The Essence of Space Mapping: Less is More

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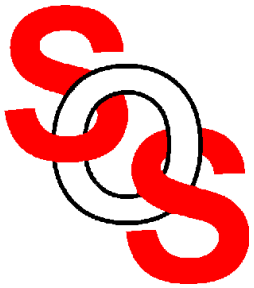

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presented at
Third International Workshop on Surrogate Modelling and Space Mapping for Engineering Optimization (SMSMEO 2012)
August 9-12, 2012, Reykjavik University, Iceland

Physics-based Surrogates

facilitate optimal engineering designs

high-fidelity or “fine-model” simulation accuracy

“coarse-model” simulation speed

If Knowledge Can Be Built into a Model . . .
What about "Feel" and Intuition?

space mapping exploits the engineer's traditional "quasi-global" intuition

enhances physics-based surrogates derived from simple mappings of coarse models (the "less") to realize accurate surrogates of corresponding fine models (the "more")

space mapping explains the engineer's mysterious "feel" for a problem

Space Mapping vs. Other Surrogate-based Approaches

how the space mapping concept come into being

how it differs from other approaches that found favor at much the same time

the essential difference (oversimplified for discussion)

> **space mapping**: an understanding of the "feel" that an experienced engineer has for a complex design problem
>
> generic surrogate approach: arises from the "feel" that a mathematician has for a generic optimization problem

“Surrogate” “Model” “Simulation”

confusion sets in when these words are used arbitrarily and interchangeably to mean almost any representation of anything

imply underlying knowledge—nowadays typically the physics embodied in a simulator

this knowledge is manipulated from the “inside” or the “outside”

depends on whether the designer is oriented towards engineering or mathematics (or perhaps both)

The Grand Design
(*Hawking and Mlodinow, 2012*)

"model-dependent realism . . . is based on the idea that our brains interpret the input form our sensory organs by making a model of the world." (p. 7)

"human behavior is indeed determined by the laws of nature" (p. 32)

"it is pointless to ask whether a model is real, only whether it agrees with observation." (p. 45-46)

"The brain, in other words, builds a mental picture or model." (p. 47)

The Grand Design
(*Hawking and Mlodinow, 2012, p. 51*)

A model is a good model if it:
[**good: subjective**]

1. Is elegant [**subjective**]

2. Contains few arbitrary or adjustable elements [**subjective**]

3. Agrees with and explains all existing observations [**all existing observations? "all"?**]

4. Makes detailed prediction about future observations that can disprove or falsify the model if they are not borne out.

The Grand Design
(*Hawking and Mlodinow, 2012, p. 172*)

"Our brains interpret the input from our sensory organs by making a model of the outside world . . . trees . . .
people . . . other universes . . ."

The Essence of Space Mapping: Less is More

the technique is to build a thin layer around existing knowledge

the layer is minimally complex (the mapping is usually linear or very simple)

for model enhancement, the data required is small; a single data sample might be enough; often a star distribution is sufficient

for design, the iteration count is small; manual implementation is possible in many cases

the resulting enhanced model or design can be astonishingly good

Writer's Cliché #1: "Less is More"

Well, "zero" is about as "less" as you can get in terms of putting words to use: a blank sheet of paper if you're "writing," total, unbroken silence if you're "speaking." Here's a paradox: either a "zero" writer truly can't think of anything to say, or is yelling something quite profound from the rooftops.

Corollary to Writer's Cliché #1: "More is Less"

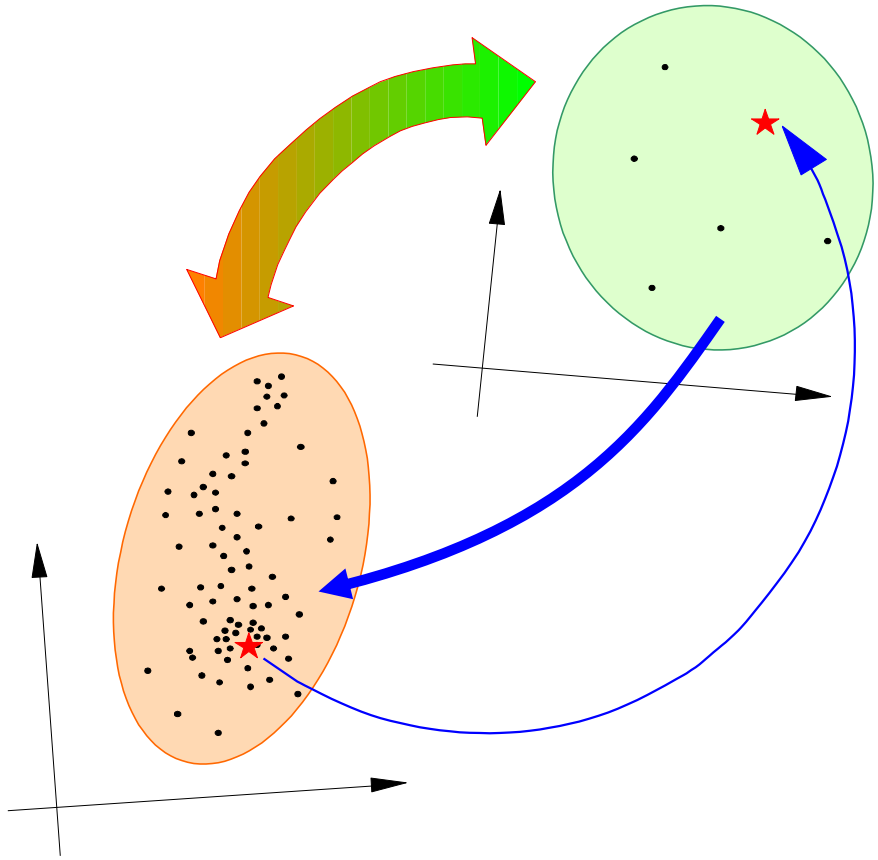
Well, "infinity" is about as "more" as you can get in terms of putting words to use: an essay as large as the Library of Congress if you're "writing," verbiage of galactic duration if you're "speaking." Here's a paradox: either an "infinite" writer truly has everything to say about anything and everything, or is yelling something embarrassingly redundant from the rooftops.

