able to save player data.
Rationale: Players are expected to play through multiple different sessions - and should be able to reload their existing profile
Fit Criterion: In player select, the caretaker can pick from an existing player.

FR-D-3
Description: The system will allow the editing of an existing player's data after creation.
Rationale: A player's data may change due to real-world changes or be entered incorrectly.
Fit Criterion: A player's weight changes, and the caretaker updates it in their profile accordingly.

FR-D-4
Description: The system shall be able to read geographic data
Rationale: Real-world geographic data was required by stakeholders to emulate real-world effort.
Fit Criterion: Data parsed from the geographic data can be read and stored in the system in a usable state.

FR-D-5
Description: The system will generate an in-game path for use in the core game loop using the data parsed from the imported real-world data.
Rationale: The system needs to generate an in-game path to emulate the effort of travelling it in the real world.
Fit Criterion: A path is created that is transversal in-game and reflects the real-world distance and elevation, as well as the effort to bike along the route.

6.5 Non-Functional Requirements

6.5.1 Look and Feel

NR-LF-1
Description: Cyclescape should feel like a game that utilizes exercise elements, rather than an exercise game.
Rationale: The game should provide an experience that motivates the player to play again and improve rather than a feel like a chore.
Fit Criterion: 90% of players during user play-testing respond positively to playing Cyclescapes

NR-LF-2
Description: The game should have means of encouraging replayability.
Rationale: The patients undergoing treatment are expected to play Cyclescape over repeated sessions.
Fit Criterion: 80% of players still respond to Cyclescapes positively after three or more repeat play sessions.

NR-LF-3
Description: The paths generated by the game must look seamless and continuous
Rationale: A continuous path will make the virtual environment feel bigger and more unified.
Fit Criterion: Players should feel like they're pedalling on a continuous path.

NR-LF-4
Description: The player controls should feel responsive.
Rationale: To prevent motion sickness, mappings from real-world actions to virtual should be responsive
Fit Criterion: Player input should provide instant feedback

NR-LF-5
Description: Information from the virtual environment should be conveyed to the player through both visual and auditory senses.
Rationale: Redundancy in information will reduce the chances the player misses important notifications from the game.
Fit Criterion: The player misses a visual notification signifying an in-game challenge but is made aware of it through a sound-effect prompt instead.

NR-LF-6

Description: The game shall minimize factors that induce motion sickness to the player.
Rationale: Cyclescape is a fully VR game, and players who get motion sick cannot continue playing comfortably.
Fit Criterion: 80% of players report little to no motion sickness after 1 game session.

6.5.2 Usability

NR-US-1
Description: The game should be optimized to run stably on the projected hardware.
Rationale: Unstable or low FPS (frames per second) can cause a lot of motion sickness.
Fit Criterion: On a HTC Vive and a GTX 1660, the player should be able to play at a stable 30+ FPS.

NR-US-2
Description: All visual interfaces should be of an appropriate size that is easily readable.
Rationale: Players will rely on these visual messages to play and track their progress.
Fit Criterion: 90%
NR-US-3
Description: Players should be given adequate time and space to focus on a given challenge.
Rationale: The game should maintain focus on one challenge at a time to not overwhelm the player.
Fit Criterion: When a player does a challenge, only one challenge appears to the user.

NR-US-4
Description: The VR display and controls should not encourage the player to move in such a way that causes loss of balance or risk of injury.
Rationale: The player should be safe while playing the game.
Fit Criterion: 99%

Chapter 7

Map Generation Goal Analysis

In Project Overview (see chapter 3.1.1), we defined **Map Generation Goals** to be:

1. Replayability
2. Encourage Cycling
3. Provide a Meaningful experience
4. Improve Mental Well-being
5. Avoid causing motion-sickness.

These goals, however, are higher level and difficult to map to an actual implementation. In this chapter, we will attempt to delve more in-depth at these goals and how they can be met, and derive more applicable goals to map generation in terms of Cyclescape.

7.1 Analysis

7.1.1 Replayability

The target audience of Cyclecsape will be children and teenagers undergoing Dialysis treatment multiple times a week whom are of varying levels of physical health. Cyclescape is meant to be played during those sessions in an attempt to meet project goals defined in 3.1.1. This constraint implies the game must offer unique replayability between repeated sessions.

7.1.2 Encourage Cycling

One of the predominant project goals is to improve the physical health of the player. Given the constraint of Cyclescape taking place on a stationary bike, this directly translates to a requirement to pedal. A goal or challenge must then be provided to encourage this behaviour.

7.1.3 Provide a meaningful experience

This goal is predominantly to supplement the other map generation goals by providing a meaningful experience to the user.

7.1.4 Improve Mental Well-being

Many of the players of Cyclescape will be suffering from worse-than-normal mental health due to both the physical and mental toll of being on dialysis constantly. Playing or completing the game must then provide some mental stimuli to improve the player's mental health.

7.1.5 Avoid causing motion-sickness

A predominant problem in VR that has yet to be fully solved to this day. Being in VR for a normal, healthy person can cause a lot of motion sickness. As the players are expected to be of less-than-average health and undergoing dialysis, Cyclescape must try its hardest to avoid causing motion sickness.

7.2 Deriving Design goals

1. The map generation will mimic the real-world effort to transverse the path. This will provide a solution to map-generation goals 2, 3 and 4. The path can be generated from something relevant to the player (such as from their home to school) which should in theory, encourage them to cycle. It will also tie it to a real-life goal to answer questions such as "Can I bike to school" - and help reinforce their mental wellbeing.

2. **The map will use chunk-based procedural generation in order to create a unique map on every playthrough**, even when using the same real-world data. This is extremely important, as the path generated from terrain data will be replayed many times (the player is not expected to successfully get to the end on their first try, but would rather work their way up to it after each playthrough).

From the same goals, we can also deduce an additional design constraint: From the geographic data obtained above, we are limited to a 2D height map from an origin to the destination point. There is also no access to real-world environment data, such as what buildings are where, what landmarks, etc.

Chapter 8

System Architecture

In chapter 3: Project overview, Cyclescape was described as an asynchronous video game consisting of a Game component for the player to experience in virtual reality and a Caretaker user-interface component allowing them to both configure the game for the patient, as well as monitor their current biometric data. In chapter 6: Project Requirements, a third component “Data” can be inferred, facilitating the flow of data between the Game Component and the Caretaker Component.

8.1 System Overview

Cyclescape is an application that is used asynchronously for two completely different users with completely different use cases. As a result - the software was divided into two main components - one facing the player and one facing the caretaker. The **Player component** controls most of the actual game aspects, such as the setting, challenges, gameplay, and VR controls. The **Caretaker component** focuses on taking desktop mice and keyboard input and managing player data, metrics, and level data. While the two components have different use cases, the data created or modified in one component - is greatly important to the other. As a result, a third component - a **Data component** was introduced as a central entity, allowing both the player and caretaker component to read and write data. Both the Player and Caretaker component can be loosely treated as separate systems with their own architecture.

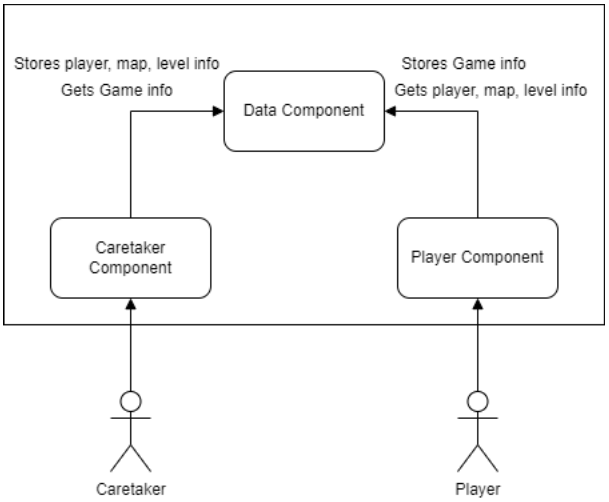


Figure 8.1: Relationship between main Components

8.2 Player Component

The architecture of the Player Component tries to follow Unity's recommended software design: component-based architecture mixed with PAC architecture (where each component has its own presentation, abstraction and controller). Note that Unity's game engine provides many of the core functionality for a game, such as (but not exclusive to) graphics rendering, physics, and game run-time. The following diagram displays the different components inside the Player component and their relationship with each other. The components are as follows:

1. Player Input
2. Game Controller
3. Game State Monitor
4. Level Generator
5. Movement Controller
6. Challenge Controller

The architecture of the player component was split up such that each component has one primary responsibility - each being fully modular. The decomposition revolves around the Game Controller, which acts as the main control hub. Almost every component will either send data to the game Controller or require data from it. The Game State Monitor, Level Generator and Movement Controller all perform their independent tasks - and update the Game

Controller on what those components have accomplished. The Game Controller then parses the information it receives and sends information on the player's status and position to the challenge Controller. The challenge controller will then request the challenge component to create a suitable challenge and then spawn said challenge.

