UNIVERSITÀ DEGLI STUDI
DI GENOVA

Open-source Shape Optimization

An application to Bulbous Bow

FINCANTIERI
The sea ahead

DLTM
DISTRETTO LIGURE
DELLE TECNOLOGIE MARINE

wolf dynamics

OPTIMAD
ENGINEERING

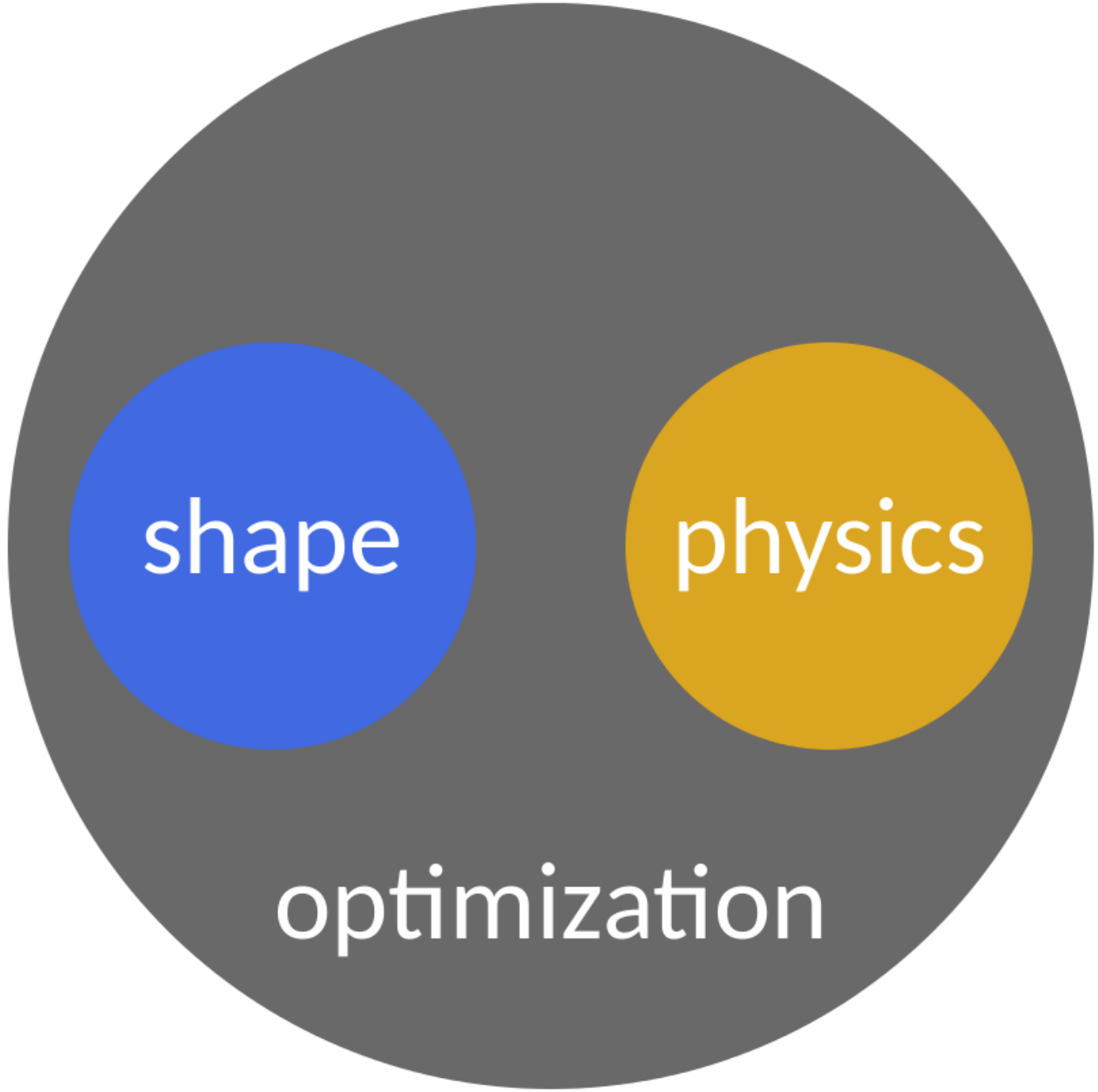
Purpose

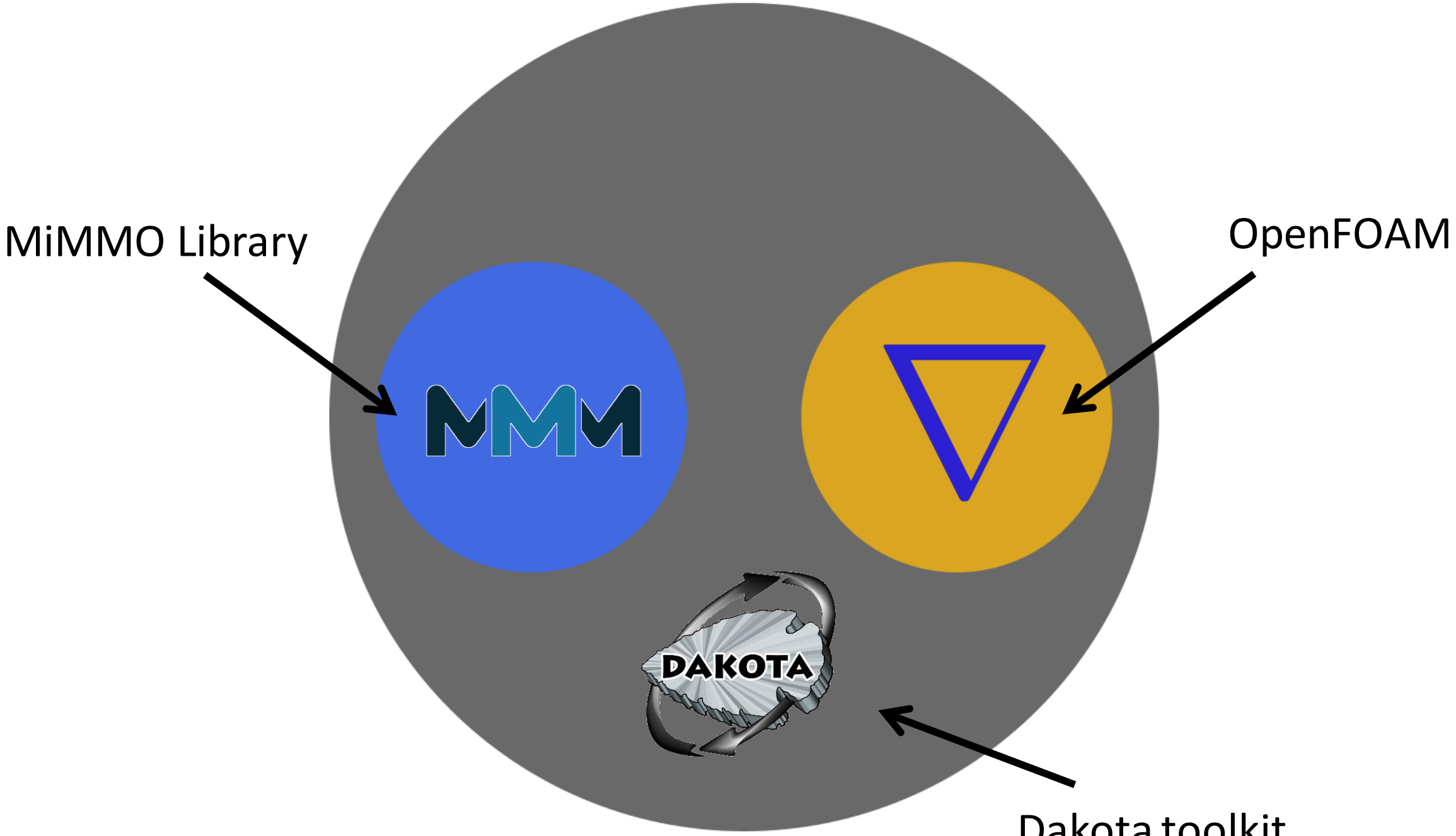
Build an Open Source Shape Optimization Framework for Fluid Dynamics

Why?

Numerical

Open source


shape
physics
optimization

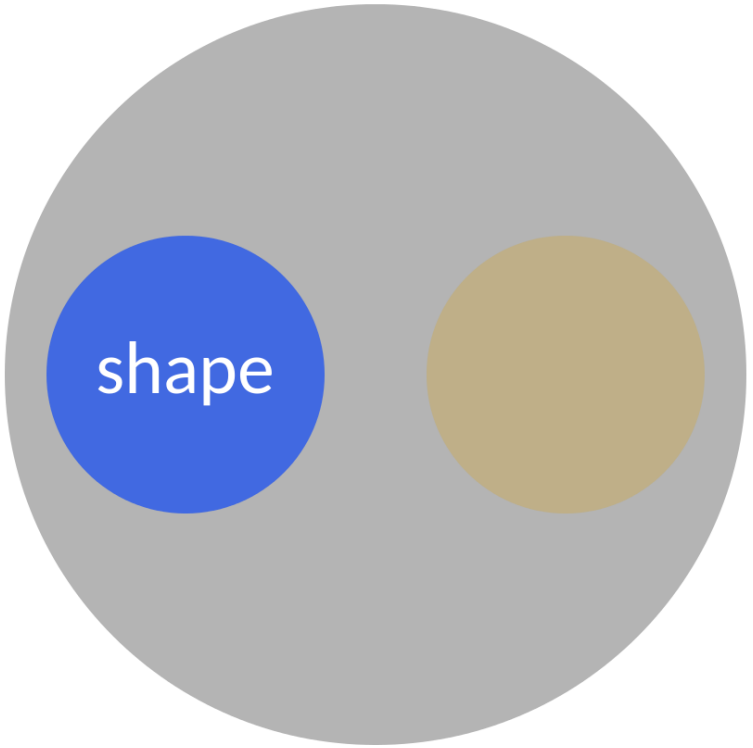

MiMMO Library
OpenFOAM
MMM
DAKOTA
Dakota toolkit

MiMMO library

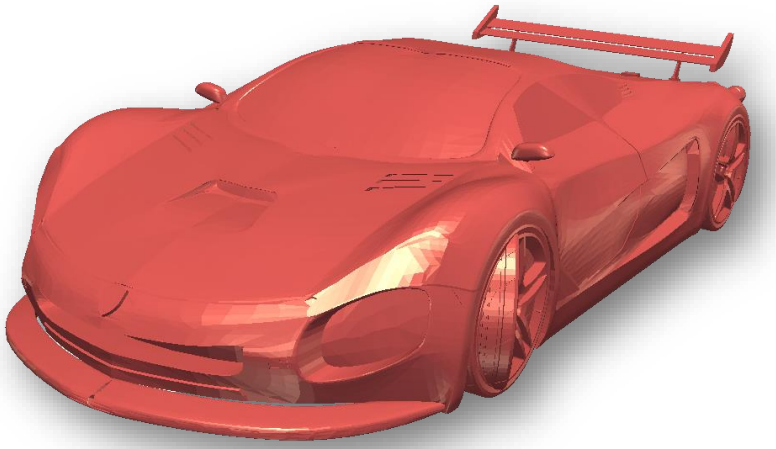
Radial Basis Functions

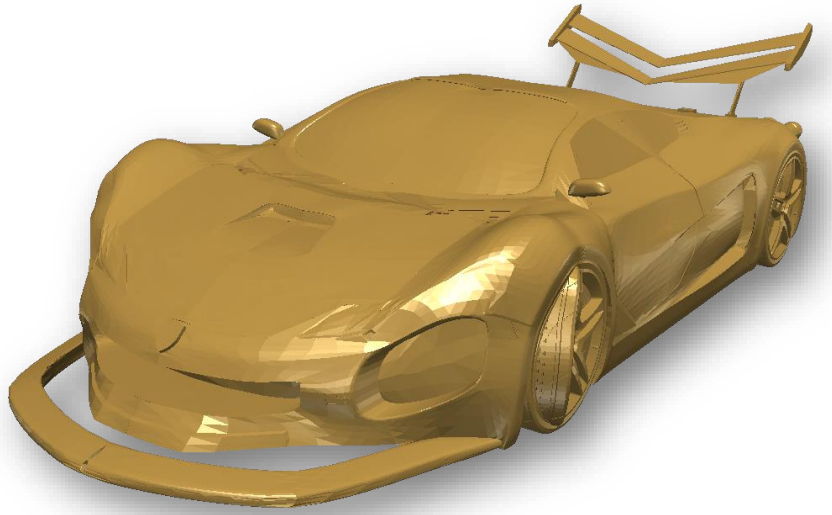
Control Points/Selection Box

No need to generate geometries

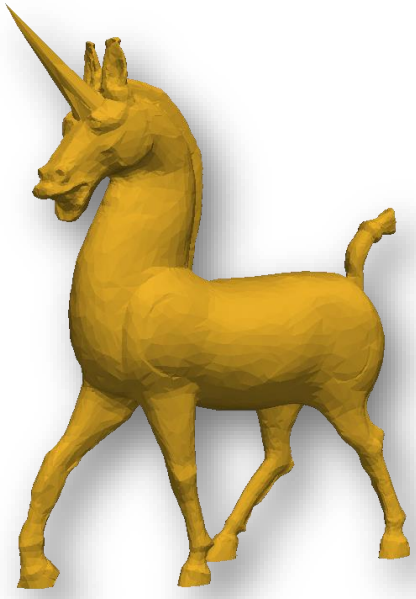


Shape morphing

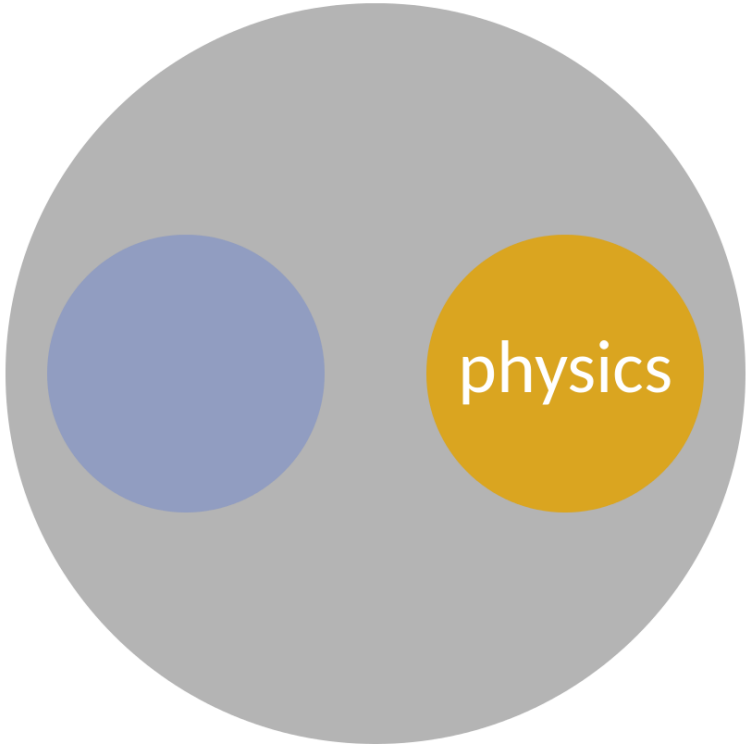




Shape morphing



Shape morphing



OpenFOAM

Simulates the physics

Benchmark with experiment

Accuracy/Costs trade-off

Physics simulation

Optimization

"an act, process, or methodology
of making something
(design, system, or decision)
as fully perfect, functional, or effective
as possible".