Space Mapping
(*Bandler et al., 1994*)

follows the engineer's traditional experience

exploits the engineer's "intuition"

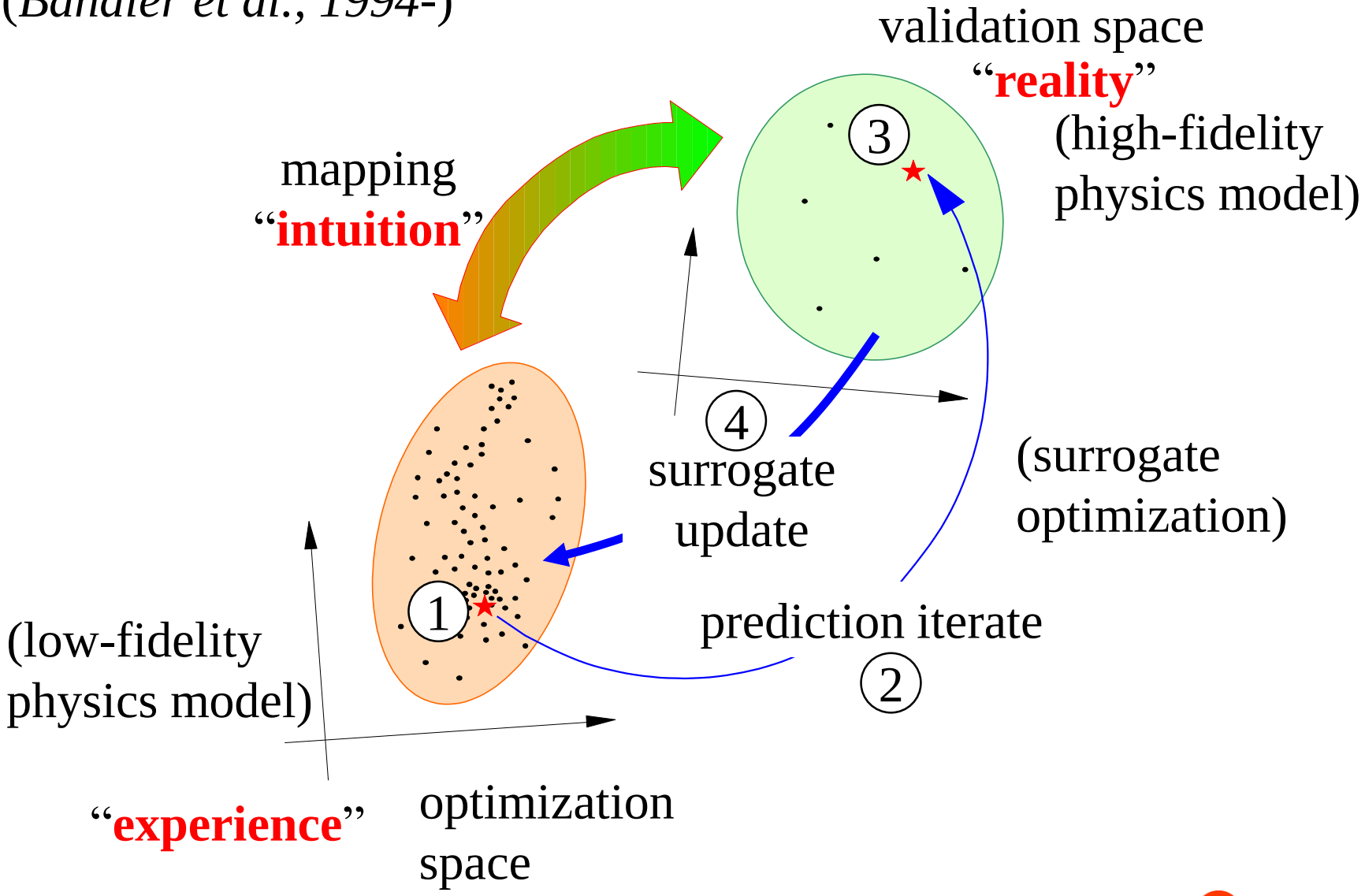
uses iterative enhancement of physics-based surrogates



"space mapping" offers a quantitative explanation for the engineer's mysterious "feel" for a problem

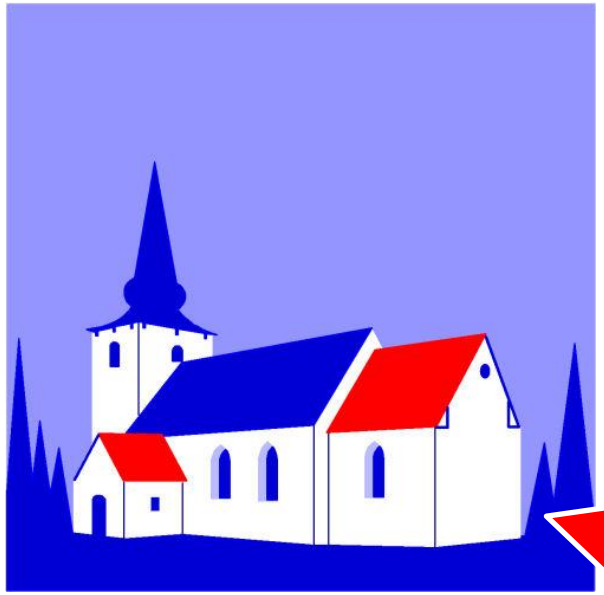
The Space Mapping Concept

(*Bandler et al., 1994-*)



Summer 1993, Near Copenhagen. John Bandler Strolls In A Forest With Mathematician Kaj Madsen . . .