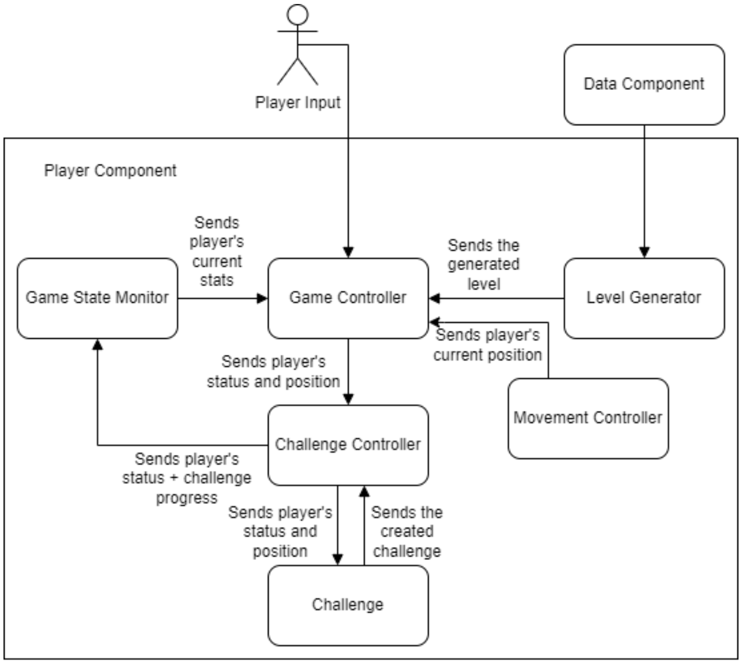


Figure 8.2: Relationship between sub-components of the player component

8.2.1 Player Input

This component handles the interaction between the player and the system. Unity's default functionality and assets will handle the conversion of raw data from hardware recording the player's input into easily usable data (such as vector positions, rotations, etc.) for the game. There are three pathways from which input will arrive:

1. VR Headset Locomotive: Regarding Cyclescape, the only VR motion of relevance is the current rotation of the VR headset. Any rotations done by the player will be recorded and sent to the Game Controller

2. ANT+ Cycling Trainer: The cycling speed of the player on the bike will be recorded in rotations through a trainer attached to the stationary bike and transmitted through ANT+ signal to the Game Controller

3. Biometric Data: Heartrate data from the player will be recorded and sent to the Game Controller as BPM.

8.2.2 Game Controller

This component acts as the central controller for the game, taking in information from other components. It updates the current state in the Game State manager, tells the Challenge Controller what challenges to spawn, reads the map created by the Level Generator, and then allows the Movement Controller to set where the player is on the map.

8.2.3 Game State Monitor

This component stores the player's statistics through hardware monitors in the Player Input during the gameplay session.

1. Cycling Speed
2. Heartrate BPM (beats per minute)
3. Distance travelled

This component will then send that data to the Game Controller, which then sends that data to the Caretaker Component.

8.2.4 Level Generator

This component encapsulates all map and level generation taking place. It will read the *session profile* (8.4.3) stored in the Data Component, which in turn was set by the Caretaker Component. From this data, it will then parse the map data and map it into a video game world. **The methods and results of this mapping will be the focus of this thesis.** It will then set level parameters and settings according to what was defined in the session data. This map is then sent to the Game Controller, allowing the Movement controller to navigate the player through it. Due to the encapsulation of all level-generated logic, supporting new ways to generate levels and changing how current levels are generated should be easy.

8.2.5 Challenge Manager

This component is an interface for the game controller to track the player's metrics and then create challenges suitable for the player's current performance. This interface allows for easy addition and modification of challenges.

8.2.6 Challenge

This component generates some in-game entities, some rules the entities must follow, and a corresponding goal that the player must achieve. It will use component-based architecture, consisting of a controller for controlling entities and interaction rules, a data structure, and a presentation to display to the player.

8.3 Caretaker Component

The Caretaker component takes in all input through a desktop mouse and keyboard. All of these user inputs go through a UI Controller interface, which interacts with the Player Component and the Data Component. Accessible through this interface are four main components:

1. Player Monitor
2. Player Management
3. Geographic Data
4. Level Configuration

Each of these components follows PAC architecture - where each component is independent with their own presentation, abstraction, and controller, allowing the easy addition and modification of new components. Through the UI Controller, the caretaker can interact with each component. Thanks to each component being modular - the UI Controller can access these components from different parts of the user interface where needed, such as accessing the Player Management component from both the player select menu, map management menu, and the level management menu. The Player monitor is the most independent component - where it'll handle the biometric and performance stats - and send that info to be displayed on the UI Controller.

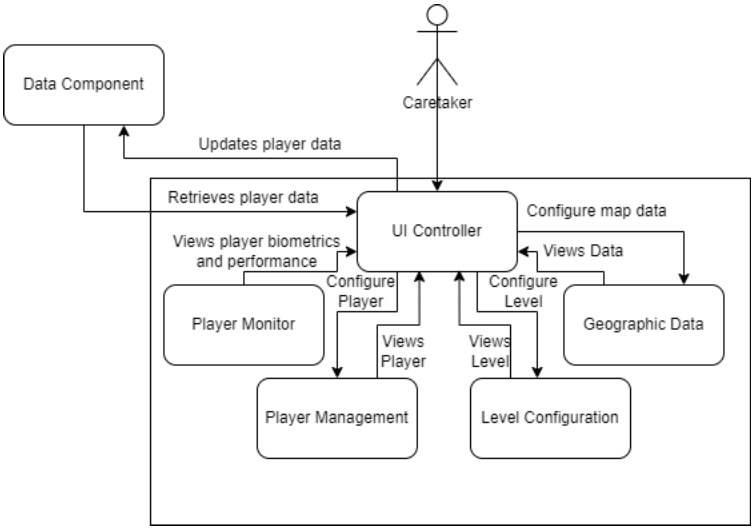


Figure 8.3: Relationship between sub-components of the Caretaker component

8.3.1 Player Monitor

This component reads data from the Player component regarding player biometrics (such as heart rate and current speed), then displays that data in a human-readable format to the Caretaker.

8.3.2 Player Management

This component allows the caretaker to add new players to the Data Component through the player profile creation menu and edit or delete existing players. This information is then stored in the Data component's *Player Profile* (8.4.1).

8.3.3 Geographic Data

This component provides a tool for the caretaker to upload KML and XML map files to Cyclescape. It will then perform a Google Elevation Query to grab elevation, then store the distance and elevation as a *height-map* for level generation. This information is then stored in the Data component's *Map Data profile.*

8.3.4 Level Configuration

This component focuses on reading from the Data Component *Player Profile* and *Map Data profile* (8.4.2, then provides an interface for the caretaker to input parameters and settings. All this information is then used to create a session profile, which the Player Profile will then access to generate a game level.

8.4 Data Component

The data component encapsulates and facilitates the transfer of all the data written and read between the Player Component and the Caretaker Component. The data contained by this component can be split into three types:

1. Player Profile
2. Map Data Profile
3. Session Profile

This component will have one additional sub-component - a File System Manager, which encapsulates the encrypting, writing, decrypting, and reading of Cyclescape game data to and from the local host system (Caretaker's desktop).