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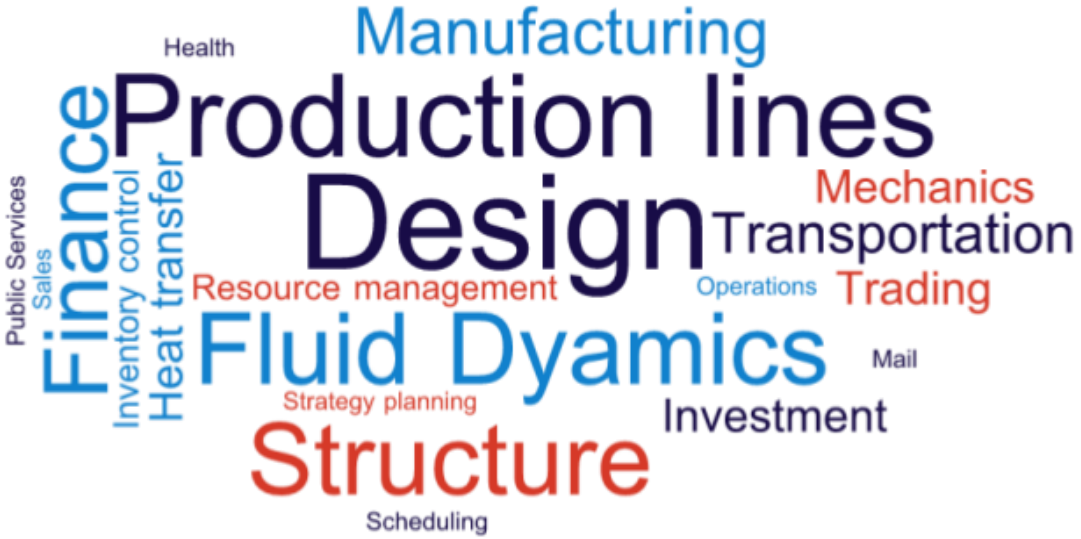
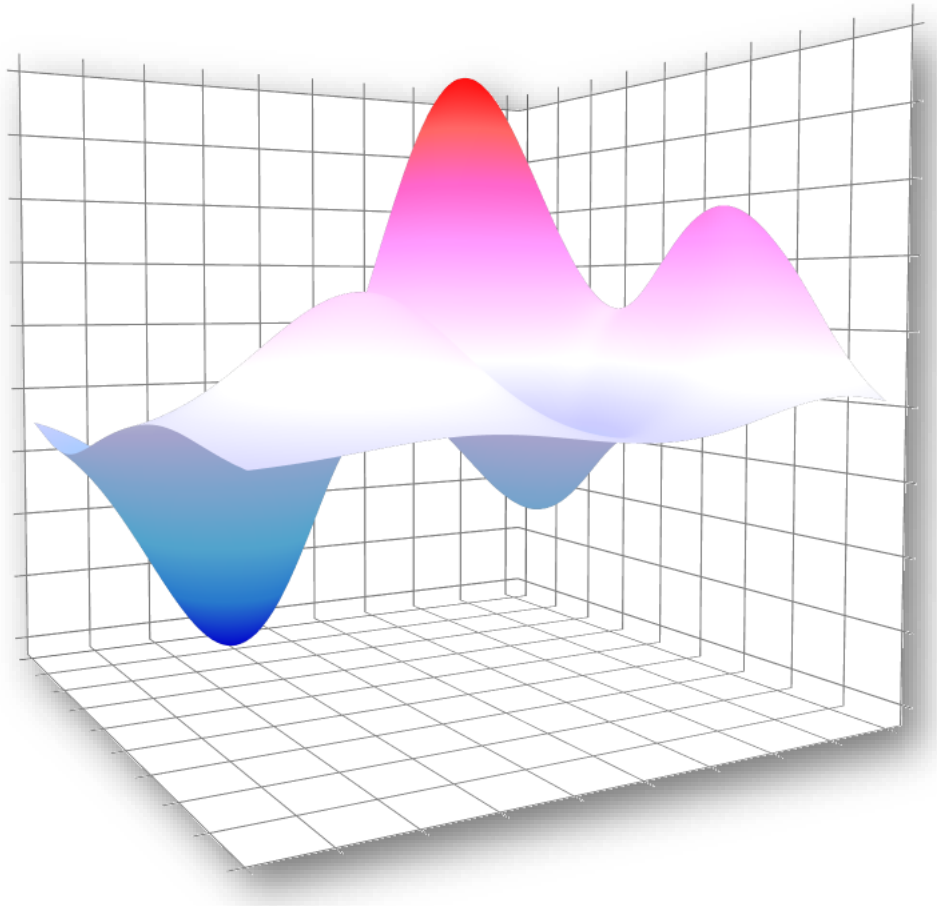
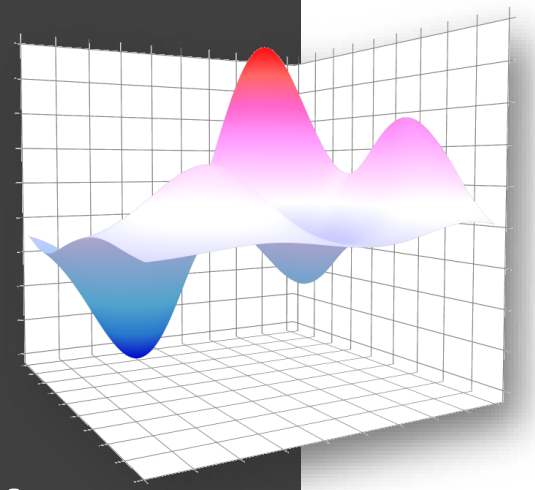


Optimization

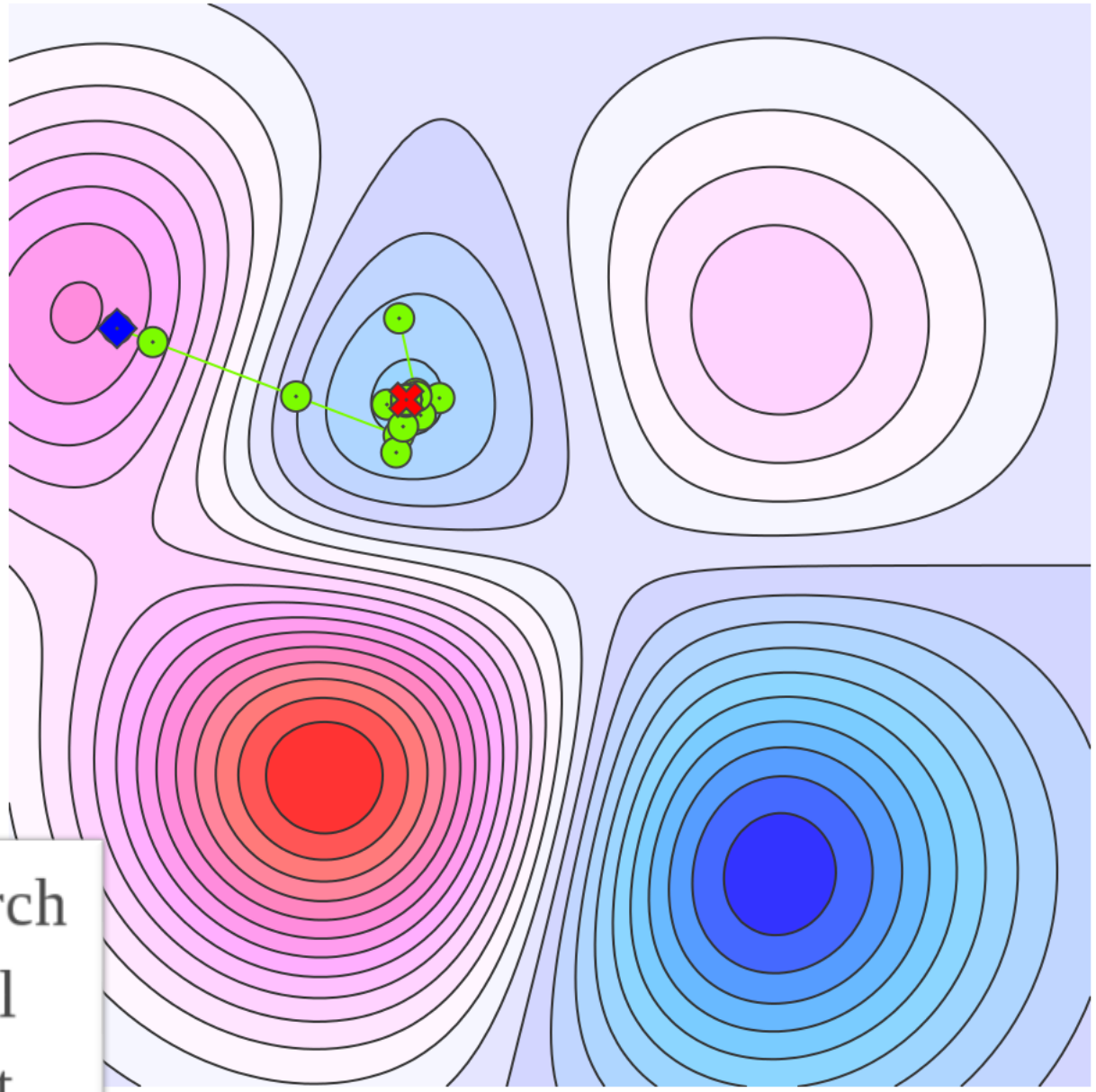
Ex.

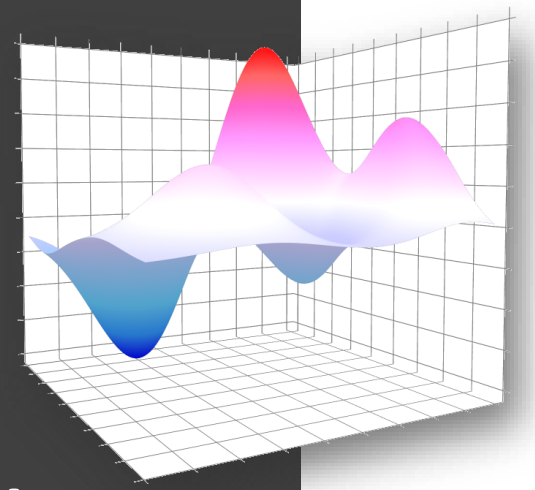
- 2 design variables
- 1 outcome
- Multimodal behavior
- t = 10 h