. . . Space Mapping Is Born



Korning Kirke, Denmark
—Asbjorn Lonvig, artist

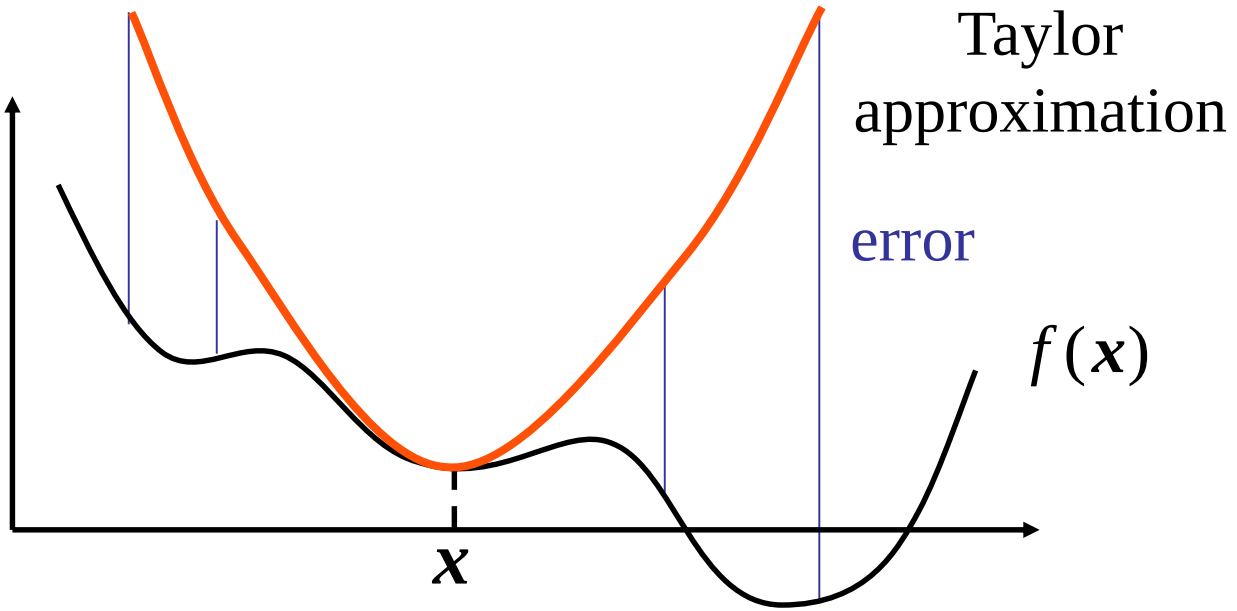
space mapping

The cathedral, Cologne
—historyfish.net

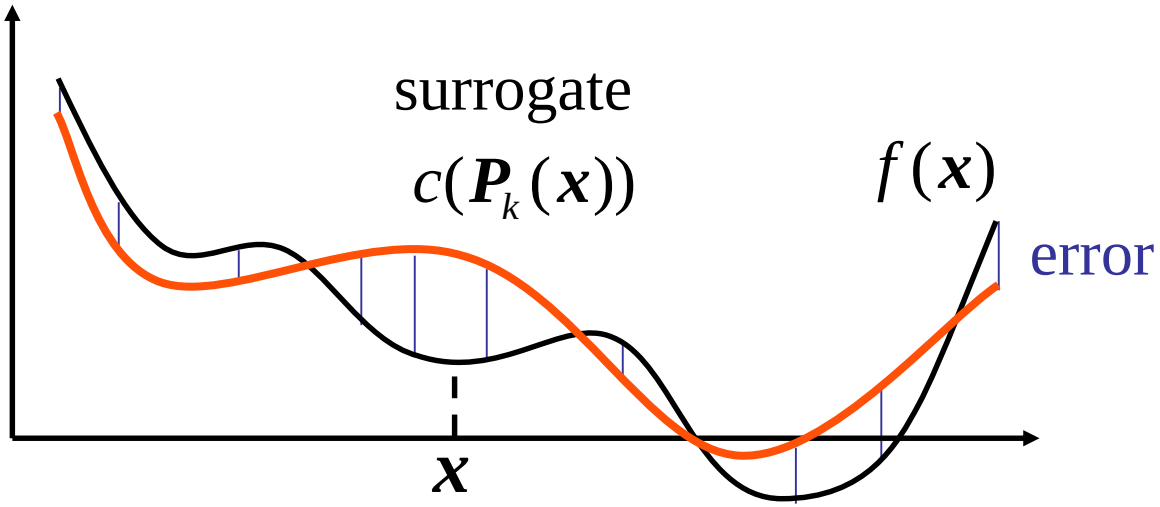
Space Mapping Optimization Methodologies

(*Bakr et al., 2002*)