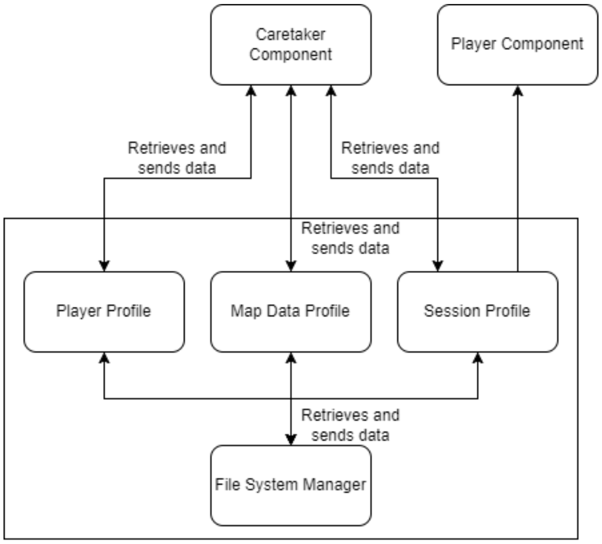


Figure 8.4: Relationship between sub-components of the Data component

8.4.1 Player Profile

This module handles the storage and organization of player-specific data, including an interface defining what parameters the Caretaker system must tell the caretaker to submit.

8.4.2 Map Data Profile

This module stores the height map (distance over elevation) of all maps uploaded by the Caretaker and provides easy access to the Player Component to use for map generation.

8.4.3 Session Profile

This module stores the level settings defined by the Caretaker for the Player Component to generate and the final results of a game session.

8.4.4 Read/Write

This module reads raw data from the Player Profile, Map Data Profile, and Session Profile, encrypts the data, and then writes to the Cyclescape System. It then provides methods for the Player and Caretaker Component to decrypt and then read the data.

Chapter 9

Design and Implementation

In this chapter, we will go over why Cyclescape was designed a certain way, as well as relevant implementation details.

9.1 Selecting the Data

In chapter 4, we discussed the many different forms of real-world data seen in video games. To briefly list them again here, they are as follows:

1. Real-World Setting
2. Real-World Landmarks
3. Satellite Imaging
4. Terrain Data

We will refer back to map-generation goals [3.1.1] and compare how the different types of real-world data score:

The map must encourage players to cycle and improve their physical fitness. This goal helps define the game goal we defined above, constraining it to require movement from the player. Terrain data 1(real-world setting) and real-world landmarks do not provide an obvious means to fulfill this goal. Terrain data, however, can be used to recreate the physical terrain in a certain area - which can then be used as the platform for encouraging players to move.

The generated map must provide an experience that is impactful to either the user, the caretaker, or the parent Real-World Settings, Real-World Landmarks and Terrain Data can all meet this requirement. The real-world data chosen can be taken from and represent the player's familiar world location (ie. real-world setting: Taking place in the same city, real-world Landmarks: The school they walk past every day, terrain data: the path they take to bike to school). Satellite imaging is a bit less inherently impactful to the player as it is generally a less detailed, more general bird-eye view over a larger area.

The map generated must encourage them to accomplish some game goal that improves their mental well-being. This goal is much more open-ended but can be summarized into this: the map must provide a game goal that, once accomplished, makes the players feel good about themselves. One way to accomplish the "feel good" is by making that in-game goal more "real" - tying that goal to a real-life goal so that once it is accomplished, the player has accomplished a very "real" goal, hopefully making them feel more accomplished or good about themselves. Unfortunately, this goal is too abstract to help narrow down real-world data types.

9.2 Selecting Geographic Data

Terrain data is one of the most easily obtainable in terms of geographic data. Most GPS maps have access to this information, and many have an API to grab this information or export the raw data. As we are trying to integrate this data directly with Cyclescape, we will only look at ones that **have an available API to interface with**. The popular sources we found were (but not exclusive to)

1. Google Elevation API
2. Open Elevation API
3. Strava API

We will then define two criteria to help pick an ideal source:

1. **Price:** - free is ideal; otherwise, a per-use basis is better than a subscription (as we wouldn't need many queries all the time)
2. **Accessibility:** - Should be easy to access, as well as fast and responsive

With those criteria in mind,

Google Maps + Google Elevation API

1. **Price:** $0.005 per query
2. **Accessibility:** Accessible through Google's Maps platform, and responsiveness is nearly instant.

Open Street Maps + Open Elevation API

1. **Price:** Free
2. **Accessibility:** Accessible through open-elevation API. API response time seems to range from an instant to 1 minute.

Strava Maps + Strava API

1. **Price:** $15/CAD per month
2. **Accessibility:** Accessible through Strava API V3. API response time is nearly instant.

Open-Elevation API is completely free; however, that comes at the cost of significantly worse responsiveness. As our focus is accessibility, we will forgo open elevation, leaving Strava and Google. Both Strava and Google have similar accessibility so that the deciding factor will be price. Strava uses a subscription model at $15/CAD per month. Google has a flat cost of $0.005 per query. For Google to cost as much as Strava, 3000 = (15 / 0.0005) separate queries must be made. As the expected monthly queries is much lower than that, Google is significantly cheaper. As a result, due to both price and accessibility advantages, **Google Elevation API** will be our method of choice for obtaining elevation data.

9.2.1 Retrieving and Managing the the Map Data

Cyclescape will likely generate levels using the same map data multiple times. Requiring a query to obtain this data on every session is both impractical and expensive. In this section, we will list the steps taken to retrieve the map data, as well as how it is stored to be easily re-usable.

Retrieving and storing the data consists of:

1. Obtain a map file consisting of a set of longitude/latitude points from point A to point B. Cyclescape accepts both KML (exported Google Maps, Open Maps) and GPX (exported through Garmin maps). These files may or may not contain altitude (elevation) data.
2. Parse the KML or GPX file for a list of Vector3 (longitude, latitude, altitude). If it lacks altitude - create a query string using the sets of longitude and latitude. Perform a query to obtain the altitude data for each vector point.

3. Translate the longitude and latitude coordinates into a flat distance, i.e. the vector distance between every 2 points. This should result in a 2D vector list in the form of a height map: height over distance.
4. Store this data as a simple 2D vector heightmap and store it locally to the machine. This data will be read and used as data to generate map levels when requested.

Heart Rate Monitor: Disconnected
Trainer: Disconnected

Cyclescape can read any GPX or KML map file, which can be exported from Google Earth Pro, Strava, Open Street maps and more (regardless if it has elevation data).

It is however strongly recommended you use Google Earth Pro, which is free, and allows the manual addition of points on a path resulting in a more detailed map file. To see a step-by-step tutorial on installing and usage of Google Earth Pro, please click Here

Figure 9.1: The 2d vector heightmap, generated from KML or GPX file

9.2.2 Implementation

A 2D height map from above reflects the distance and elevation along a specific path. Our next goal is to turn the height map into a form that the player can directly navigate.

Cyclescape accomplishes this through a spline path. A spline path in Unity is a set of points a, b, c ... x, where a curved line connects the points starting from a, b, c .... x. A spline path allows for direct mapping of the 2D height map obtained in the previous section and can be turned into a smooth path (avoiding motion sickness) for transversal. In Cyclescape, we utilize the library "Curvy Splines 7" which allows for easy spline generation and supports moving objects along the spline. This brings us to the next goal - to have the player navigate along the path while also "mimic the real-world effort to transverse the path" [1]. This is accomplished through the use of a bike trainer. This bike trainer is attached to the pedals on a bike and will adjust the resistance on the pedal relative to the slope given to it. From the height map, retrieving the slope is simply a rise/run between points between each game tick.