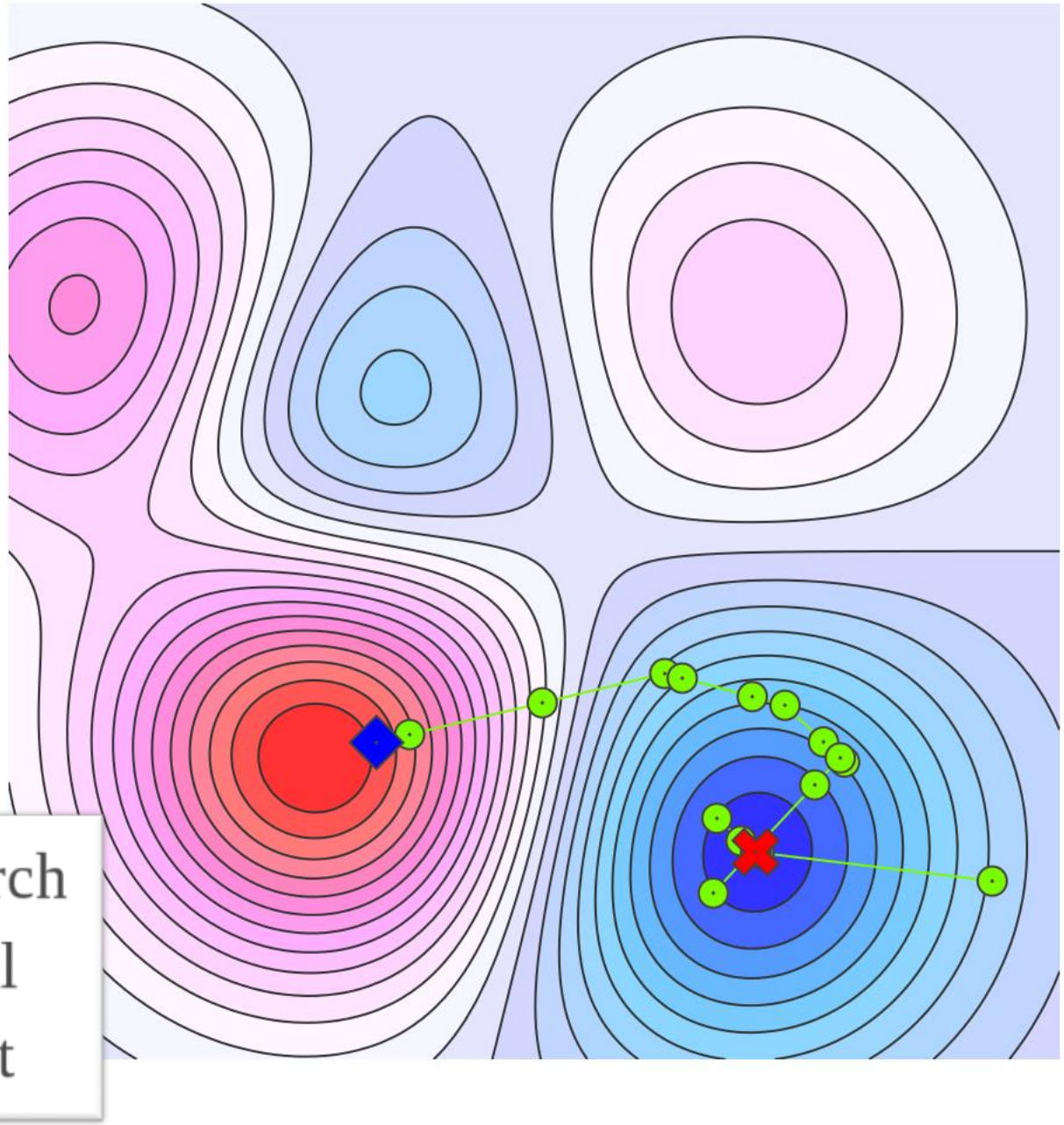
Gradient based

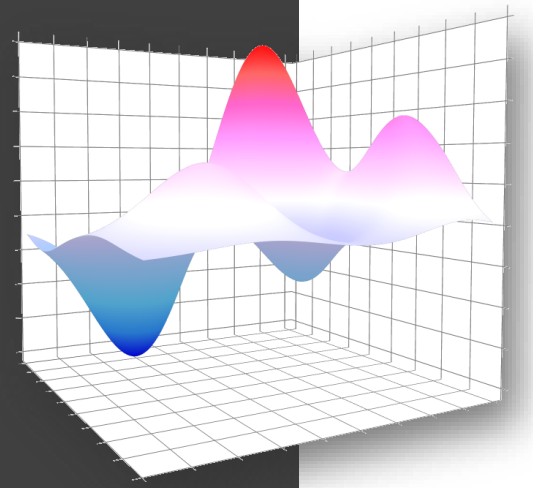




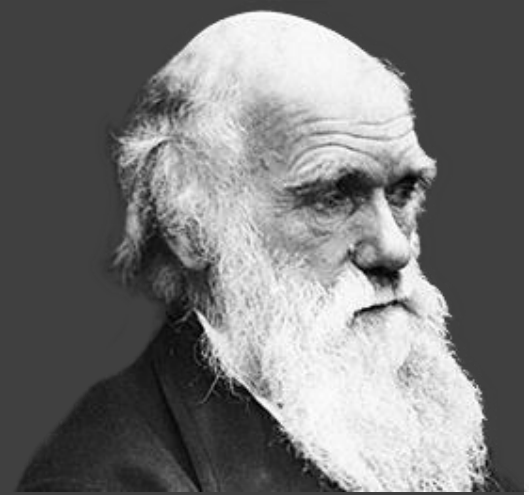
Gradient based

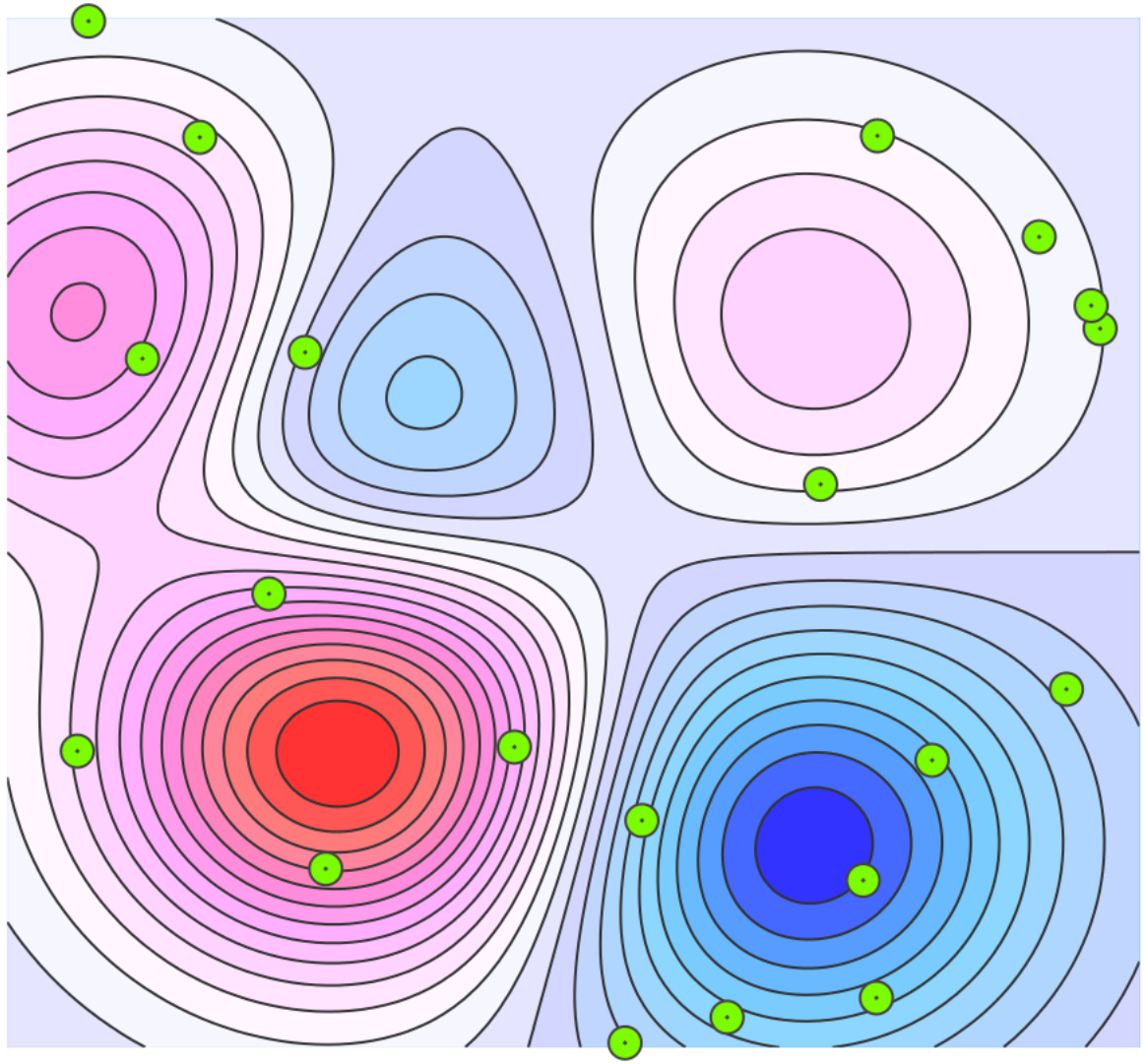
22 points +
14 gradient =
36 evaluations
15 days