mathematical model based on local information

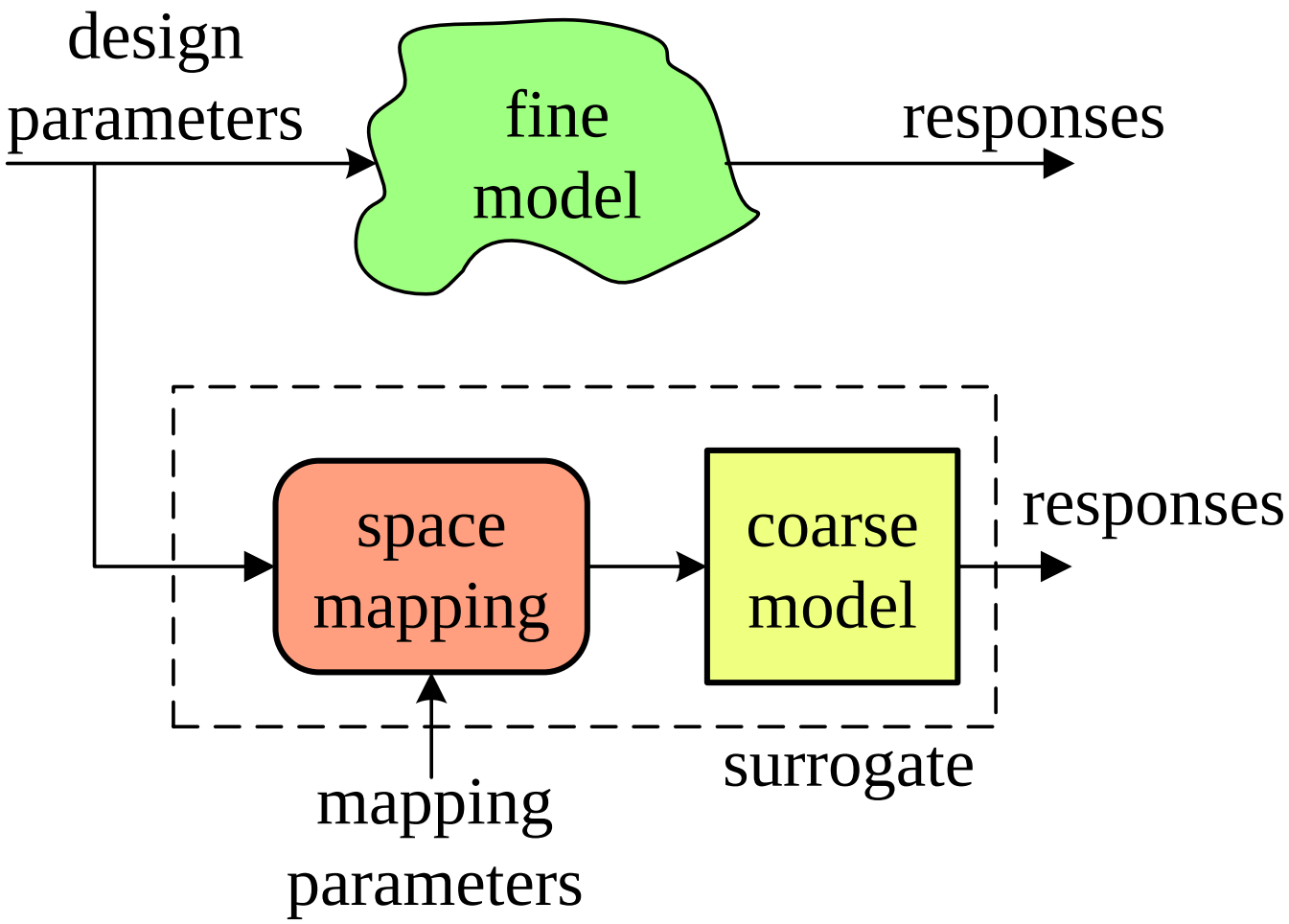


physics-based, space mapping "quasi-global" model



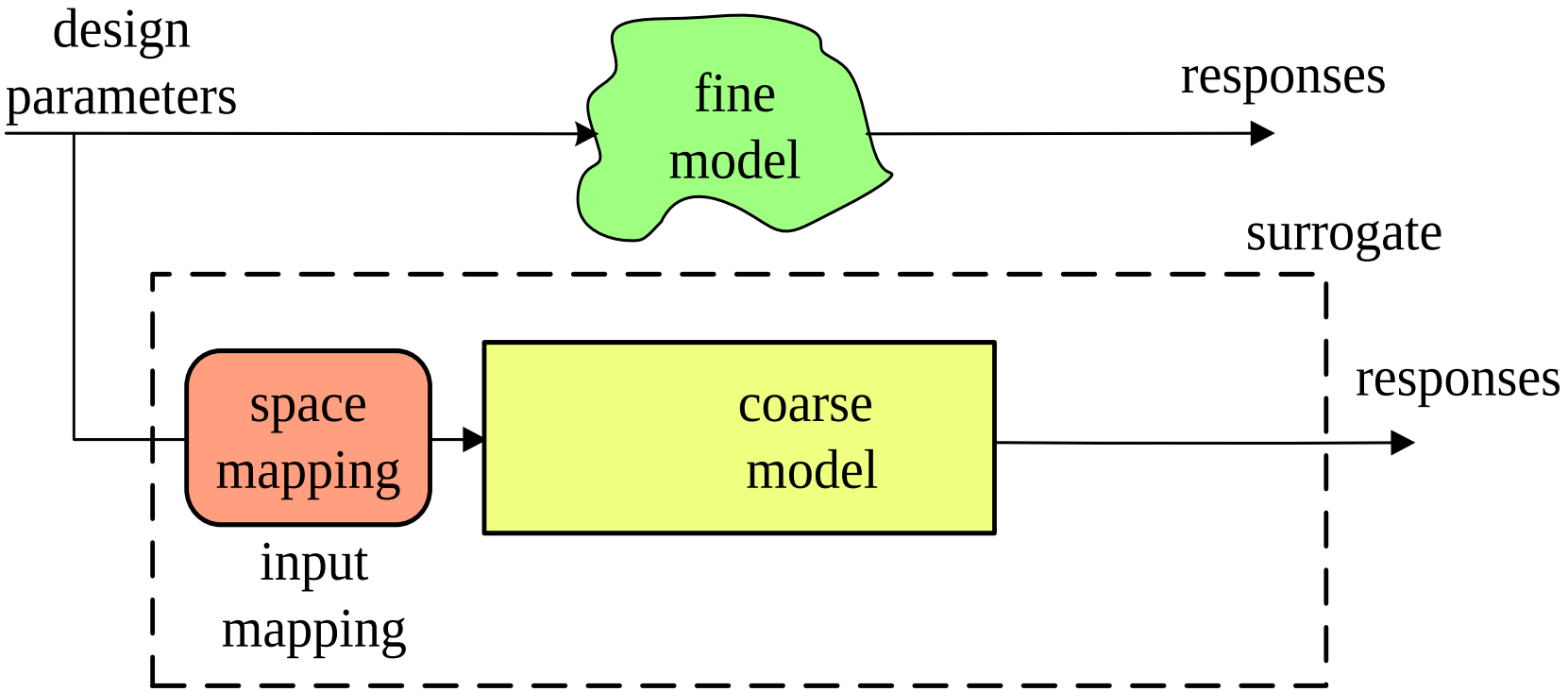
The Space Mapping Concept

(*Bandler et al., 1994-*)