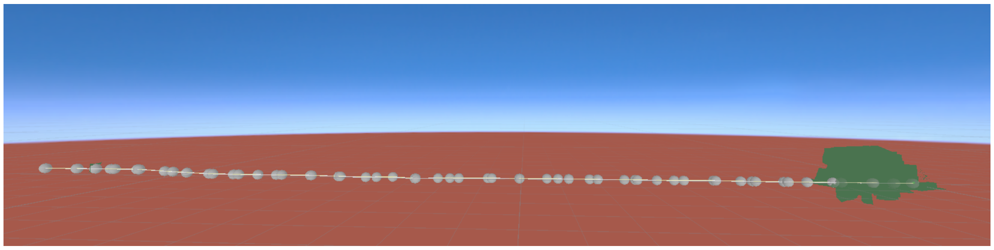


Figure 9.2: The created Spline Path

Next is to fill in the world in accordance with chapter [1], using chunk-based procedural generation. This consists of five tasks:

1. Split the spline path into uniform "chunks", where each chunk will have a different map piece loaded into. In Cylescape, this is split into 100-meter chunks, with the last trailing chunk (as not all maps divide by 100 perfectly) rounded up to the nearest 50-meter with a unique ending chunk.
2. Generate 3d terrain blocks that can be seamlessly merged together adjacent to each other to form the map. This was accomplished by manually generating 100 x 100-meter terrain chunks using various environmental assets.
3. Visualize the spline path being navigated. This depends on the type of map made in the previous step. For some maps, this is a magical trail in the sky; for others, it is a river outlining the spline path.
4. Create a system that can load in these "chunks" along with randomized transformations
5. Optimize the logic for loading in needed chunks and unloading in chunks no longer necessary

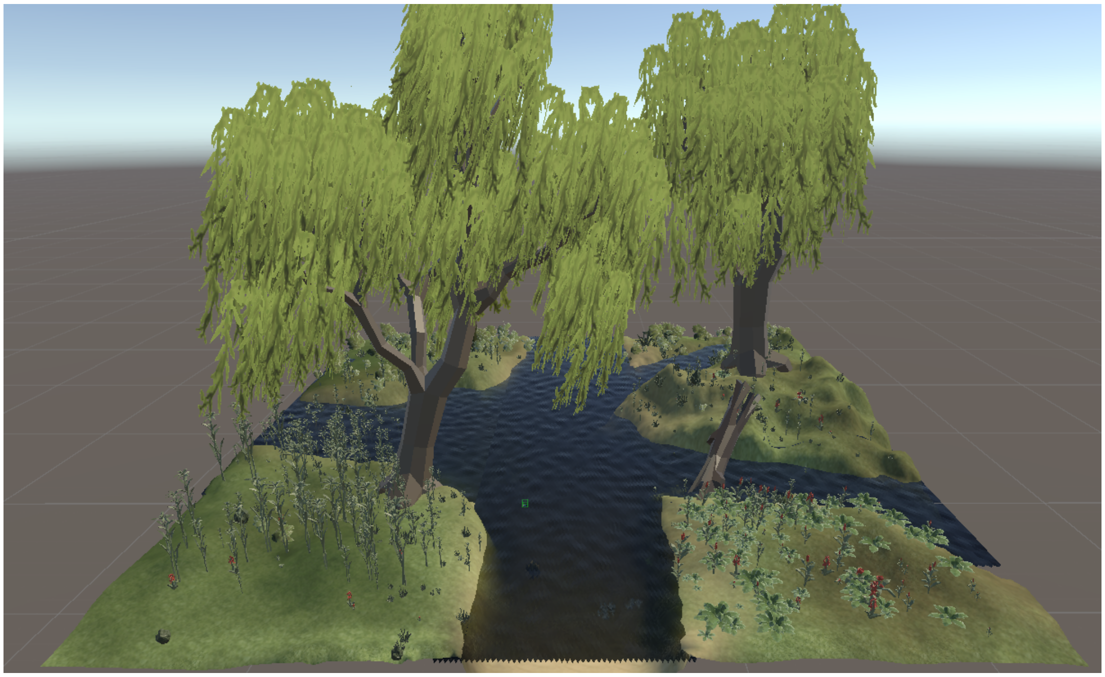


Figure 9.3: A map piece from the forest theme map

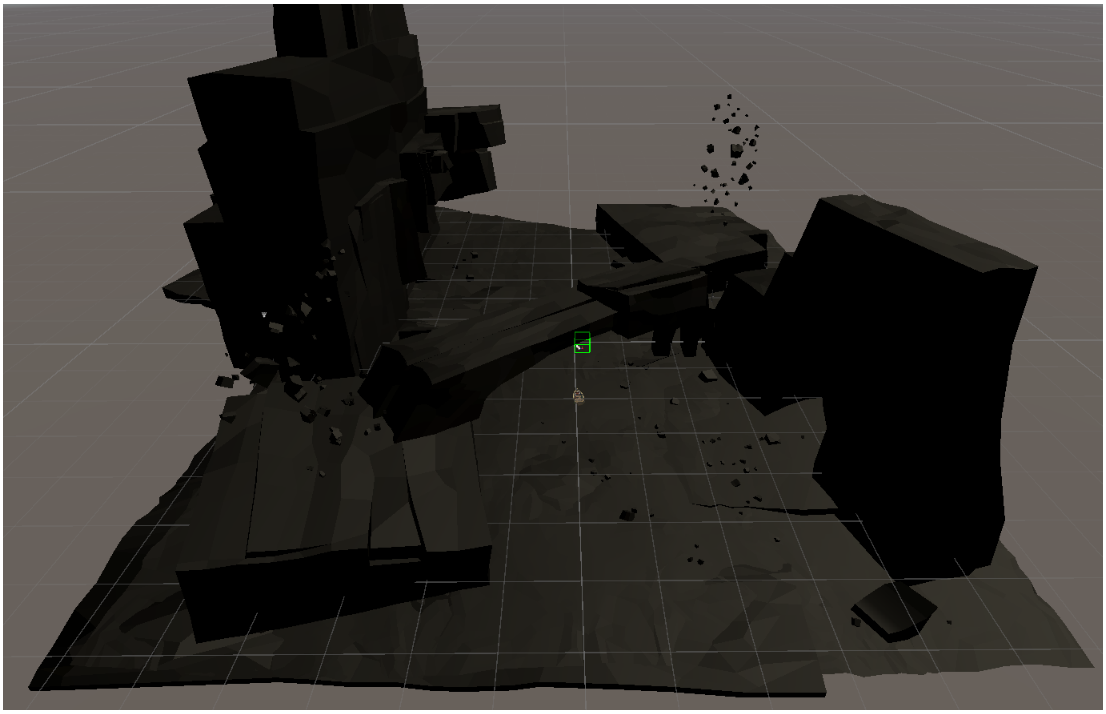


Figure 9.4: A map piece from the cave theme map

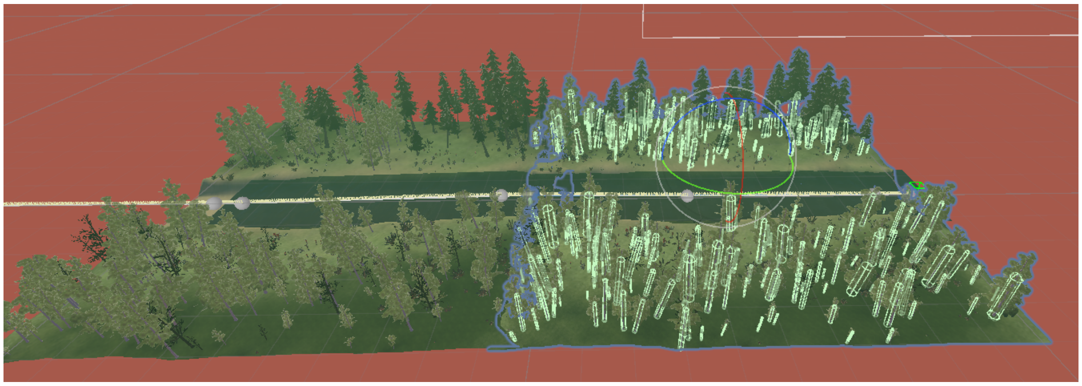


Figure 9.5: How two chunks look after being randomly selected, transformed, and merged together

Chapter 10

Evaluation

In this chapter, we will evaluate how well Cyclescape meets the requirements derived in chapter 7. Cyclescape has two intended groups of users, children age 6-18 undergoing dialysis treatment and their caretakers. While the Caretaker plays an important role in Cyclescape as a whole, the map generation requirements do not affect them.