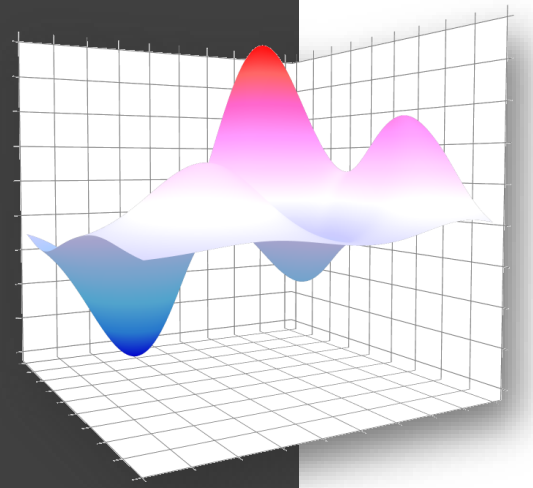


Evolutionary algorithm

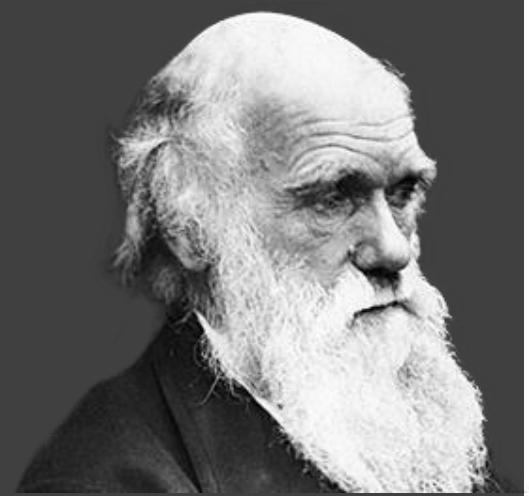


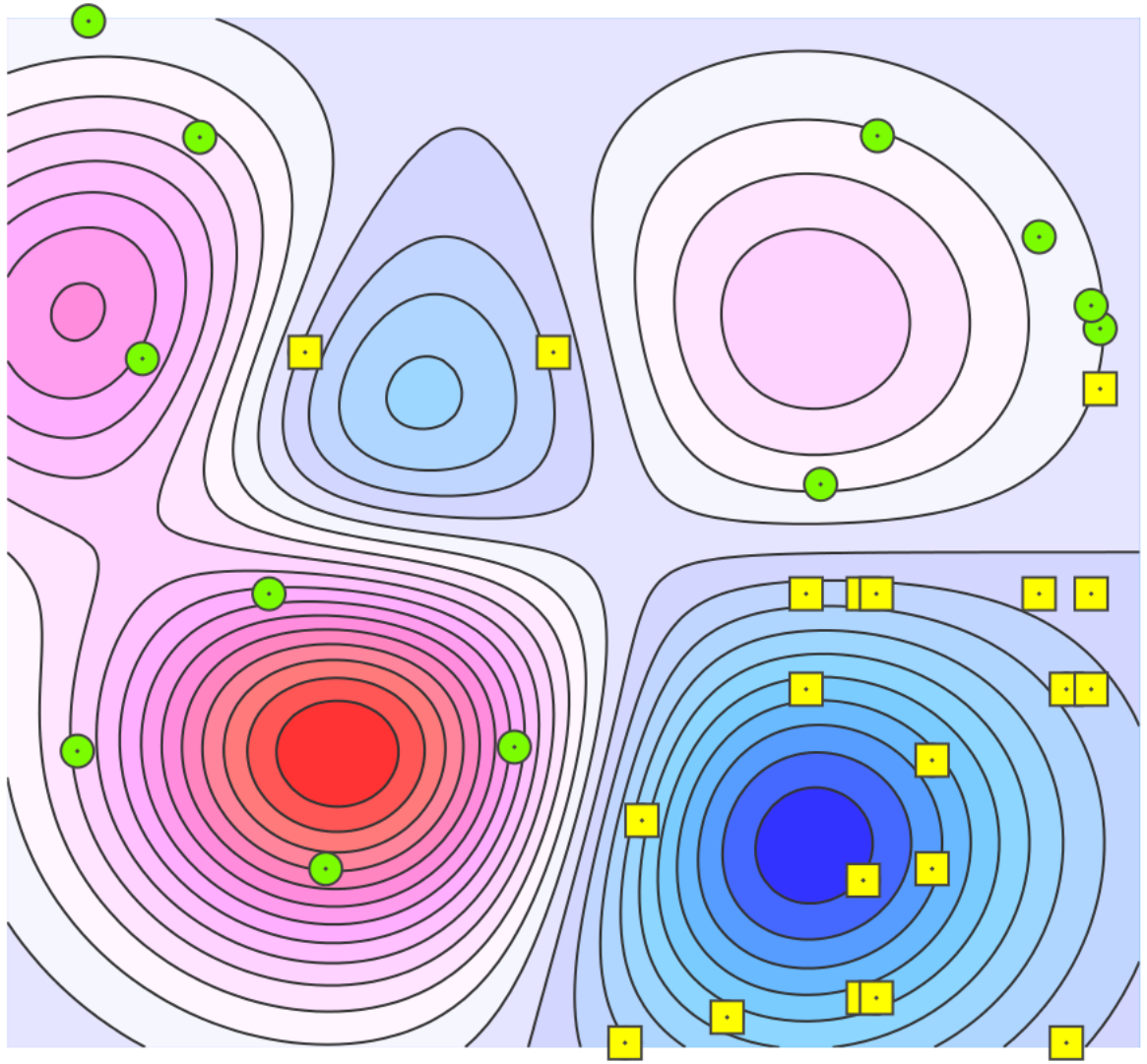


Population 0

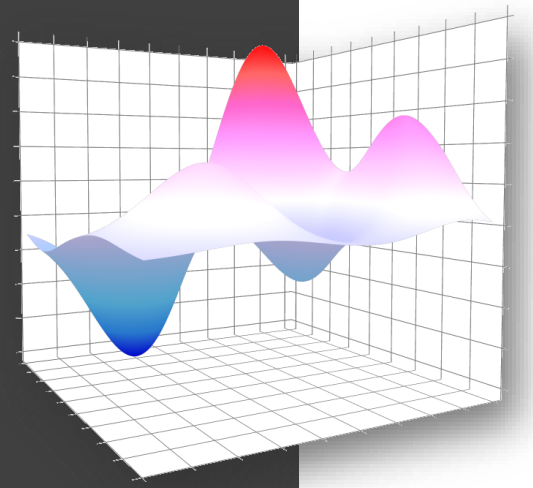


Evolutionary algorithm

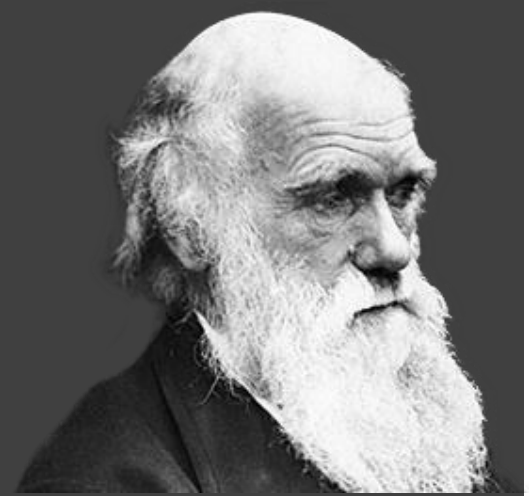


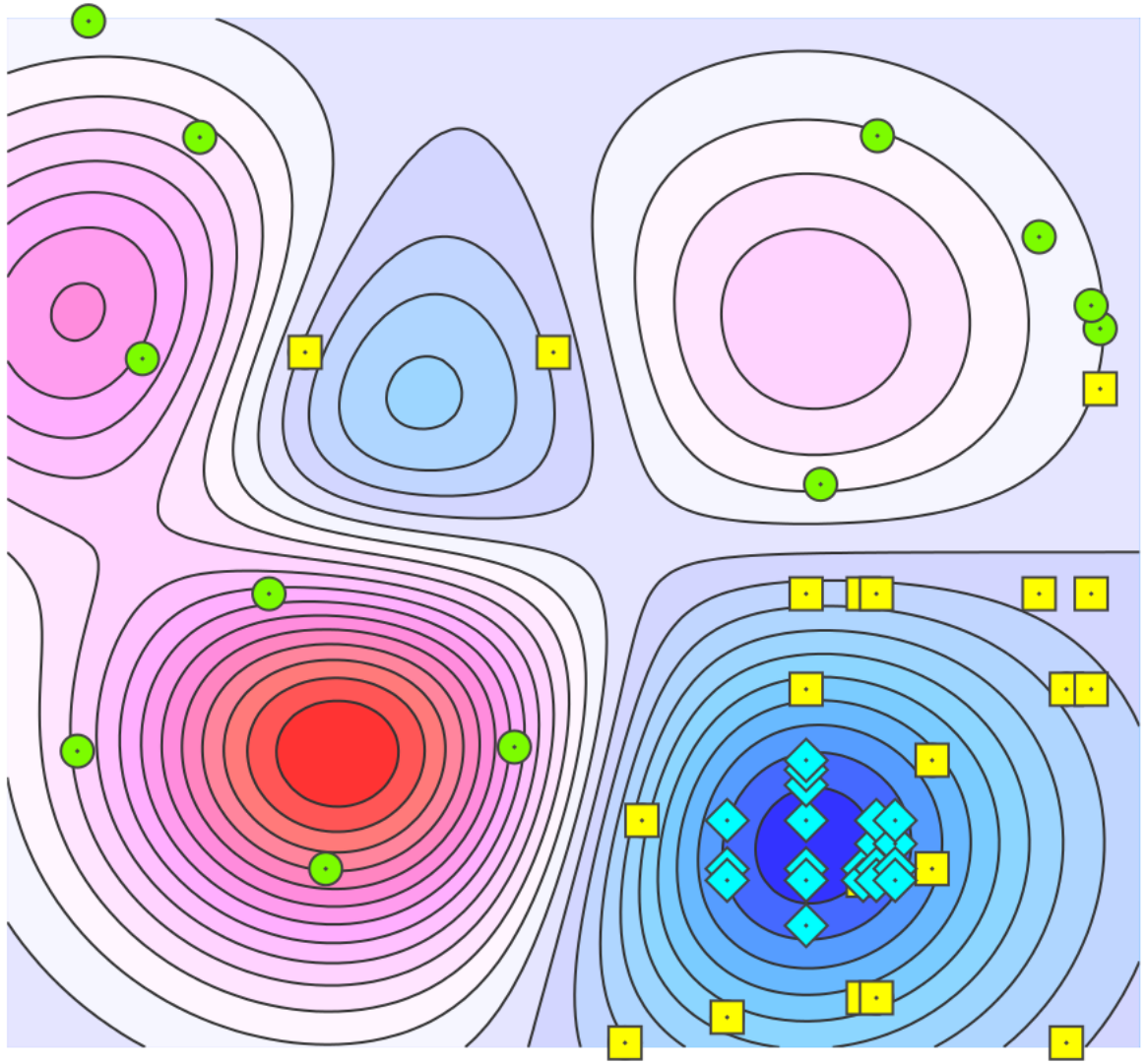


Population 3

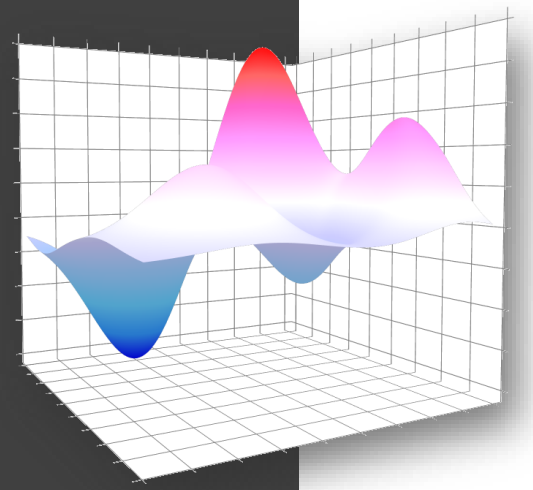


Evolutionary algorithm

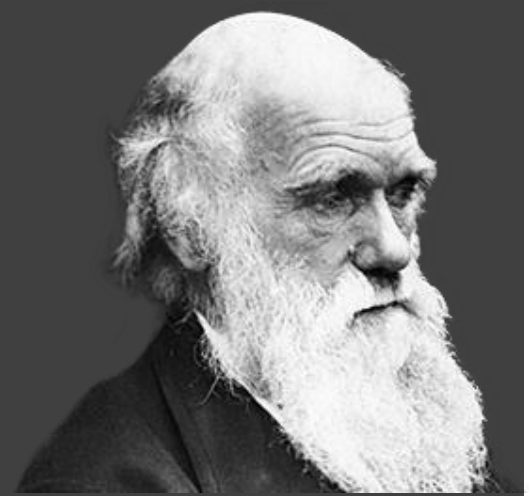


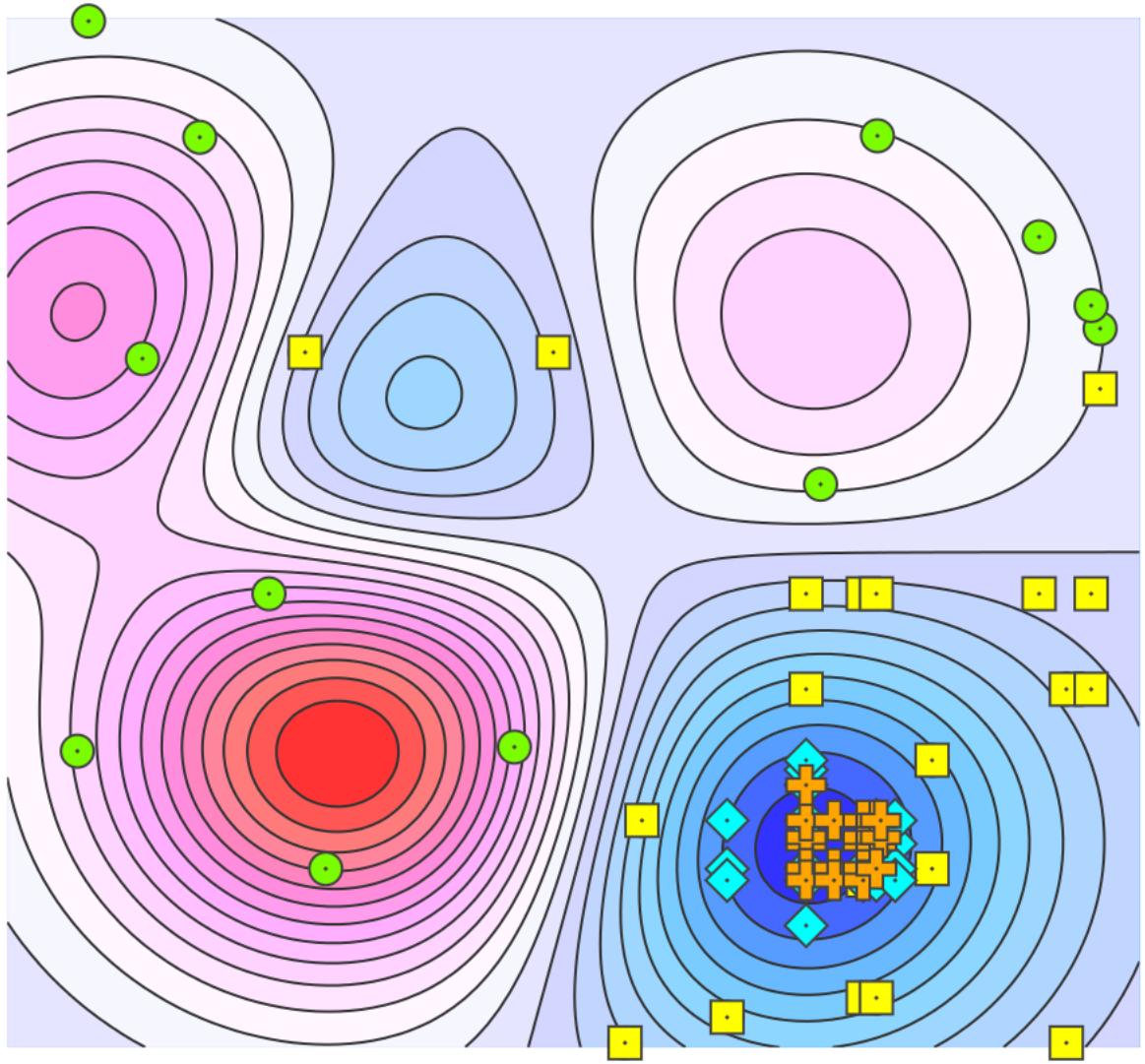


Population 20

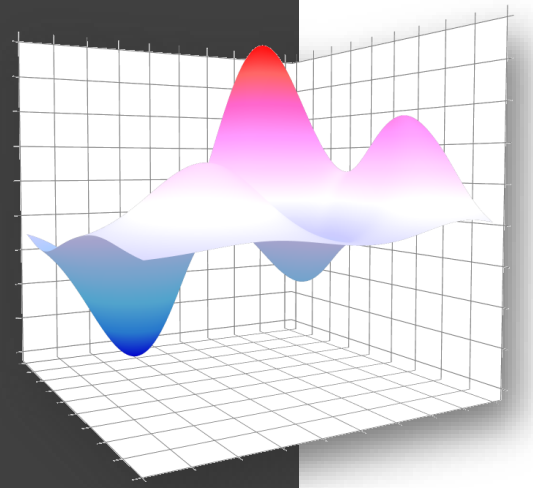


Evolutionary algorithm

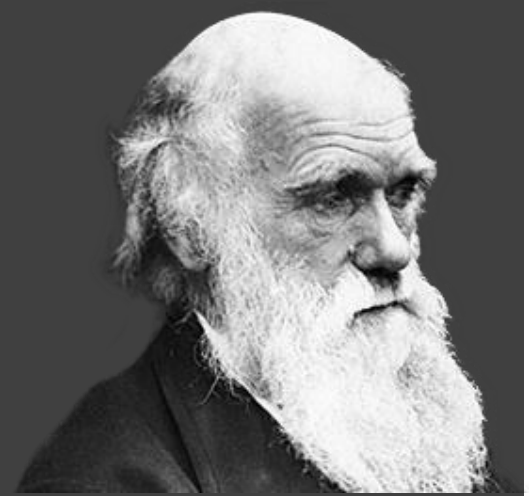


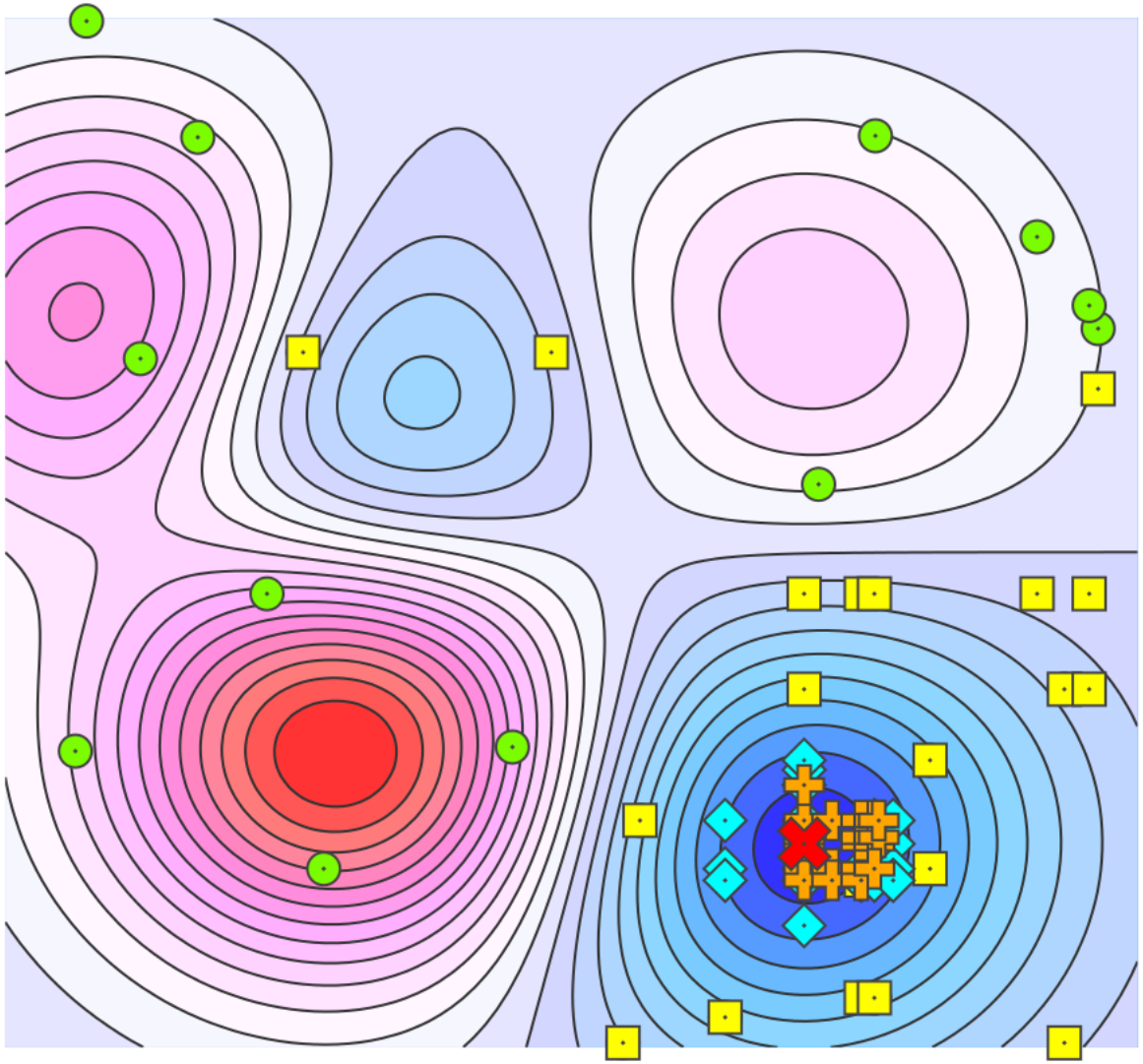


Population 40



Evolutionary algorithm

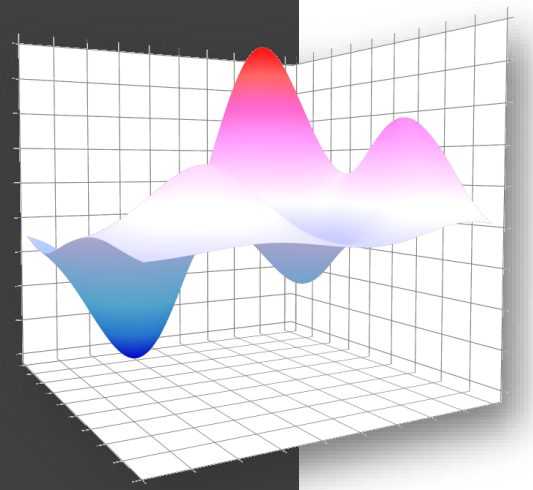




Final

3 months

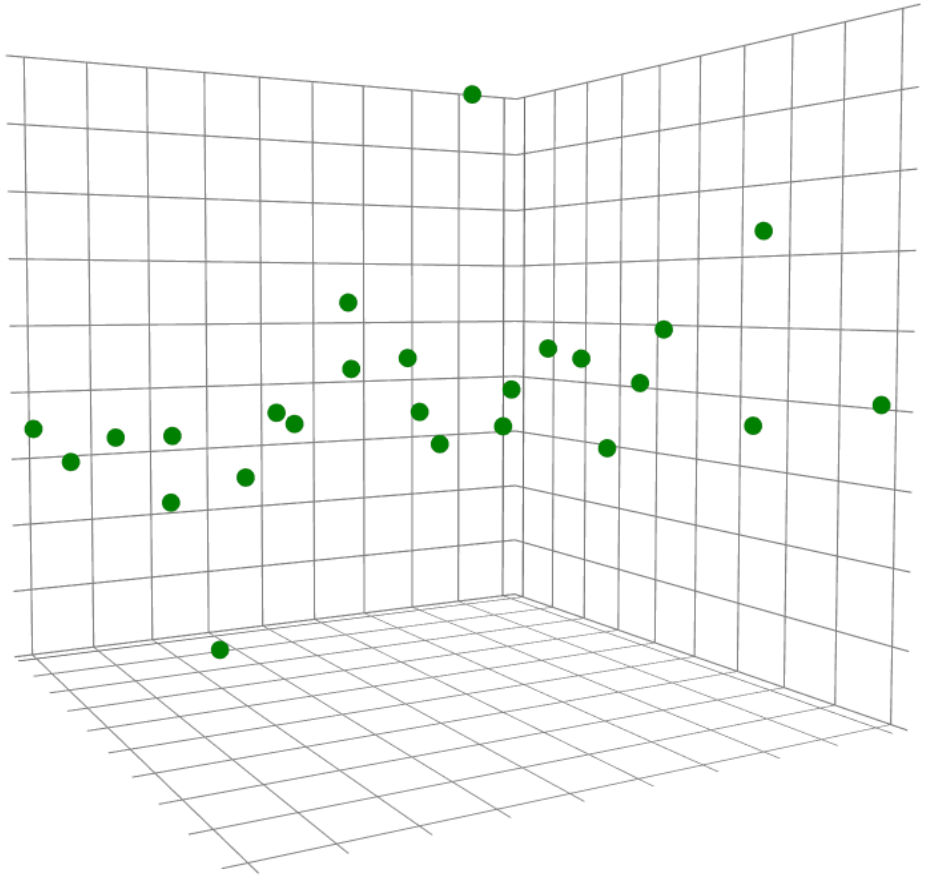
200 evaluations

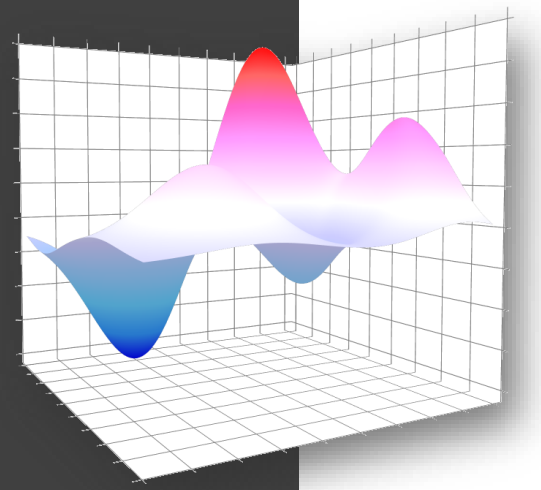


Surrogate modeling

Ex.