Input Space Mappings

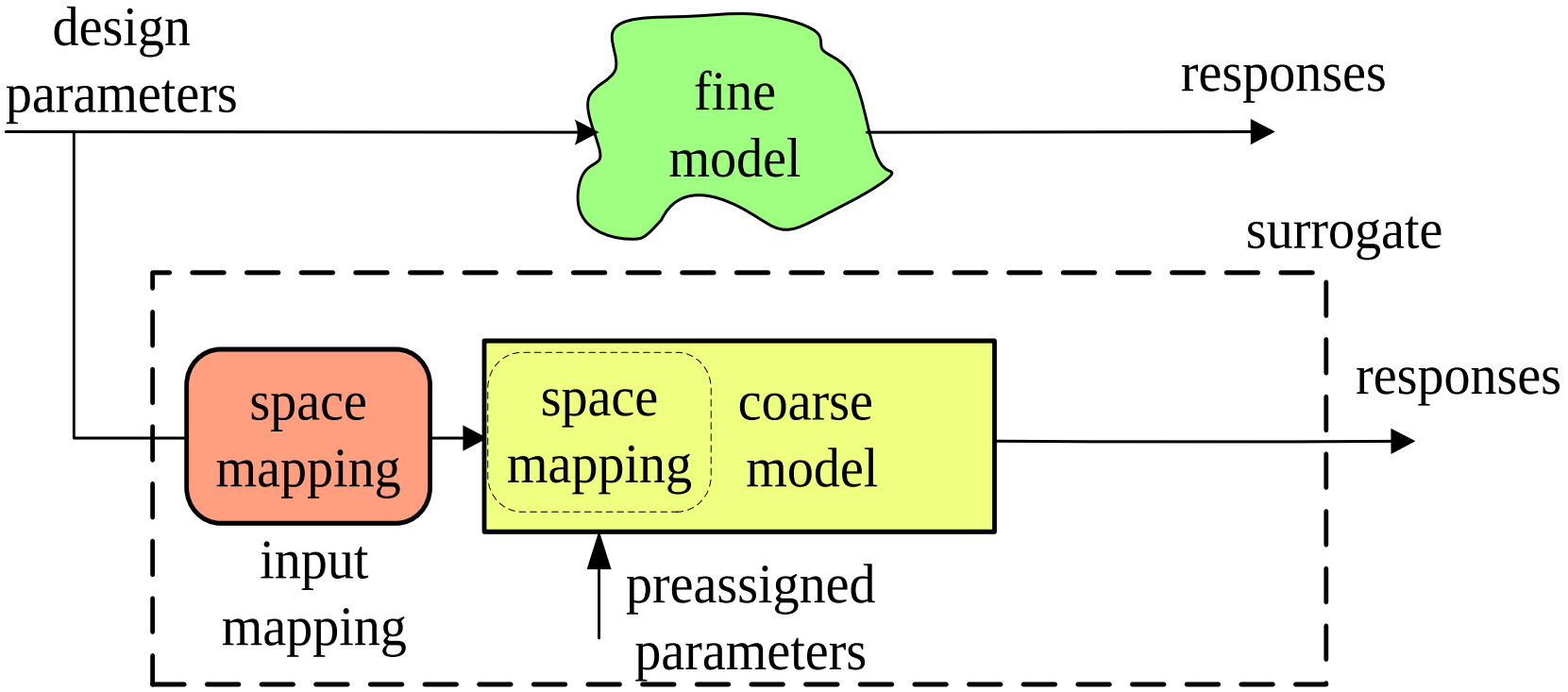
(*Bandler et al., 1994-*)



expert engineering knowledge helpful (few designable variables)

Implicit and Input Space Mappings

(*Bandler et al., 2003-*)

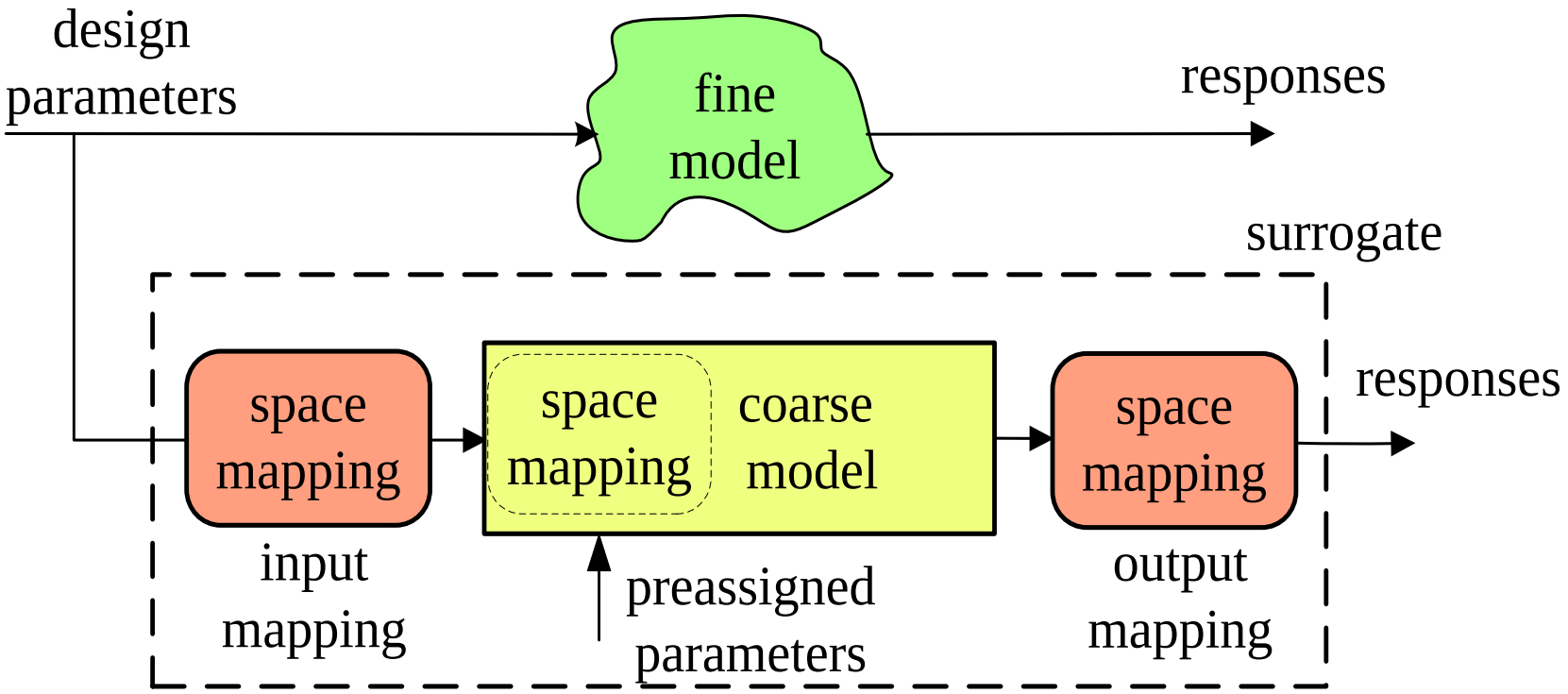


expert engineering knowledge helpful (few designable variables)

expertise helpful in "tuning the surrogate" (many possibilities, e.g., dielectric constant)