As mentioned in 1.4, due to covid-19 we were unable to properly assess Cyclescape with the intended target audience (the children undergoing Dialysis). We will instead create two personas: Persona "Target-player" will be based on the average expected characteristics defined in chapter 6.3 Persona "Beta-tester" will be based on the average characteristics of the players that tested the actual game (adult peers, friends, and other available accomplices). These beta-testers went through an informal process of playing Cyclescape for five to twenty minutes and were verbally asked for feedback regarding the goals defined below. These testers, however, have different characteristics from the target player.

The characteristics of target-player will be as follows:

1. Age 12
2. Physical capability: Low
3. VR Experience: Minimal
4. Gaming experience: Casual mobile/tablet games
5. Has no access to arms during the game as a controller

The characteristics of beta-tester will be as follows:

1. Age 20-35

2. Physical capability: Average
3. VR Experience: Minimal
4. Gaming experience: Minimal to experienced
5. Has no access to arms during game as a controller(were told they couldn't use their hands)

The target-player and beta-tester have some traits in common, as well as some traits that are vastly different. The following metrics are similar: VR Experience, Gaming Experience, and access to the arm as a controller. The metrics that differ is the age, where the beta-tester is on average more than twice the age of the target player, as well as the physical capability where the target-player is of low capability, whereas the beta-tester was of average.

Next, we will explain how well different functionalities contribute to meeting the derived goals against the derived map generation requirements, then we will compare both Target-player and beta-tester against the derived requirements.

10.1 Evaluate: Replayability

Cyclescape has implemented the following to benefit replayability:

1. Uses chunk-based map generation, where each "chunk" is picked at random, with small transformations applied to it. This results in many different variations of the game-map being generated aesthetically.
2. Cyclescape has two different aesthetic themes for the map being generated, "Caves" which consists of mystical dark mountains, floating rocks, and caves, as well as "Forest" which consists of a river surrounded by lush forest landscape. More themes are planned to be add in the future for more diversity.
3. The generated traversal path is based on any real-world longitude, latitude, and altitude path. As the amount of possible paths is nearly unlimited, the amount of possible generated paths is also.

Beta-Testers found that both #1 and #2 add a lot of noticeable visual diversity between each playthrough. They also found that #3 lets them experience different path options and goals depending on the used map. None of the above features should be specific to age or physical capability, so we will both assume and hope that target-player will experience similar to beta-testers.

10.2 Evaluate: Encourage Cycling

The following features were implemented to encourage Cycling:

1. The generated map has different scenery and terrain to see. This should make the player want to "explore" and see what else the map offers as they continue pedalling forward.
2. The generated map has challenges for the player to do, that will both provide mental stimuli, as well as a reward "score".
3. Score should provide a means of measuring performance for each playthrough, as well as provide motivation to reach higher.

Beta testers felt that #1 was a big factor in encouraging cycling, as the different scenery, mixed with the novelty of viewing it in VR, strongly encouraged them to want to explore further. Beta testers also enjoyed having the challenges that appear (#2), which provide an optional, additional source of stimuli to encourage them to progress forward to complete the challenges. While beta-testers cited these as good motivation to cycle, we cannot assume that it is enough for target-players. Target-players have much worse physical health, and as a result, cycling requires considerably more effort relatively. As a result, there is a much bigger threshold of "motivation" required for target-players even to begin as well as continue cycling for an extended period of time.

#3 score however was harder to measure due to lack of data. Most beta-testers only tested the game once, and hence have no grasp of what a "good" score is, nor where they can strive to improve their goal. As a result, beta-testers did not find higher scores as a big motivation factor, and we have no direct proof of how target-players will react. We can only hope that Target-players would be playing Cyclescape over multiple sessions, as well as have potential peers to discuss it with, and in theory, this will mean scores will matter more, as they have other people to measure against and strive to improve their score relative to themselves.

10.3 Evaluate: Provide a meaningful experience

The following features were implemented to provide a meaningful experience

1. The player is able to emulate the action of cycling a real-world path virtually, including the effort required

Tester-players found that the fact they could emulate a real-world task virtually, without having to go outside to be very meaningful. Furthermore, they found that because it was open-ended on what the path could be, it can be used continuously to emulate different, and new goals. We can assume that target-players would feel similarly **once they are willing to cycle**. However, adverse effects may be possible. If someone who has lower physical capability fails to achieve their goals, such as realizing that they can in fact not be able to cycle to school, and would make them feel even worse, and potentially lead to a negative spiral rather than provide any beneficial experience. The opposite effect could also be true. Due to requiring more effort to achieve their goals, they may also feel more rewarded when successful.

10.4 Evaluate: Improve Mental Well-being

Cyclescape aimed to provide an entertaining exercise game that would improve the player's well-being. This quantification of this however was not within the scope of this thesis. Some features, however were implemented in a way that should support this:

1. Positive reinforcement, as opposed to negative reinforcement for both challenges and score. There is no explicit "lose" condition, and successfully completing part of the game (even if they don't reach the end) is rewarded.
2. Provide means for them to improve and push themselves.

We were unable to test this at all with beta-testers as it would require long-term testing. Similarly, for target-players, we are also unable to draw any conclusion.

10.5 Evaluate: Avoid causing motion-sickness

The following features were implemented to attempt to alleviate motion sickness:

1. Provide a constant, focal point to steady themselves on (the constant boat and the player does not move on the boat, but rather the boat itself is moving)
2. The path generated is straight (with elevation) and does not contain any sharp or sudden turns

We have tested how much motion-sickness beta-testers felt while playing Cyclescape, and the amount they felt seemed about relative to other VR games, neither more nor less. The beta-testers also tested on a regular bike, rather than the intended recliner bike for the final product that target-players would be playing on. The target-players should then in theory, be sitting on a set-up that is even more stable, should loss of balance as a result of motion sickness be an issue. We are aware that both the age and physical capability of the target-players differ from the beta-testers, but there is no concrete, indisputable proof that age [7] or health has a direct correlation with capacity for withstanding motion sickess.

Chapter 11

Conclusion

In this section, we will summarize what we learned through the process of using real-world data in Cyclescape. We will then examine the difficulties faced during the process and what we learned as a result. Next, we will summarize the results of how Cyclescape meets the requirements. Then, lastly, discuss future works and changes that could be made to improve Cyclescape.

11.1 Challenges/what-was-learned

Cyclescape was a game incorporating some unique requirements. It is not just Asynchronous and uses VR, but it also incorporates **pedalling as a control** and the **use of real-world data** as one of its primary features. Furthermore, the target audience was also special - children on Dialysis with under-average physical capacities. Creating Cyclescape, as a result, created the need to overcome many unique challenges that aren't normally encountered.

The first biggest challenge was designing a game around a very unconventional control, pedalling. Most game's primary input is through a hand-related peripheral device, such as a mouse, keyboard, gamepad, or a hand-held motion-tracking device for VR. The main control input for Cyclescape was instead to be the pedalling speed recorded from a bike trainer from the player pedalling on a stationary bike. Earlier iterations of Cyclescape used both the pedalling control to move and the VR hand-held tracking device to deal with game mechanics. However, some of the target audience of Cyclescape - kids undergoing dialysis may be undergoing treatment through their arm - leaving at most one arm free. However, using the remaining arm to hold the controller makes it difficult to stay balanced on the stationary bike, as no arms are left to stabilize themselves on the bike. Pair this with the fact that they will have a VR headset on, which on its own makes it hard for players to see their surroundings and maintain balance; these earlier iterations were scrapped. The goal instead was to figure out how to use pedalling not just to move but also as the main means of user control. The final iteration instead focused on mechanics revolving around pedalling instead, for example, pedalling faster, slower, or maintaining a specific pace.

The next biggest challenge was how to use real-world data in a game. This includes two parts - what type of data should we use, its form, and how to use it. In chapter 4, we explored the different ways that other games have used real-world data - and in 4 we explored the types of data available. To meet the requirements of allowing a player to emulate real-world effort to do a task, we settled on the usage of terrain data, or specifically using the longitude, latitude, and altitude coordinates of a path from point A to point B. We then had to figure out how to map this into something the player can transverse and ensure it can be auto-generated for any input map data. Furthermore, we had to make sure to avoid causing motion sickness in this transversal path. A spline path was eventually chosen, a curved line in 3D space that can curve along the path at specific radiuses. To avoid motion sickness, the 3d vector of the longitude, latitude, and altitude was simplified into a 2D height map of distance over altitude. We then directly converted this into a spline path that the player moves along. But now we had to figure out how to automatically fill in the rest of the game level for a non-fixed, dynamically created spline path.