- Full Factorial Sampling
- 25 design points

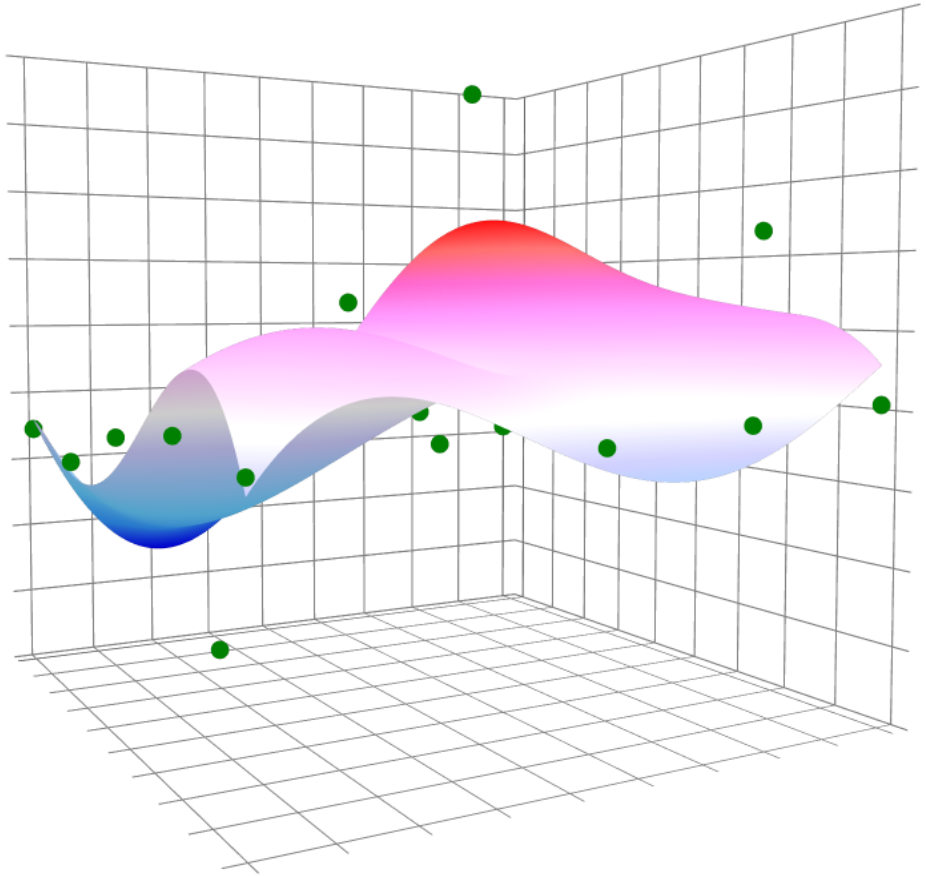


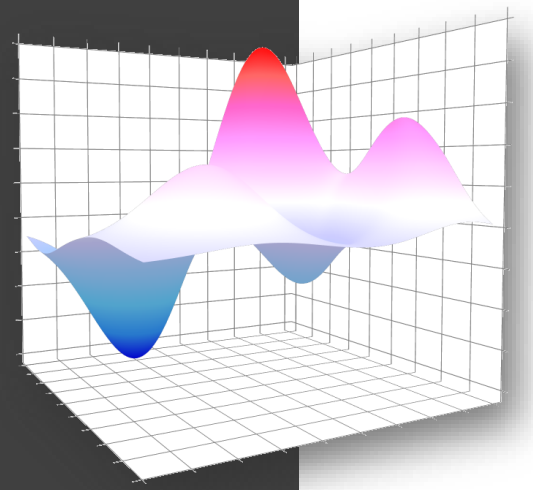


Surrogate modeling

Ex.

- 4-order polynomial regression

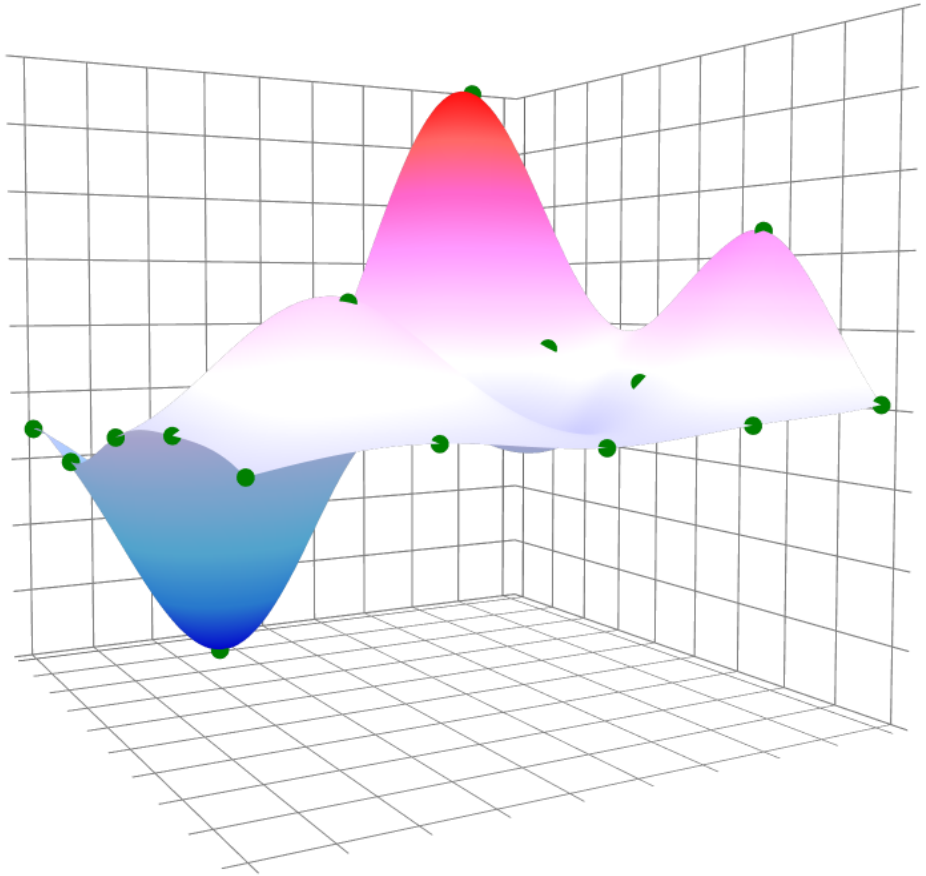


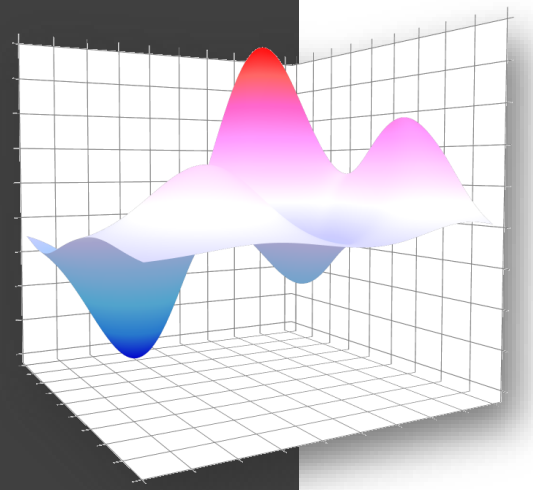


Surrogate modeling

Ex.

- Kriging interpolation

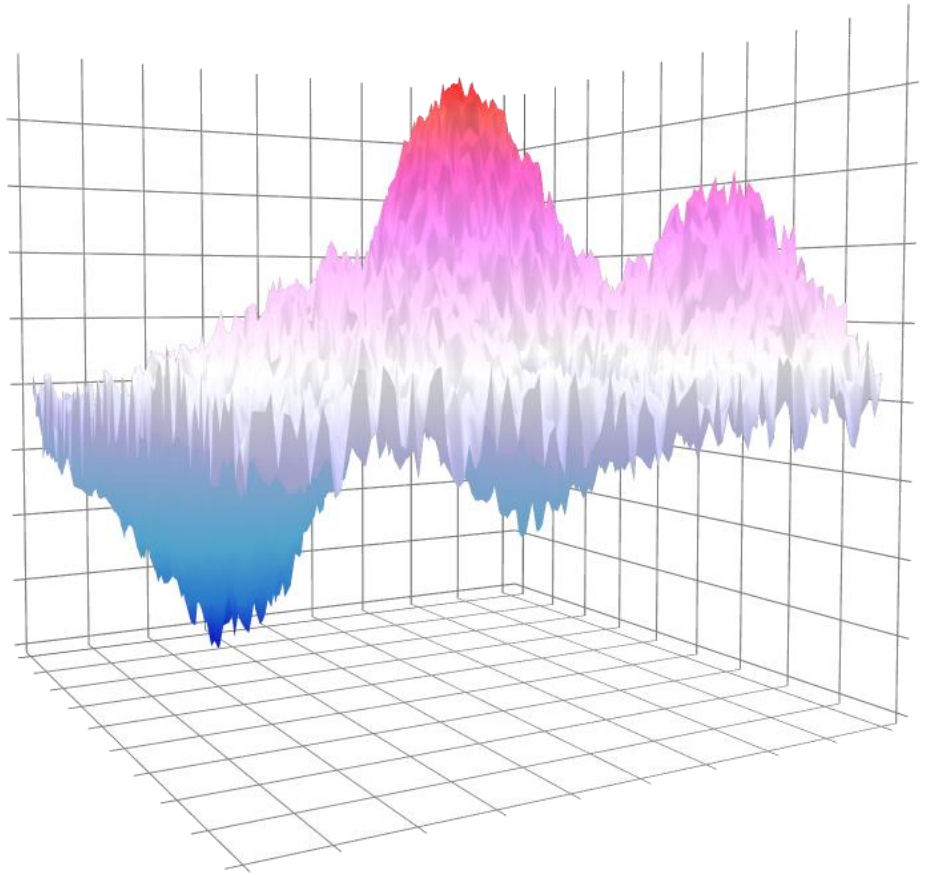




Surrogate modeling

Attention!

- Deterministic "noise"

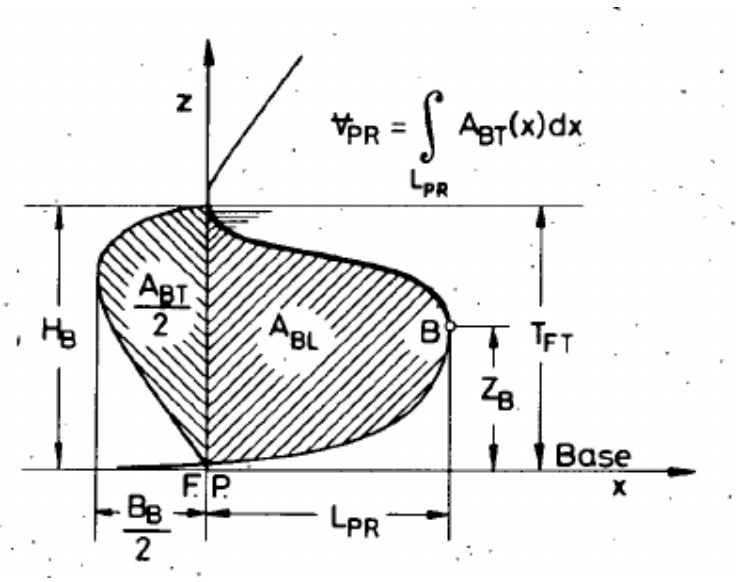


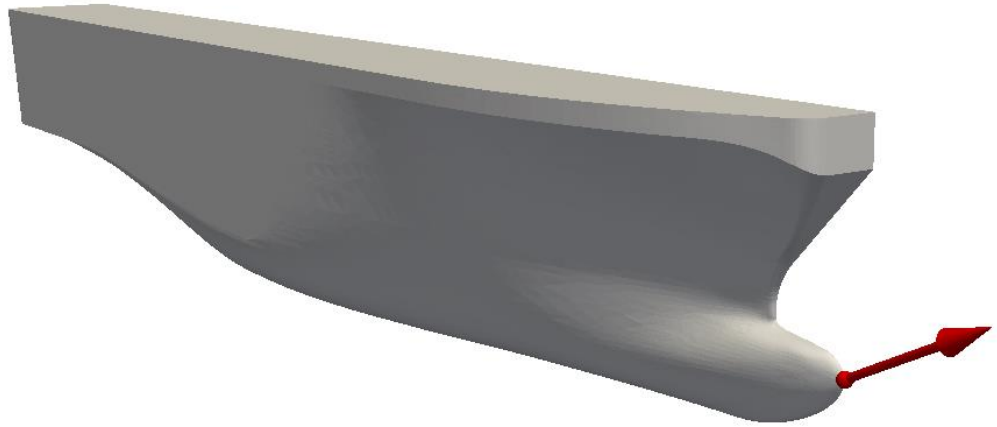
Case study

Bulb design variables:

$$C_{LPR} = \frac{L_{PR}}{L_{PP}}$$

$$C_{ZB} = \frac{Z_B}{T_{FT}}$$





Case study

Assumptions:

- Model scale
- Calm water
- Bare hull
- Fixed trim condition
- Symmetry

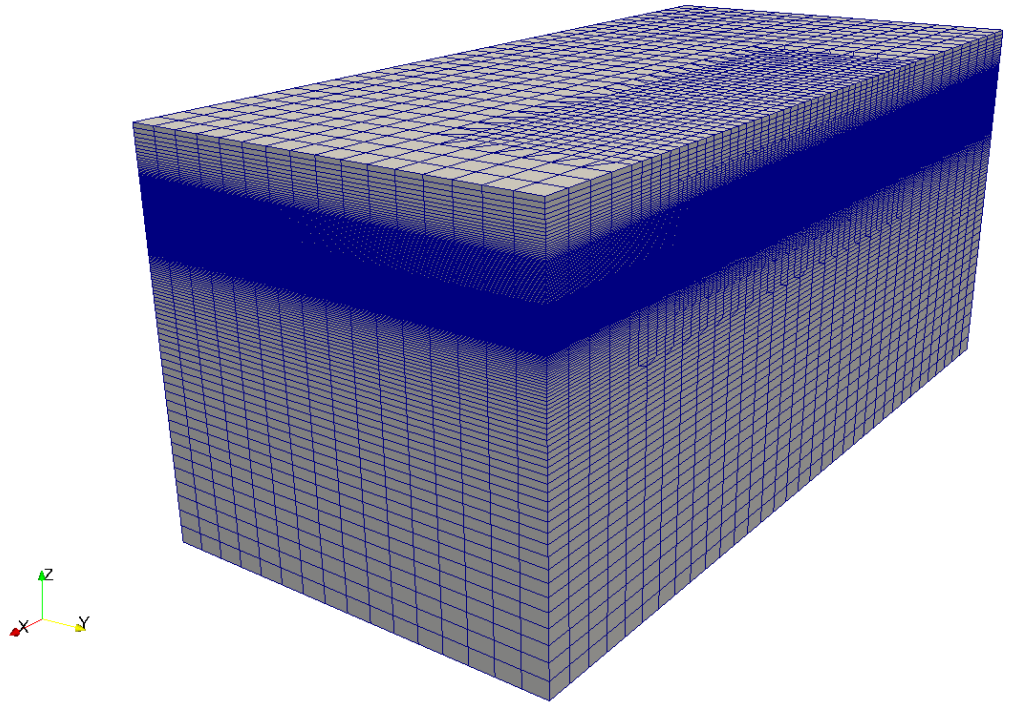
$$Fn_{model} = Fn_{ship}$$

$$\frac{V_{model}}{\sqrt{gL_{model}}} = \frac{V_{ship}}{\sqrt{gL_{ship}}} \Longrightarrow \boldsymbol{V_{model} = \frac{V_{ship}}{\sqrt{\lambda}}}$$

Case study

Numerical model:

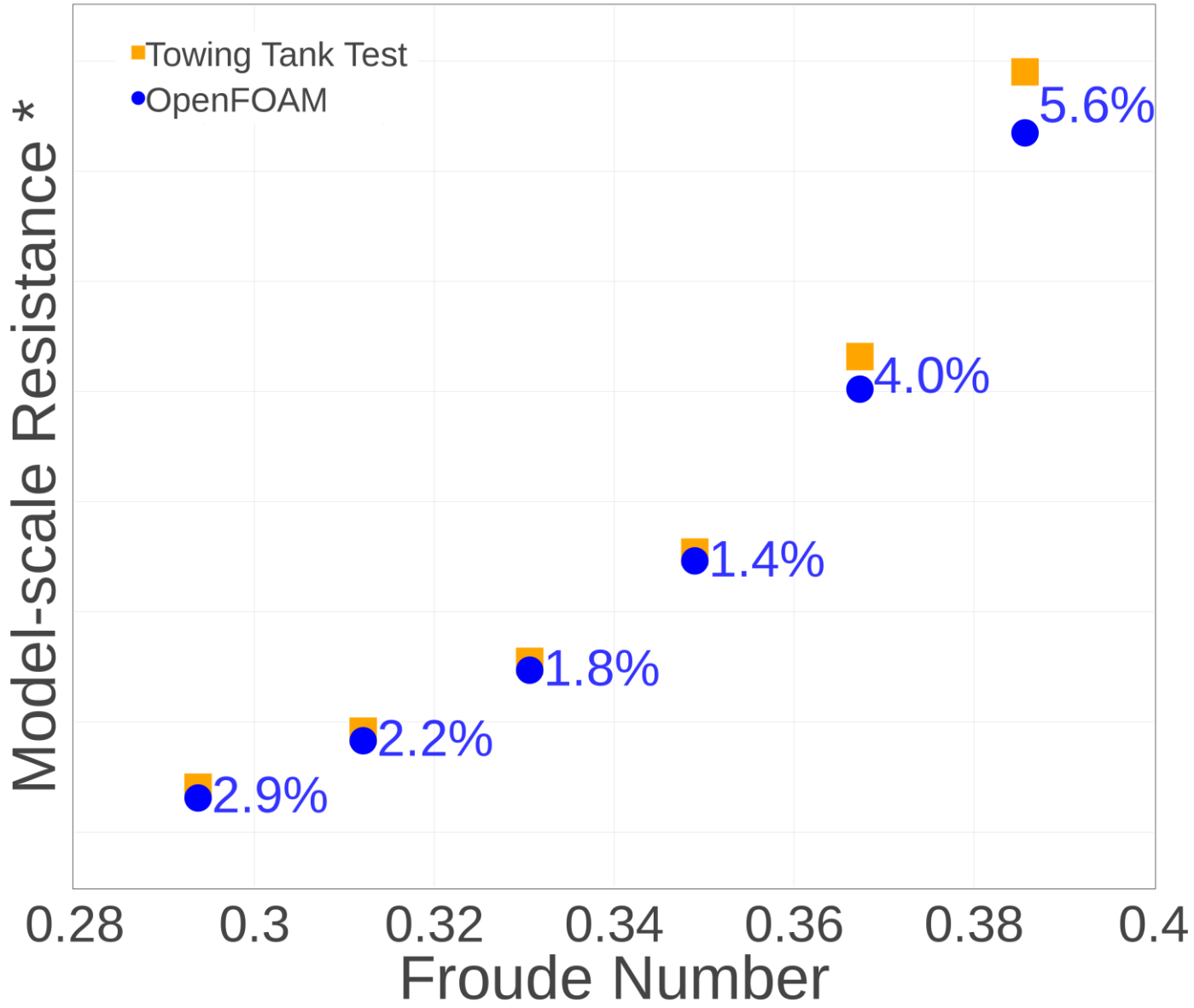
- Mesh 700k cells
- Local Time Stepping (LTS)
- **`interFoam`** solver (VOF)
- k-ω SST



Benchmark

** Numerical values are confidential*

Velocity-Resistance Trend



Benchmark

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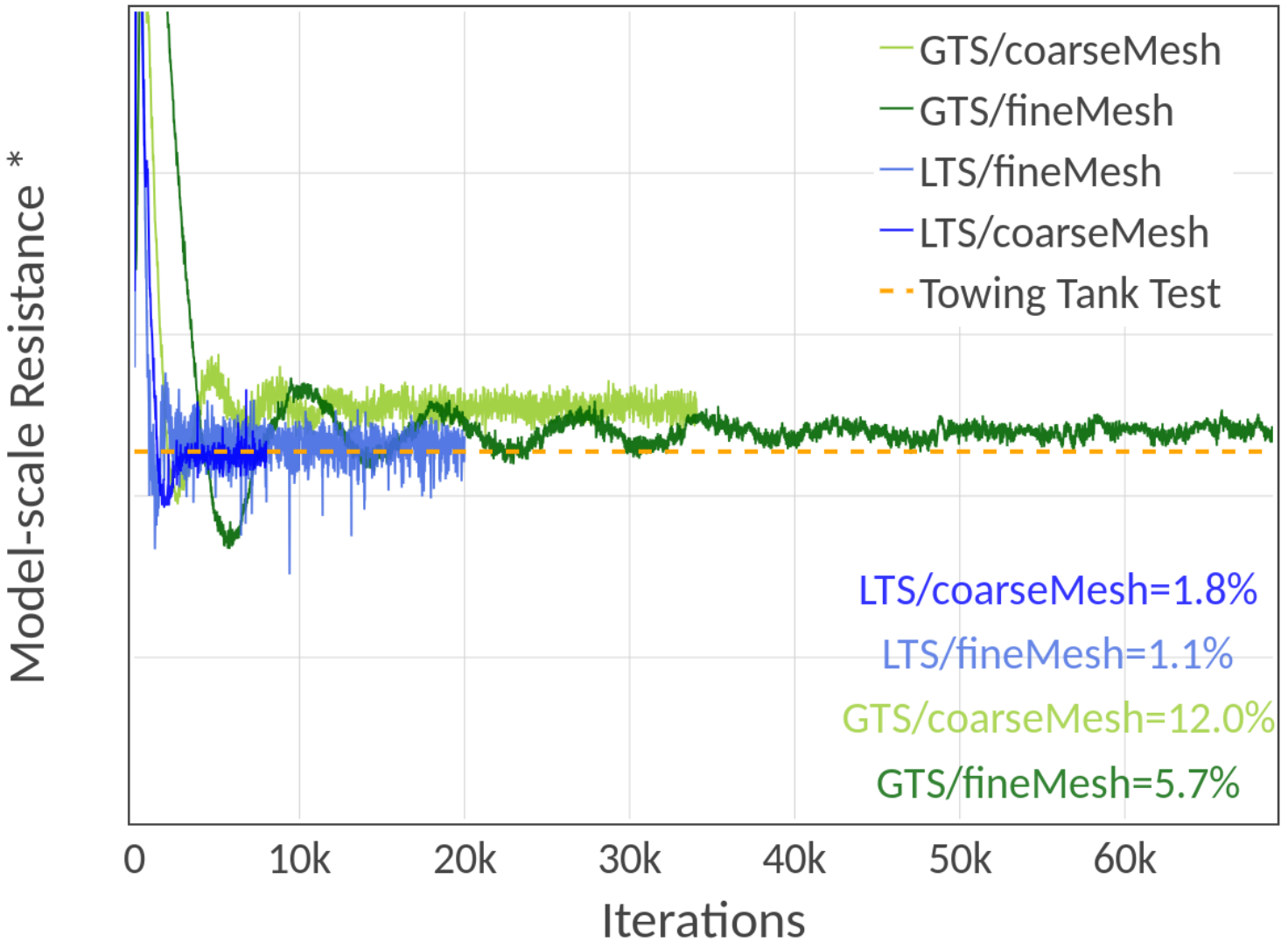
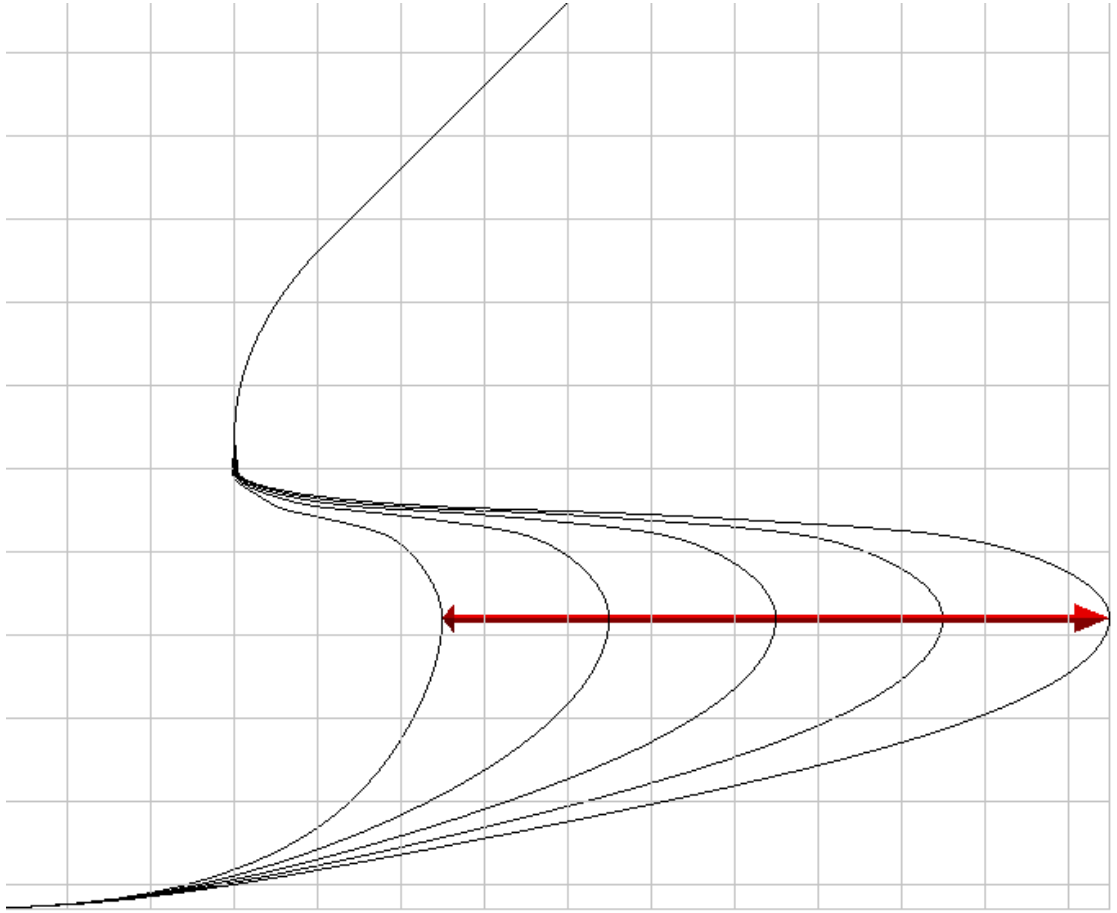
Numerical dependencies



Results

** Numerical values are confidential*

One-design-variable



Results

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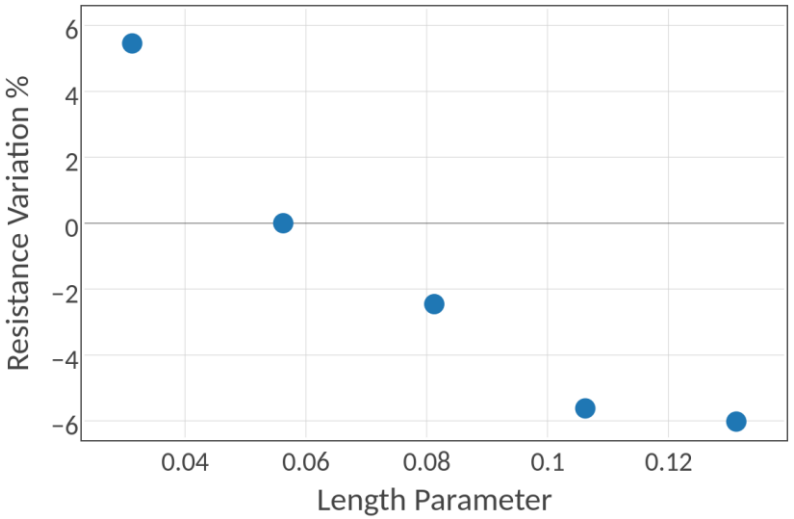
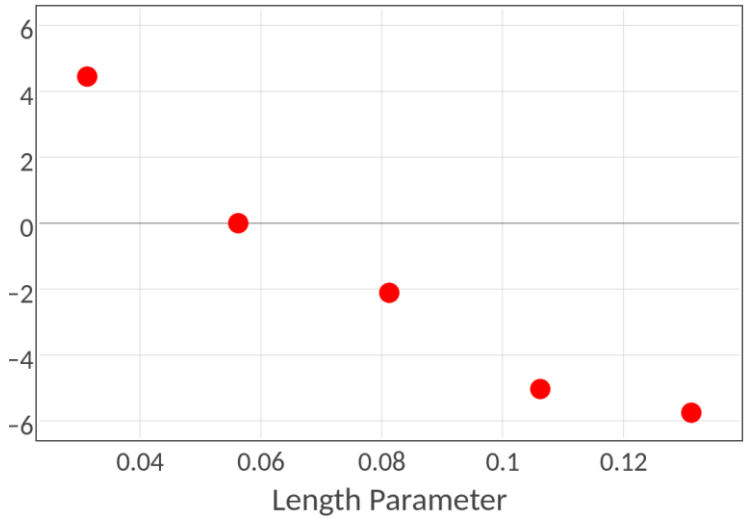
One-design-variable