Implicit, Input and Output Space Mappings

(*Bandler et al., 2003-*)



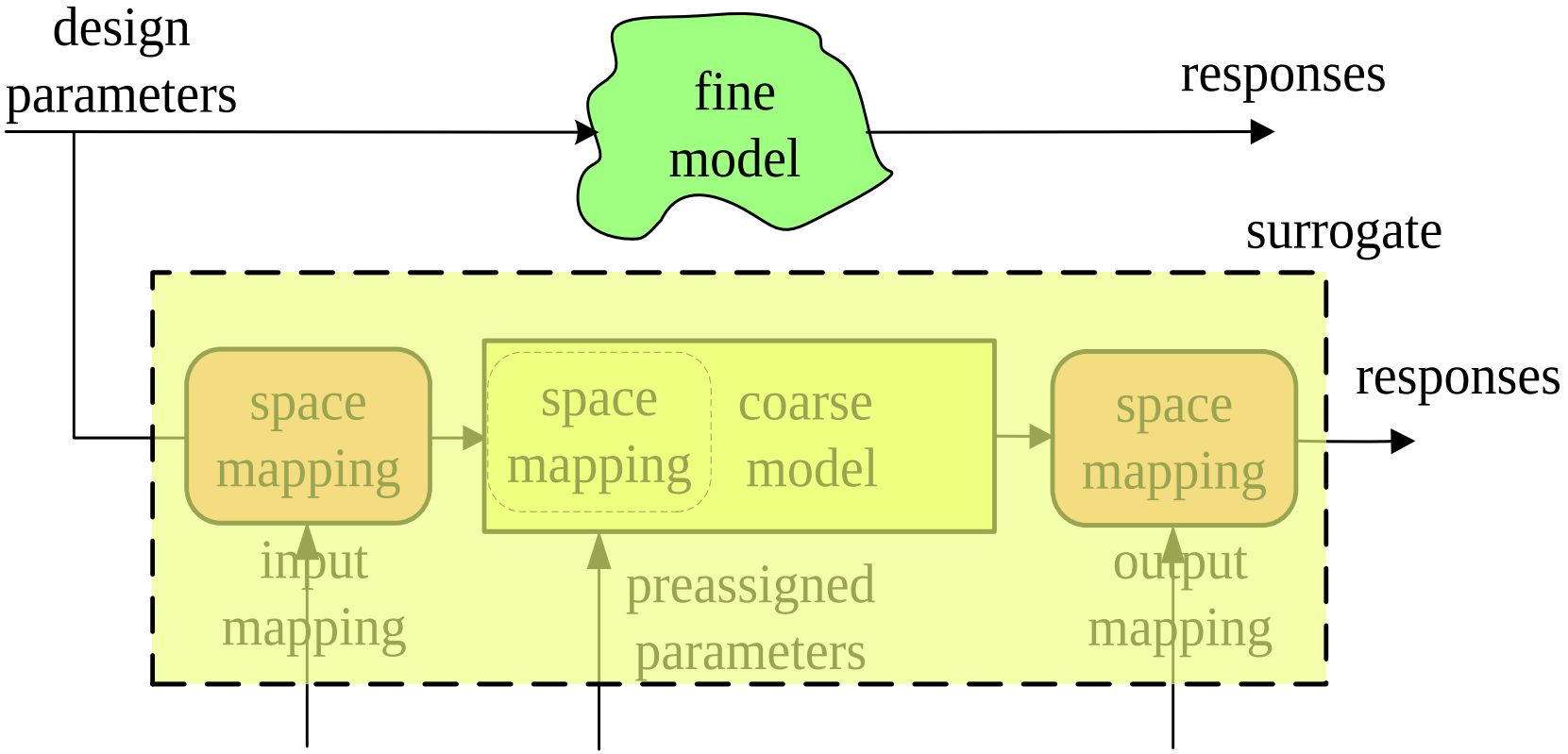
expert engineering knowledge helpful (few designable variables)

expertise helpful in "tuning the surrogate" (many possibilities, e.g., dielectric constant)

engineering expertise perhaps less necessary (many output variables)

Implicit, Input and Output Space Mappings

(*Bandler et al., 2004-*)