Generating the rest of the level was difficult. The player's path was of indeterminate length as well as indeterminate height. Furthermore, the map had be replayable. lastly, the path the player transverse is a simple 2D height map - it would be plain and uninteresting without other things to fill it up. From these requirements, we decided to create building blocks of terrain that we would use to generate along the player's path procedurally. We would have different types of blocks, to fit different specific themes (such as caves, or forests in the current iteration of Cyclescape). Game mechanics would also be generated along the route where the player is currently.

The next challenge was designing for the target audience - children undergoing dialysis. The game has to be designed revolving around positive feedback rather than negative. As many of these players would have lower physical capacity, we need to strive to make them feel rewarded for every little bit of progress they make without punishing them for not doing so. Failing to do so will likely result in them not wanting to play Cyclescape for multiple iterations and striving to improve.

The last challenge was developing for VR, a type of game development still in its infancy stage. One of the many challenges was learning how different the same view looks through a monitor screen versus in VR. Everything appears much closer and, as a result, more intimidating. Many things that would look “funny” or “harmless” through a screen can be much more intimidating to the viewer. Dealing with motion-sickness is another big factor in VR games that has yet to be fully solved - which we partially kept under control by doing a spline path with no turns and providing a “vehicle” for the player to stabilize their focal point on. Lastly is dealing with performance - VR renders to both eyes separately, resulting in twice the screen to render to. Furthermore, a framerate under 90 FPS induces additional motion sickness [3]. An inconsistent framerate is also known to cause motion sickness to be worse.

11.2 Results

Testing of Cyclescape was difficult as the target audience of Cyclescape is immuno-compromised, and we could not test with them live. Instead, we had to make predictions for how our target audience would experience Cyclescape. We do this by comparing the actual players who tested the game, as well as created personas: in chapter 10, we evaluated Cyclescape against two groups, beta-tester and target-player. Beta-testers were an average culmination of people aged 20-35 from mixed, diverse familiarity in technology, games, and all of average health. Target-player was a created persona of the target audience based on the original requirements given for Cyclescape. They would be around age 12, have a mixed and diverse familiarity with technology and games, have low physical capability, and are undergoing dialysis.

To re-iterate, there were five derived requirements we tested against:

1. Replayability
2. Encourage Cycling
3. Provide a Meaningful experience
4. Improve Mental Well-being
5. Avoid causing motion-sickness.

Both beta-testers and we predict target players found the game could always offer something new and different on each iteration they played due to the implementation of an indefinite amount of generated paths, along with map generation. The challenges, score, and scenery encouraged the beta-testers to want to explore more via cycling, but we were unable to confirm if this was enough motivation for the target audience to want to play Cyclescape, as the effort required for them to cycle was much higher due to their lower physical abilities. Beta-testers and, from what we can infer, target-players both found that Cyclescape provided a meaningful experience, as each path they travelled was a "real" path in the world rather than just a non-personalized path being generated from made-up data. Next, the map design was made to have a focal point, no sharp turns, and a smooth framerate, taking motion sickness in mind. As a result, Cyclescape causes an average amount of motion sickness (compared to other VR games) to our beta-testers. And as motion sickness is age and health-independent, we can assume that the target-players will experience similarly. Lastly, Whether or not Cyclescape improved mental well-being was a metric we could not verify due to a lack of long-term testing.

In summary, while Cyclescape could not be tested with the target-players, we could infer the results by comparing it to the beta-testers we had. From those results, we can conclude that the map generation from real data was able to provide replayability, encourage cycling, and provide a meaningful experience to players undergoing dialysis.

11.3 Future Changes

Through the process of researching, designing, and developing Cyclescape, many things were discovered in hindsight or limited by scope. In this section we will briefly go over changes that would be planned for the future.

1. **Test Cyclescape with the actual target audience.** The testing phase of Cyclescape was during the peak of COVID-19, with our target audience being immuno-compromised children. As a result, we were unable to ever test or even meet the target-audience once during the entire process of creating Cyclesape.

2. Integrate the game challenges with the map more thoroughly from a design perspective. The original challenge of the game involved shooting enemies using one hand-held motion controller. This idea was scrapped due to potential balance issues with not having a hand to be steady on the bike. As a result, the current pedal-based challenges were added after everything else had already been completed.

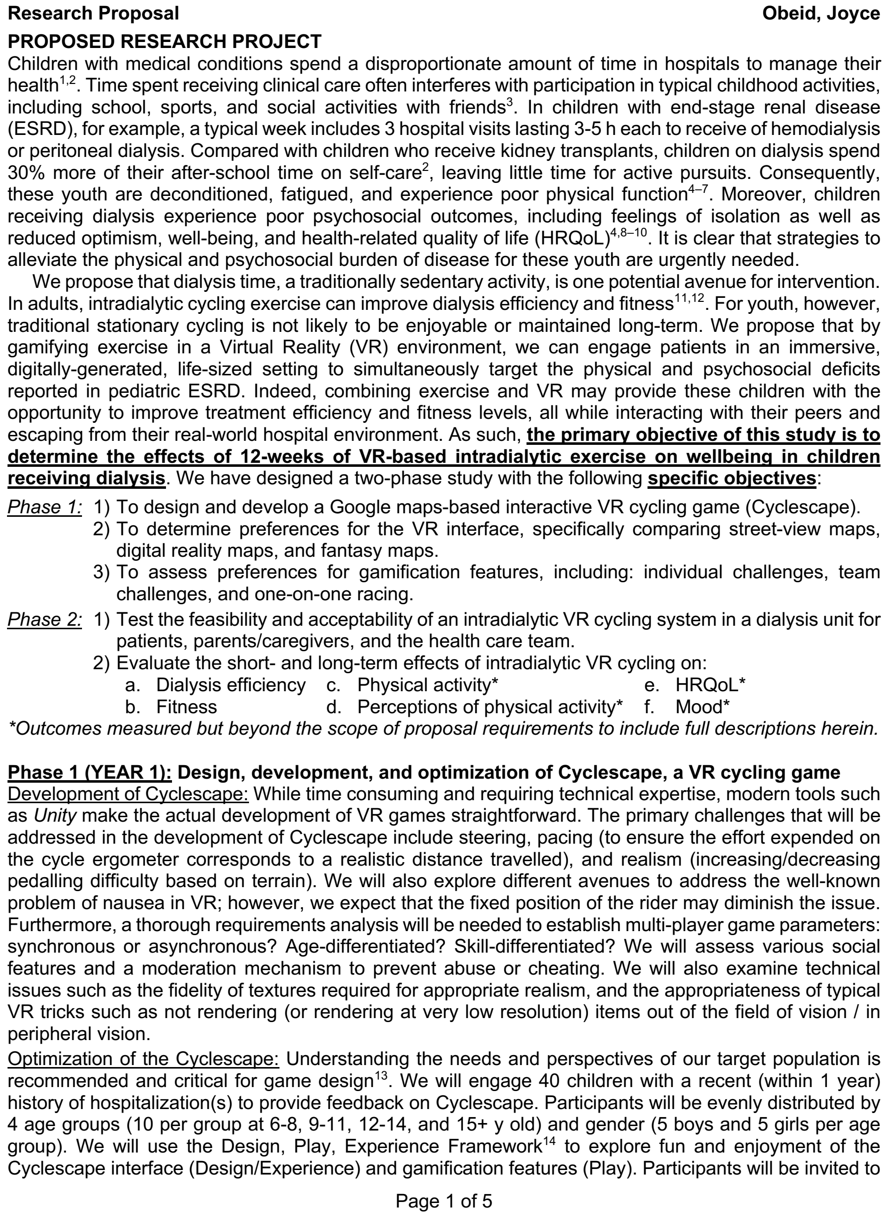
3. Test the game with actual planned deployment equipment, such as a reclined exercise bike (testing was done with a mountain outdoor bike outfitted with a trainer). This would let us more accurately test the player's balance on the bike while wearing a VR headset.