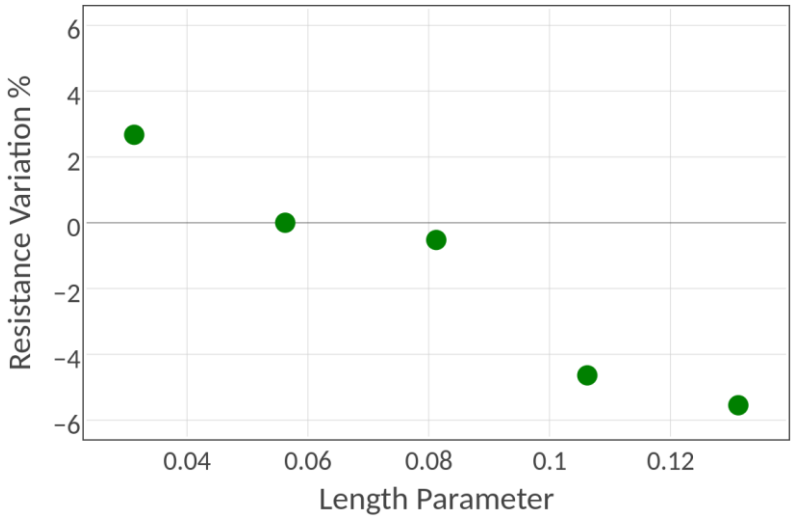
16 knots



18 knots



20 knots



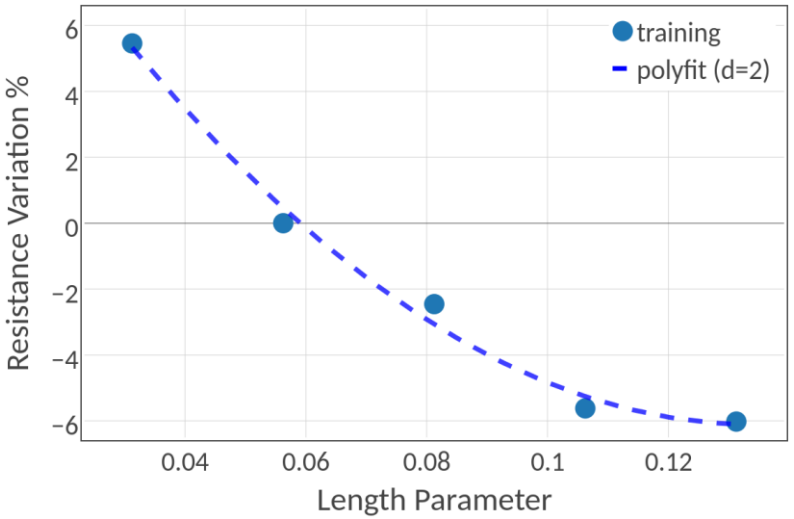
$$\Delta R_{\%} = \frac{R_{morphed} - R_{original}}{R_{original}} 100$$

Results

** Numerical values are confidential*

One-design-variable

16 knots



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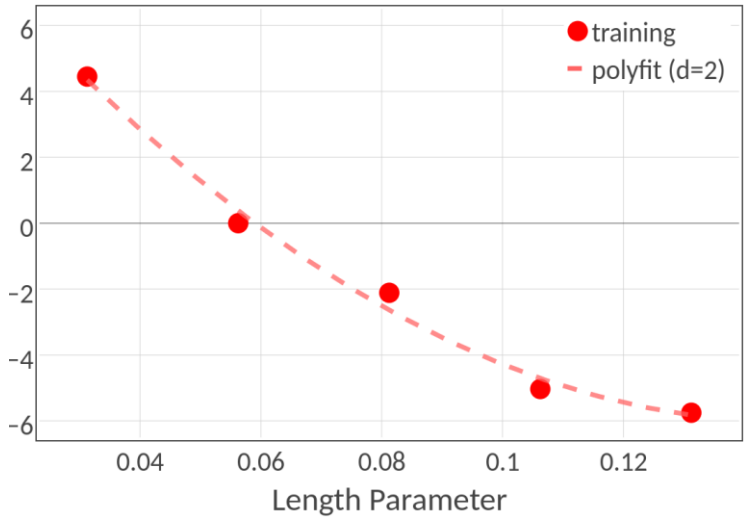
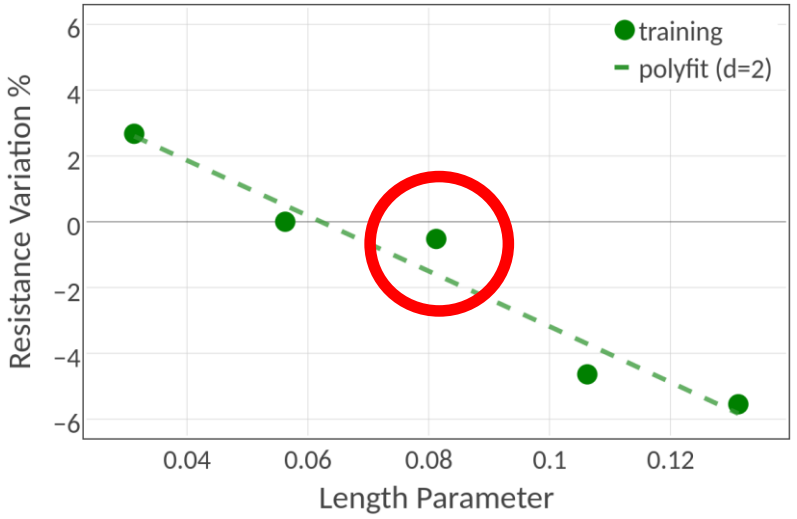