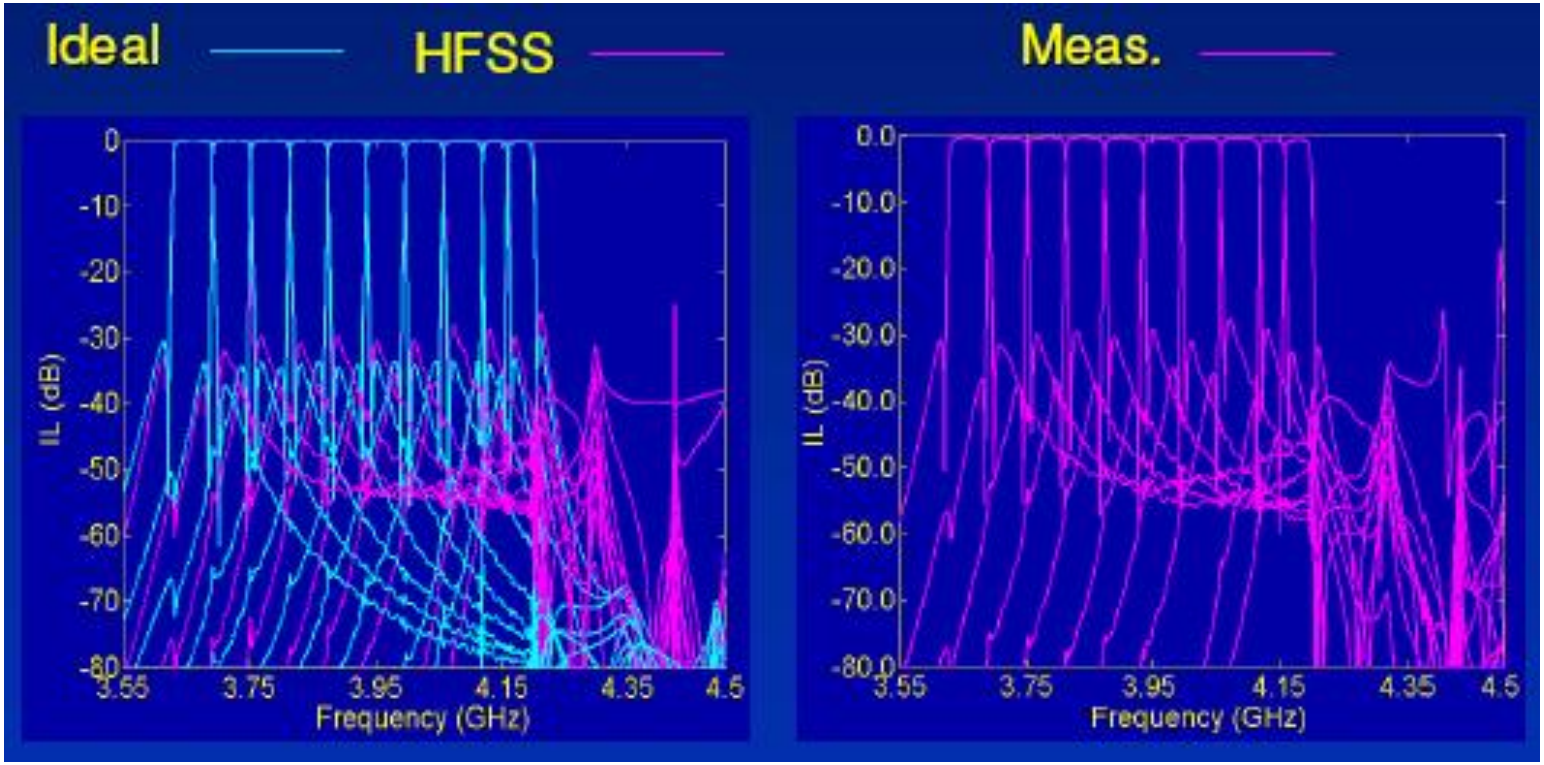


but all types of space mapping can be viewed as special cases of implicit space mapping

Aggressive Space Mapping Design of Dielectric Resonator Multiplexers

(*Ismail et al., 2003, Com Dev, Canada*)

10-channel output multiplexer, 140 variables



Space Mapping Crashworthiness Design of Saab 9[3]
(*www.studyinsweden.se, 2005*)

space mapping cuts calculation times by three fourths compared with traditional response surface optimization methods

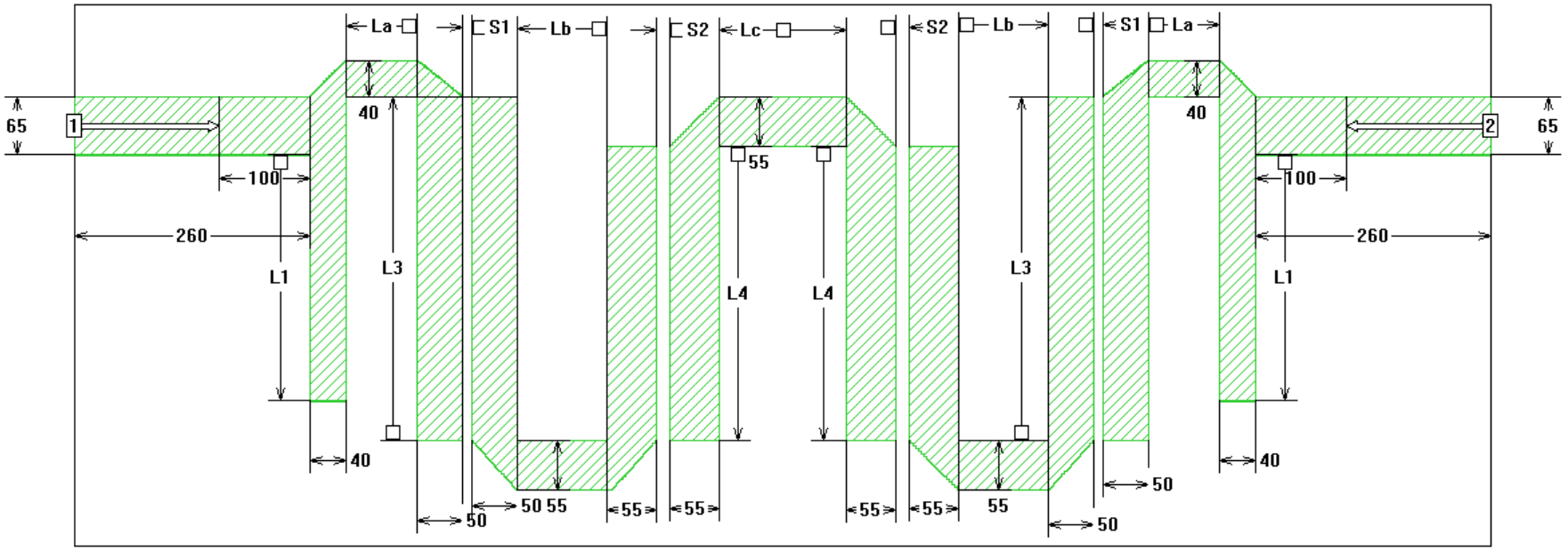
driven straight into a steel barrier
at 56 km/h

penetration of the passenger space
by the material was reduced by
32 percent

Microstrip Hairpin Filter: Implicit Space Mapping

(*Cheng et al., 2008*)

fine model in Sonnet ***em***



Twelve Section H-plane Waveguide Filter (*Cheng et al., 2012*)