4. Test making the transversal path more interesting, such as small gradual turns, without compromising on motion sickness.

5. Incorporate more real-life elements into it, such as landmarks using Google's place API to give the players a deeper connection with the generated map.

Appendix A

Cyclescape Project Proposal:



PROPOSED RESEARCH PROJECT

Children with medical conditions spend a disproportionate amount of time in hospitals to manage their health[1,2]. Time spent receiving clinical care often interferes with participation in typical childhood activities, including school, sports, and social activities with friends[3]. In children with end-stage renal disease (ESRD), for example, a typical week includes 3 hospital visits lasting 3-5 h each to receive of hemodialysis or peritoneal dialysis. Compared with children who receive kidney transplants, children on dialysis spend 30% more of their after-school time on self-care[2], leaving little time for active pursuits. Consequently, these youth are deconditioned, fatigued, and experience poor physical function[4–7]. Moreover, children receiving dialysis experience poor psychosocial outcomes, including feelings of isolation as well as reduced optimism, well-being, and health-related quality of life (HRQoL)[4,8–10]. It is clear that strategies to alleviate the physical and psychosocial burden of disease for these youth are urgently needed.

We propose that dialysis time, a traditionally sedentary activity, is one potential avenue for intervention. In adults, intradialytic cycling exercise can improve dialysis efficiency and fitness[11,12]. For youth, however, traditional stationary cycling is not likely to be enjoyable or maintained long-term. We propose that by gamifying exercise in a Virtual Reality (VR) environment, we can engage patients in an immersive, digitally-generated, life-sized setting to simultaneously target the physical and psychosocial deficits reported in pediatric ESRD. Indeed, combining exercise and VR may provide these children with the opportunity to improve treatment efficiency and fitness levels, all while interacting with their peers and escaping from their real-world hospital environment. As such, **the primary objective of this study is to determine the effects of 12-weeks of VR-based intradialytic exercise on wellbeing in children receiving dialysis**. We have designed a two-phase study with the following **specific objectives**:

Phase 1:
1) To design and develop a Google maps-based interactive VR cycling game (Cyclescape).
2) To determine preferences for the VR interface, specifically comparing street-view maps, digital reality maps, and fantasy maps.
3) To assess preferences for gamification features, including: individual challenges, team challenges, and one-on-one racing.

Phase 2:
1) Test the feasibility and acceptability of an intradialytic VR cycling system in a dialysis unit for patients, parents/caregivers, and the health care team.
2) Evaluate the short- and long-term effects of intradialytic VR cycling on:
    a. Dialysis efficiency
    b. Fitness
    c. Physical activity*
    d. Perceptions of physical activity*
    e. HRQoL*
    f. Mood*

**Outcomes measured but beyond the scope of proposal requirements to include full descriptions herein.*

Phase 1 (YEAR 1): Design, development, and optimization of Cyclescape, a VR cycling game

Development of Cyclescape: While time consuming and requiring technical expertise, modern tools such as *Unity* make the actual development of VR games straightforward. The primary challenges that will be addressed in the development of Cyclescape include steering, pacing (to ensure the effort expended on the cycle ergometer corresponds to a realistic distance travelled), and realism (increasing/decreasing pedalling difficulty based on terrain). We will also explore different avenues to address the well-known problem of nausea in VR; however, we expect that the fixed position of the rider may diminish the issue. Furthermore, a thorough requirements analysis will be needed to establish multi-player game parameters: synchronous or asynchronous? Age-differentiated? Skill-differentiated? We will assess various social features and a moderation mechanism to prevent abuse or cheating. We will also examine technical issues such as the fidelity of textures required for appropriate realism, and the appropriateness of typical VR tricks such as not rendering (or rendering at very low resolution) items out of the field of vision / in peripheral vision.

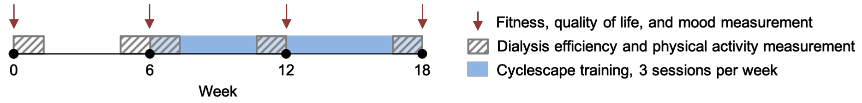
Optimization of the Cyclescape: Understanding the needs and perspectives of our target population is recommended and critical for game design[13]. We will engage 40 children with a recent (within 1 year) history of hospitalization(s) to provide feedback on Cyclescape. Participants will be evenly distributed by 4 age groups (10 per group at 6-8, 9-11, 12-14, and 15+ y old) and gender (5 boys and 5 girls per age group). We will use the Design, Play, Experience Framework[14] to explore fun and enjoyment of the Cyclescape interface (Design/Experience) and gamification features (Play). Participants will be invited to complete 1 individual and 2 group sessions. At the end of 2 gaming sessions, participants will be asked to provide feedback and preferences of gaming world and gamification features. A 3rd session will be conducted as a focus group by age group. The focus group facilitator will ask participants to frame their answers in the context of their recalled experience as an in-patient. Feedback from all sessions will be used to improve Cyclescape: modifications recommended by ≥50% of the study sample will be incorporated, and settings ranked as least favourite across ≥75% of age/gender combinations will be removed. **Importantly, we will examine all feedback by age group and gender to ensure that the Cyclescape interface and gamifications are appropriately tailored and appealing for a diverse group of children in Phase 2.**

Phase 2 (YEAR 2): Training Intervention

Participants: Boys and girls (N=20) will be recruited from the McMaster Children's Hospital Pediatric Dialysis Unit. Children must be ≥6 y.old (to fit on the bicycle and VR headgear) and must have completed at least 3 months of dialysis to ensure they have reached a stable baseline therapy. All participants will be cleared to exercise by their nephrologist. Since all cycling challenges will be personalized to the exercise capacity of the participant, we will not exclude any patient based on disease status or severity.

Training intervention: All eligible patients will be invited to complete an 18-week study, consisting of 6 weeks of standard dialysis care, followed by 12-weeks with intradialytic cycling performed 3×/week (Figure 1). All training sessions will follow a similar protocol and be supervised by a trainer to monitor for any safety concerns. Following a brief 3 min warm-up on the cycle ergometer, participants will select their preferred cycling interface and route, the trainer will enter the cycling time and instruct the participant to cover as much distance as they can within 10 min. Cycling time will increase by 1 min at each subsequent session such that participants will be cycling for 45 min by the final (36th) training session. Participants will have the option to ask a friend, sibling, or parent to participate in the training session with them. Due to fluctuations in health status, if a participant is not able to complete the cycling, the additional 1 min will not be added to their next session. If the participant is unable to complete two consecutive sessions, cycling time will be reduced by 2 min. Heart rate (HR) will be monitored continuously during exercise, to ensure participants maintain a target 60-80% of their maximum HR. Rating of perceived exertion during exercise will be collected using the Borg scale. Blood pressure will be monitored every 5 min for safety.

Figure 1. Overview of training study.



Feasibility and acceptability of intradialytic VR exercise: One of the first studies examining exercise training in children with ESRD reported that only 5 of 20 participants were able to complete a home- and community-based training program[8]. The authors reported that this low adherence rate was largely attributable to the setting, wherein children were asked to complete exercise outside of their hospital visits[8]. To overcome this limitation, we will implement an intradialytic exercise program. We will assess feasibility by examining recruitment, withdrawal, retention, completion rates, and adverse events. Acceptability will be assessed via questionnaires to patients, parents, and the health-care team using Likert scales. **We will examine results by the self-reported gender of respondents to determine if there are any meaningful sex/gender differences in perceptions of VR exercise acceptability.**

Short- and long-term effects of intradialytic VR exercise: All participants will undergo 4 assessment visits at 0, 6,12, and 18 weeks of the training program (**Figure 1**). **All time comparisons will include a covariate for sex.**

a) Dialysis efficiency will be measured from pre- and post-dialysis blood samples collected at 3 consecutive appointments. Efficiency is defined as the Urea Reduction Ratio (URR) and rate of fluid through the dialyzer relative to fluid in the patient's body (Kt/V)[15].
b) Fitness, defined as maximal volume of oxygen uptake, will be assessed on a cycle ergometer using the McMaster continuous test, as reported by our team in children with chronic kidney disease[16].