HFSS fine model

$x_f = [L_1\ L_2\ L_3\ L_4\ L_5\ L_6\ W_1\ W_2\ W_3\ W_4\ W_5\ W_6\ W_7]^T$

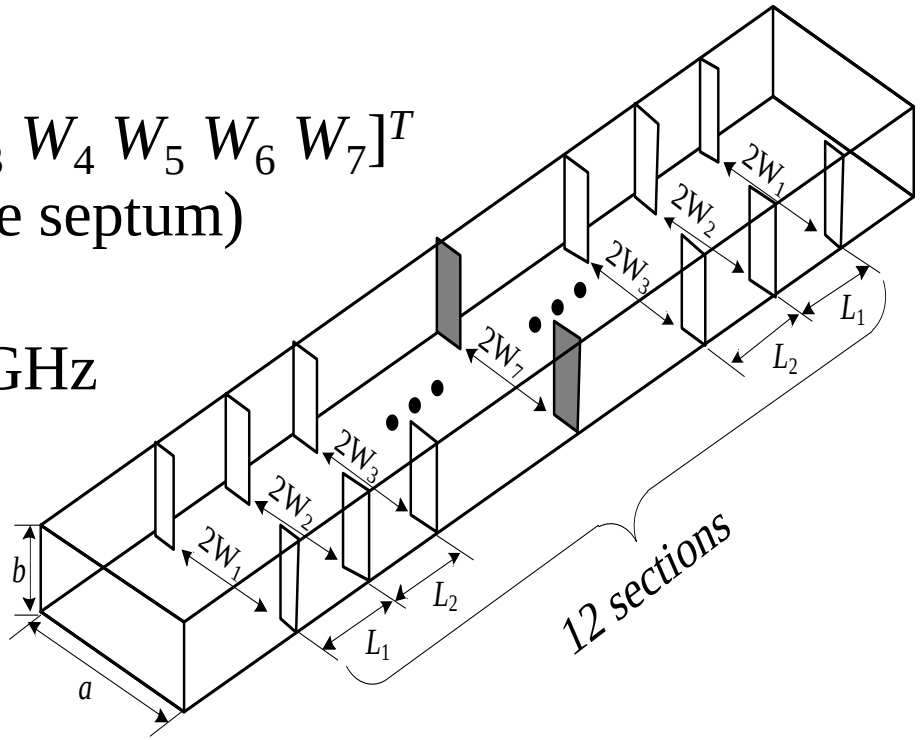
(symmetrical w.r.t. the mid-plane septum)

specifications:

$|S_{11}| \leq 0.075$ for $5.4 \leq \omega \leq 10.4$ GHz

$|S_{11}| \geq 0.95$ for $\omega \leq$ 5.25 GHz

$|S_{11}| \geq 0.6$ for $\omega \geq 10.7$ GHz



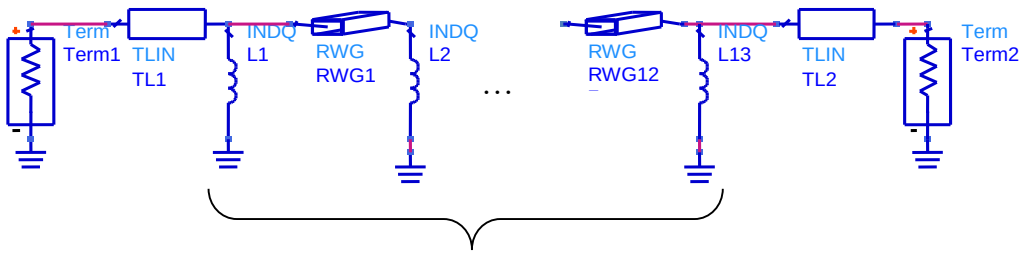
ADS coarse model

preassigned parameters:

section widths and

frequency coefficients

of inductive susceptances



Twelve Section H-plane Waveguide Filter (*Cheng et al., 2012*)

Modeling Relative Error[a] Using 50 Random Test Points

PE samples (linearly-approximated samples)	+/–5% region	+/–10% region	+/–10% region[b]	+/–15% region	+/–15% region[c]
before PE	120.7%	104.2%	107.4%	95.3%	97.3%
1(0)	6.6%	10.2%	10.4%	14.3%	14.5%
1(13)	6.7%	9.2%	9.4%	13.2%	13.5%
14[d] (0)	6.6%	9.8%	10.1%	14.2%	14.4%
27[e] (0)	6.9%	9.2%	8.9%	12.5%	12.9%
27[e] (27x13)	6.7%	9.2%	9.0%	12.6%	13.1%

a. ($\|\boldsymbol{R}_f - \boldsymbol{R}_s\|/\|\boldsymbol{R}_f\|$); b. HFSS fast sweep; c. solution frequency at 5 GHz;
d. half of star distribution; e. star distribution.

Space Mapping: a Glossary of Terms (*Bandler et al., 2009*)

space mapping	transformation, link, adjustment, correction, shift (in parameters or responses); "internal" fine-tuning transformation
coarse model	simplification or convenient representation, companion to the fine model, auxiliary representation, cheap model, "idealized" model
fine model	accurate representation of system considered, device under test, component to be optimized, expensive model, an optimization process

Space Mapping: a Glossary of Terms (*Bandler et al., 2009*)

surrogate	model, approximation or representation to be used, or to act, in place of, or as a (temporary) substitute for, the system under consideration
(updated) surrogate	mapped or enhanced coarse model, corrected coarse model, tuning-parameter-augmented fine-model iterate
surrogate model	alternative expression for surrogate
target response	a response the fine model should achieve, (usually) the optimal response of an idealized "coarse" model, an enhanced coarse model, or surrogate

Space Mapping: a Glossary of Terms (*Bandler et al., 2009*)

surrogate update	rebuilding of a coarse- or ideal-model-based surrogate using, e.g., parameter extraction; supply new fine-model data to a surrogate
surrogate optimization	prediction of the next fine model; "internal" fine tuning of a tuning-parameter-augmented fine-model iterate (tuning model)
parameter extraction	aligning a coarse model or surrogate with the corresponding fine model

Conclusions

space mapping harnesses physics-based "quasi-global" surrogates (knowledge) to achieve fast model enhancements

space mapping facilitates full-wave electromagnetics-based as well as multidisciplinary engineering design and modeling

space mapping offers a quantitative explanation for the engineer's mysterious "feel" for a problem

the essence of space mapping: less is more

space mapping is "elegant"

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