HIGH RISK

The proposed multidisciplinary study was designed to address the consequences of chronic hospital visits for children receiving dialysis, which include: (1) deconditioning, fatigue, and poor functioning; (2) limited time for typical childhood activities; (3) social isolation, reduced optimism; (4) reduced health related quality of life.

Our goal is to simultaneously tackle these deficits by focusing on the development and application of a VR technology that delivers a physical and emotional stimulus in a meaningful and engaging format. There are numerous inherent risks in this study:

1) In Phase 1 (Year 1) of this study, we will develop a custom VR cycling game called Cyclescape. Unlike existing VR games, Cyclescape will incorporate real-world maps and terrains such that participants will feel climbs, descents, as well as bumpy and smooth surfaces based on their location on the map. This approach is both novel and advantageous in that it will allow the patient to remain connected to a familiar environment. In fact, they can choose to cycle in their own neighbourhoods, which provides them the opportunity to test out routes they would normally avoid in real-world settings.
2) In Phase 2, we chose to conduct an observational cohort study design, rather than the conventional randomized control trial (RCT). This non-traditional approach aligns more closely with our broad outcomes, and inclusive study recruitment criteria. More specifically, RCTs typically evaluate 1 intervention and cannot be used to understand complex interactions within study arm[17], as might be expected in our proposed study. Perhaps more importantly, the RCT is designed to assess the mean treatment effect, and as such, participant selection criteria are often highly restrictive to maximize homogeneity within the sample[18]. In the proposed study, we have minimized the exclusion criteria to ensure that as many patients as possible can participate in our Cyclescape game. From a pragmatic perspective, this approach is favourable in that our results will be more broadly applicable to the ESRD population. It is important to note that we are not dismissing the value of a control group, rather, we will use the 6-week dialysis only as our control. Based on our experience with administering exercise trials in a pediatric clinical setting, we believe that the advantages of the non-traditional study design outweigh the limitations of our 6-week control period.
3) Although there is evidence that exercise is beneficial for adults receiving dialysis[11, 12], studies in children are limited, and often report contradictory findings. This is likely related to the feasibility of existing studies, which often require participants to cycle for at least 30 minutes continuously at a standardized intensity[15], or the community-based exercise intervention that requires an additional time commitment outside of hospital visits[8]. Much like our study design, we are proposing a pragmatic exercise trial. Participants will cycle in the dialysis unit, and as such, will not require any more time outside of clinic. Participants will also be given options for cycling location, interface and gamification settings, allowing for more choices in the exercise stimulus. We hypothesize that this will yield meaningful changes in health outcomes, while also maintaining a level of enjoyment and engagement over the course of our training program.

HIGH REWARD

The proposed study will design and optimize a VR-based cycling game, and test the effectiveness of this game on health and wellbeing in children receiving dialysis. Although the focus of this project is on the population of children with ESRD, which has an incidence of approximately 6.9 to 21.8 per million children in Canada, it is important to note that the findings of this study will be more broadly applicable to children receiving any form of chronic or in-patient hospital care. Indeed, there is no reason to expect that children with other medical conditions that require frequent hospitalizations could not benefit from this technology. For example, much like youth with ESRD receiving dialysis, children diagnosed with acute lymphoblastic leukemia also experience deconditioning, poor function, reduced quality of life, and social isolation[19]. **As such, we expect that the primary "reward" of our innovative research study will be its scalability across for different pediatric clinical populations.**

In addition to the potential scalability of the setting, we are confident that by engaging different clinical groups in Phase 1 of the project, as well as our cohort of children receiving dialysis, we will develop additional modifications to the Cyclescape game to enhance its appeal to a broader audience of children, including those who are not diagnosed with any medical conditions. For example, expanding the cycling maps to include off-road adventures, including avatars with the ability to time travel to ancient maps or future cities. **Therefore, we expect that the Cyclescape game will be scalable in with respect to novel interfaces and gamification settings, which will in turn enhance its appeal to a wider audience.**

INTERDISCIPLINARITY

The proposed study **incorporates themes from each of the Tri-Council agencies**, and specifically includes the disciplines of:

- **Computer and information sciences** and **Medical and biomedical engineering:** In Phase 1, human-centered computing will be used in the development of the Cyclescape virtual reality game. This virtual reality game is will use cycling as a form of exercise and rehabilitation in children with end stage renal disease. This will be led by Dr. Carette.
- **Social Sciences:** In Phase 1, participants will provide quantitative and qualitative feedback on their preferences and enjoyment of Cyclescape. This information will be used to optimize and tailor the game by age and sex for Phase 2 of the study.
- **Clinical medicine** and **Health Sciences:** In Phase 2 of the project, we will assess the use and effects of Cyclescape, our VR game, on health outcomes in children receiving dialysis. We will specifically look at factors including dialysis efficiency, physical activity levels, health-related quality of life, and mood.

We are using approaches that align with NSERC mandates (VR technology) to improve CIHR-specific (hemodialysis efficiency, quality of life, mood) and SSHRC-specific (physical activity behaviour) outcomes. The overlap tri-council in our process, measures, and outcomes makes it unlikely that this project will be funded through a single council. **Our approach is needed because it provides a multi-faceted solution to a multi-faceted problem.** Indeed, studies to date that have used exercise to improve health outcomes have focused on the exercise time and intensity to target dialysis efficiency and fitness, while other interventions have been designed to target psychosocial outcomes and health behaviours[11]. **Our goal is to simultaneously tackle the physical and psychosocial deficits observed in children receiving dialysis by focusing on the development and application of a new technology that delivers a physical and emotional stimulus in a meaningful, engaging format.**

EQUITY, DIVERSITY, AND INCLUSION

The proposed research project requires a team of faculty, staff, and trainees to execute. Our proposed study team is formed based on the McMaster Policy on Building an Inclusive Community with a Shared Purpose, which states: "*At McMaster University, an inclusive community is one in which there is real, visible and meaningful representation of the diversity evident in the wider community at all levels and in all constituencies on campus (faculty, staff, students, administration).*" More specifically, our team, by design, is made up of an equal number of females and males. We have intentionally recruited a female PhD candidate (Ms. Jennifer Zuccolo) and research coordinator (Ms. Nicole Proudfoot). Moreover, our Master's trainees (Mr. Ethan Chan and Mr. Thien Trandinh) both identify as members of a visible minority.

The proposed study is designed to encourage these team members to collaborate to drive the project forward. At the outset, before any data collection begins, all team members will be required to complete a workshop at McMaster University offered through our Equity and Inclusion Office, focusing on the Equity, Diversity, and Inclusion Policies in the Campus Community. Throughout the 2-year project timeline, we will have regularly scheduled team meetings, where each team member will be asked to provide a 5 minute update on their progress. This approach will ensure that all team members are included and that their contributions are valued regardless of the phase of the project.

For the training component of Phase 2, we will recruit several interns to monitor the exercise training sessions. Ms. Proudfoot will lead the recruitment process along with Ms. Zuccolo. Before recruitment can begin, Ms. Proudfoot and Ms. Zuccolo will complete a workshop offered by the Equity and Inclusion Office at McMaster University focusing on Equity, Diversity, and Inclusion Framework and Strategy. For safety purposes, all interns must obtain a certification (Canadian Society for Exercise Physiology Certified Personal Trainer), which will naturally limit our applicant pool. Nevertheless, position postings for interns will be advertised widely, throughout campus, on social media, and through the certification mailing list. Potential applicants will not be excluded based on any physical differences, gender, or race. Interviews will be conducted with a broad but standardized list of questions and prompts to ensure that all candidates receive fair assessments. Upon selection of the successful candidate(s), Ms. Proudfoot and Ms. Zuccolo will be responsible for creating a written report outlining the process and rationale for the successful and unsuccessful candidates.

We have also extended the equity, diversity, and inclusion policies into our study recruitment. More specifically, we will not exclude any participants based on their gender, race, or abilities. In fact, we do not have any exclusion criteria that surround disease type or severity to provide all pediatric patients an opportunity to participate in either Phase 1 or Phase 2 of our project.

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