20 knots

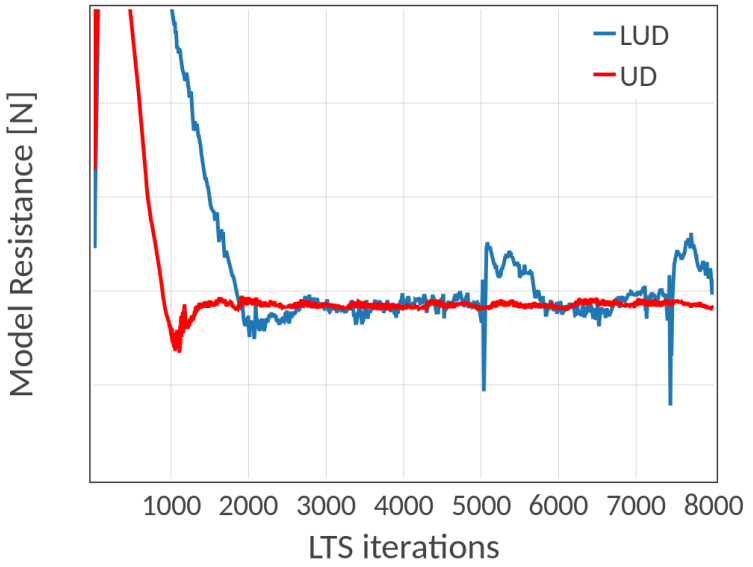


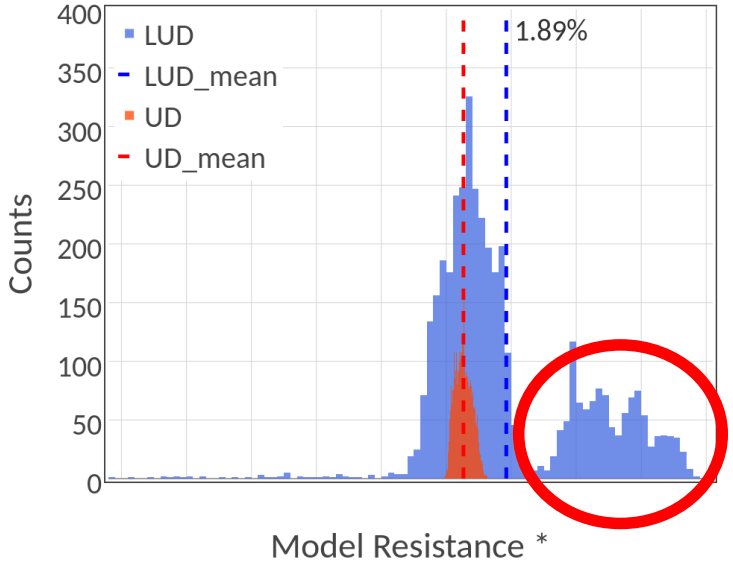
Let's check the noise

Results

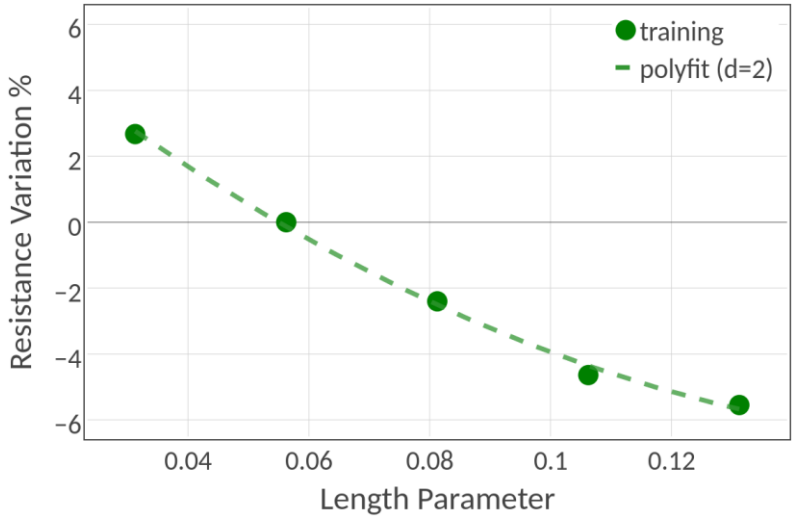
** Numerical values are confidential*

One-design-variable





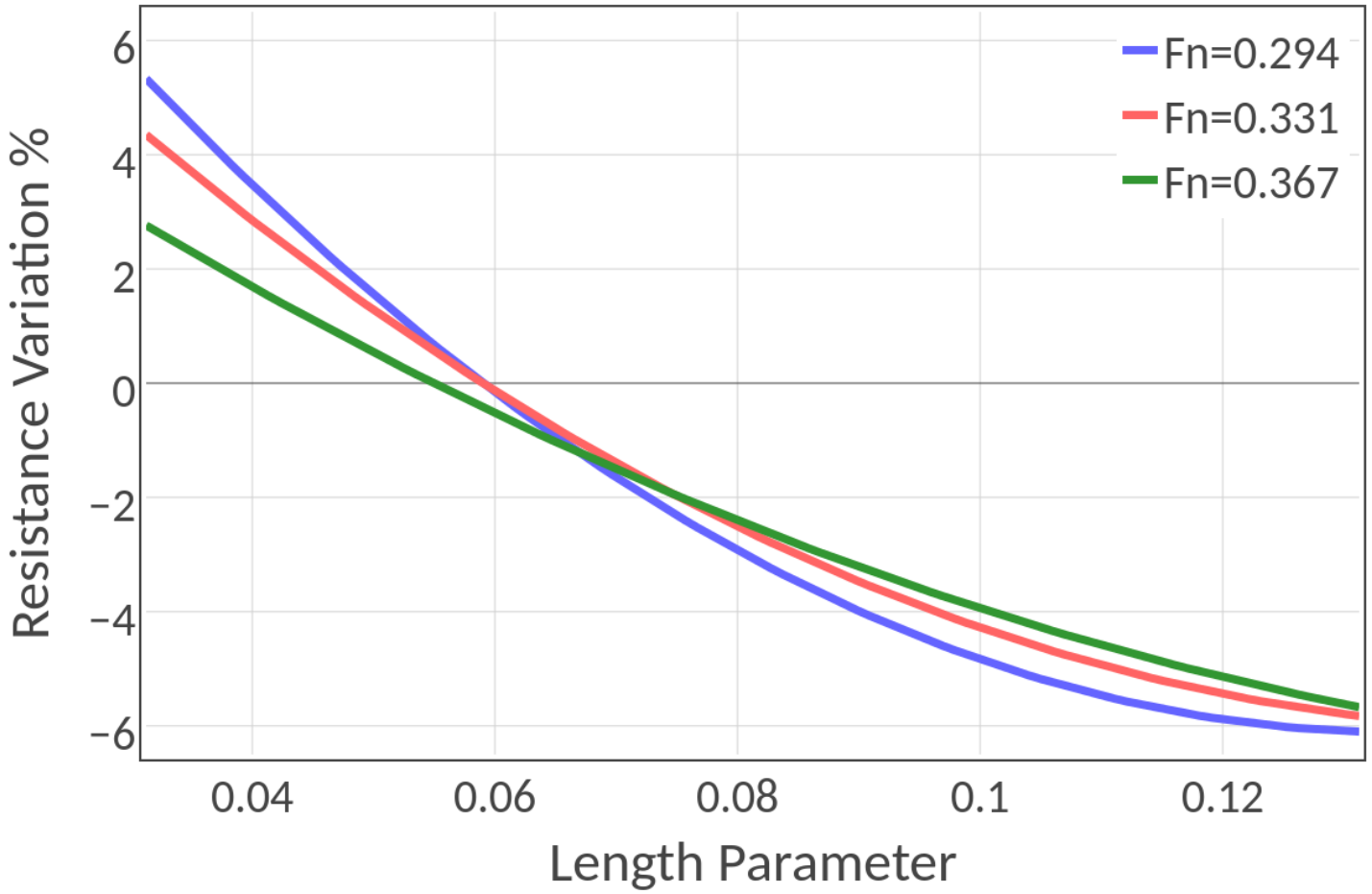
20 knots



Results

** Numerical values are confidential*

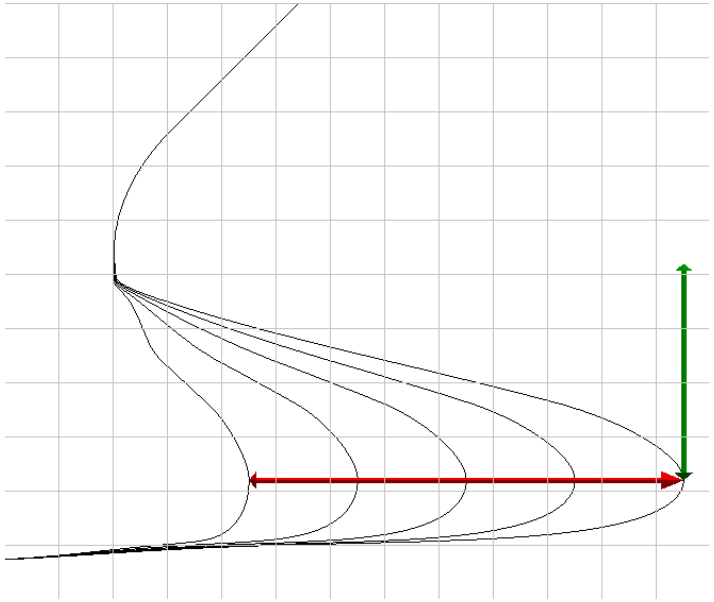
One-design-variable

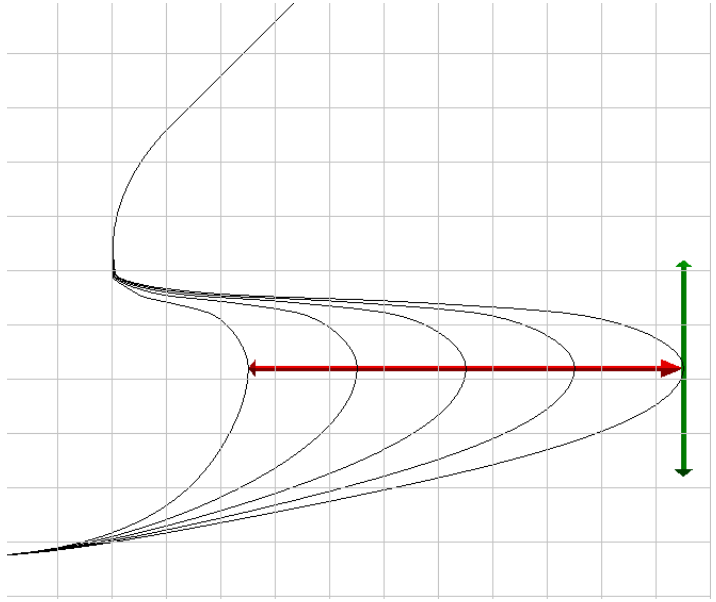


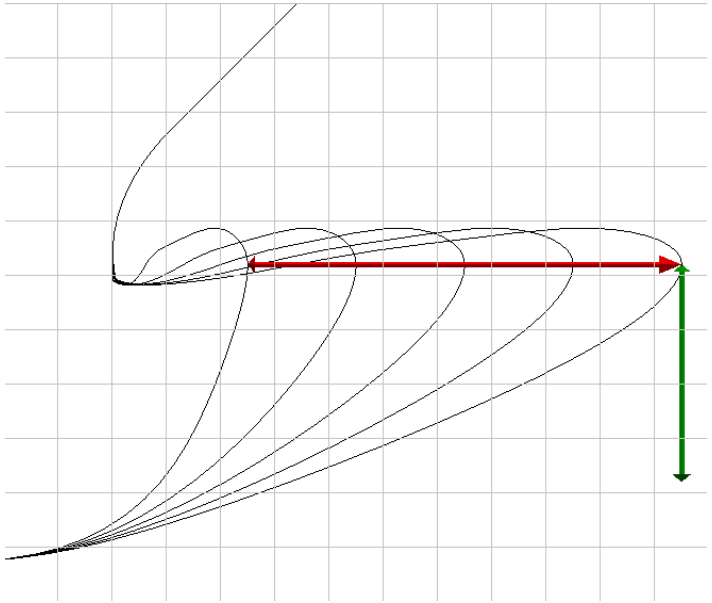
Results

** Numerical values are confidential*

Two-design-variables



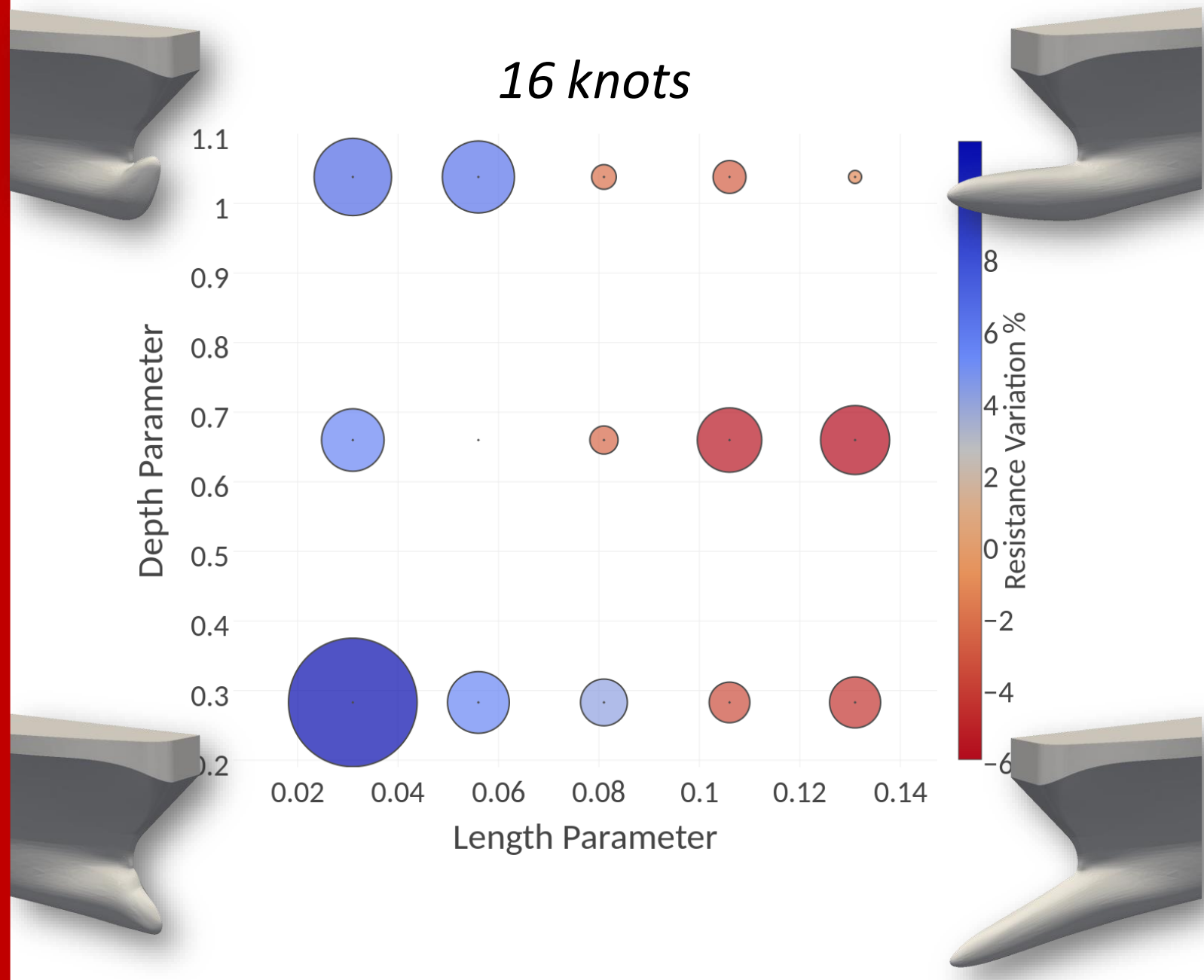




Results

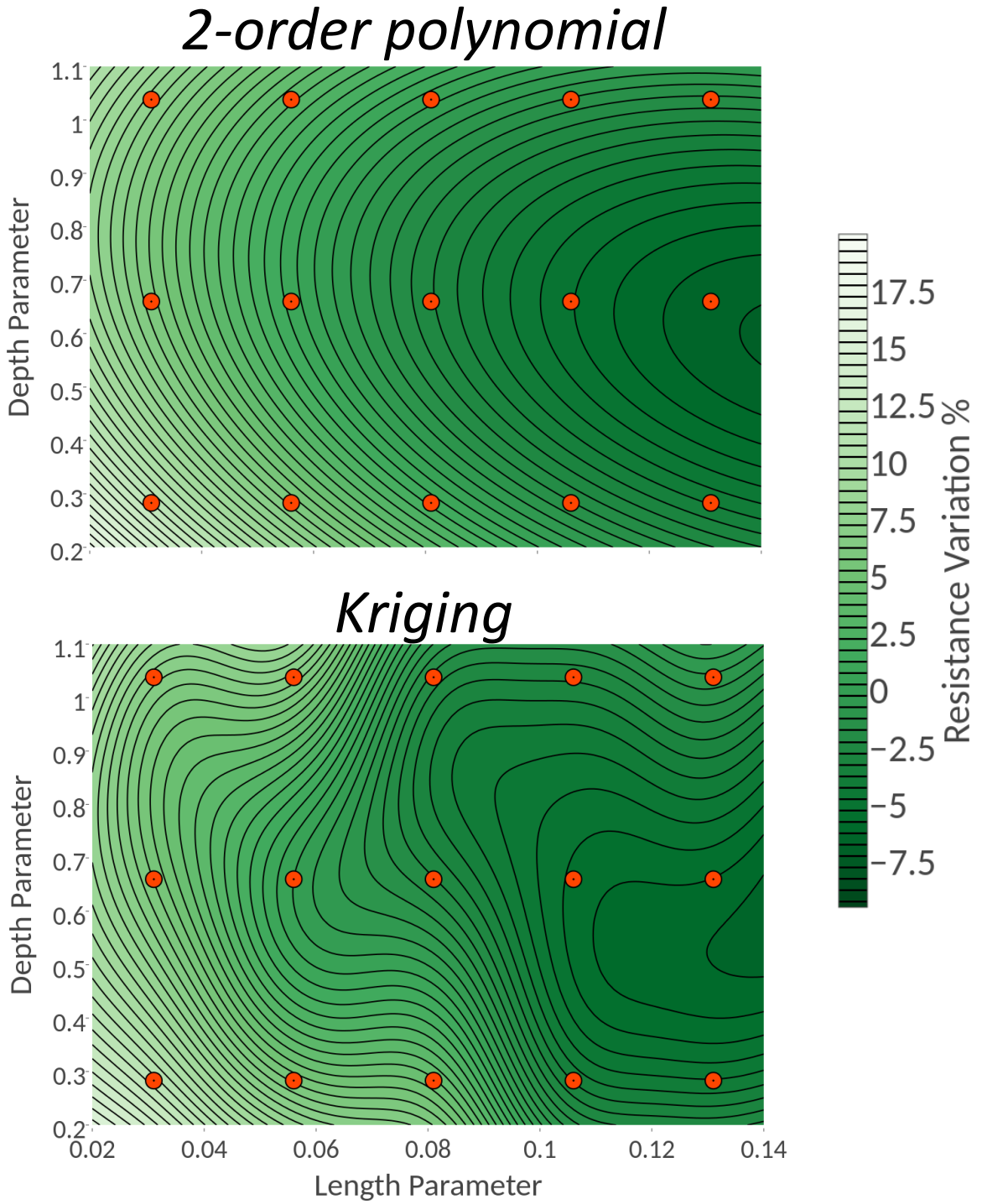
** Numerical values are confidential*

Two-design-variables



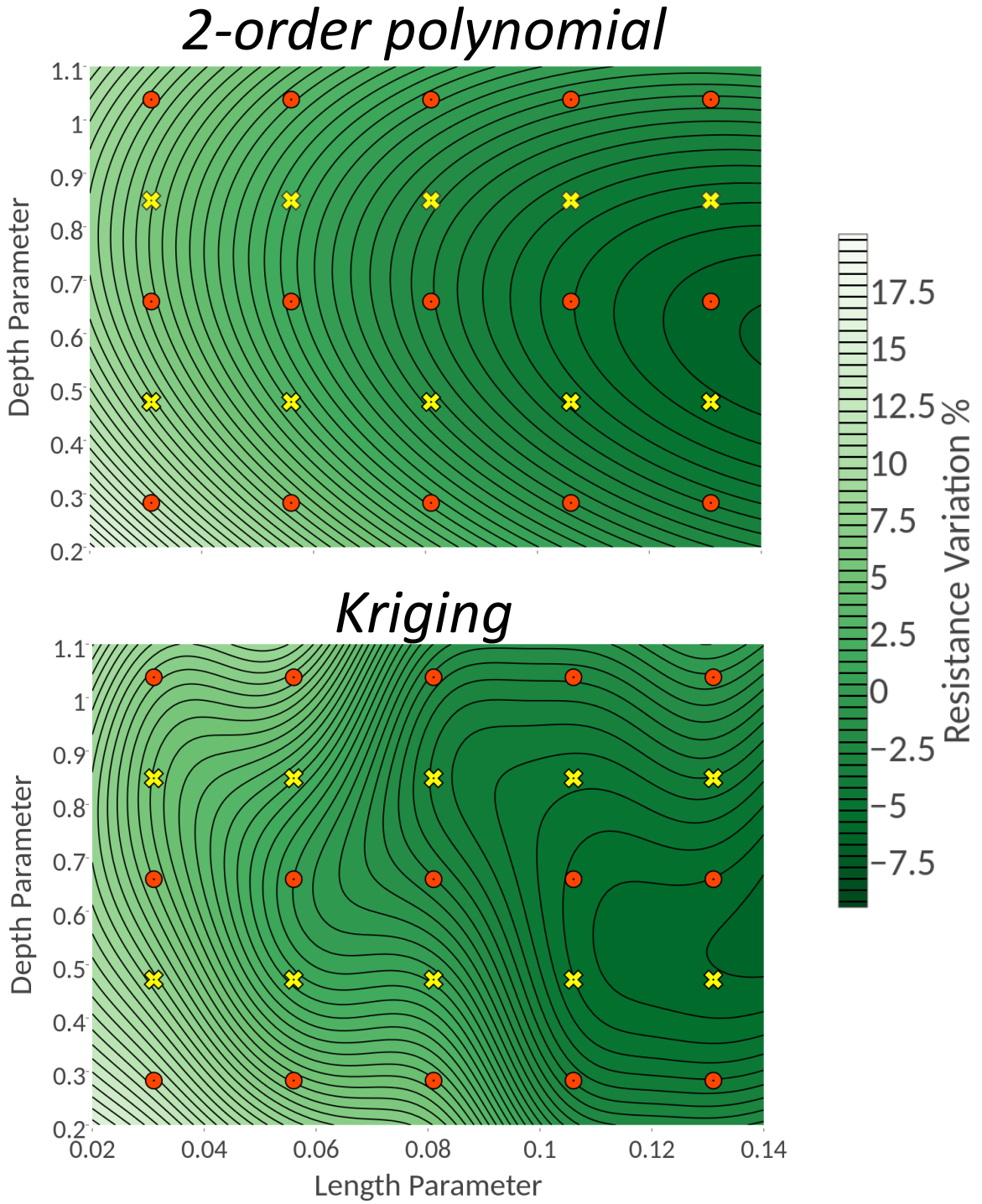
Results

** Numerical values are confidential*

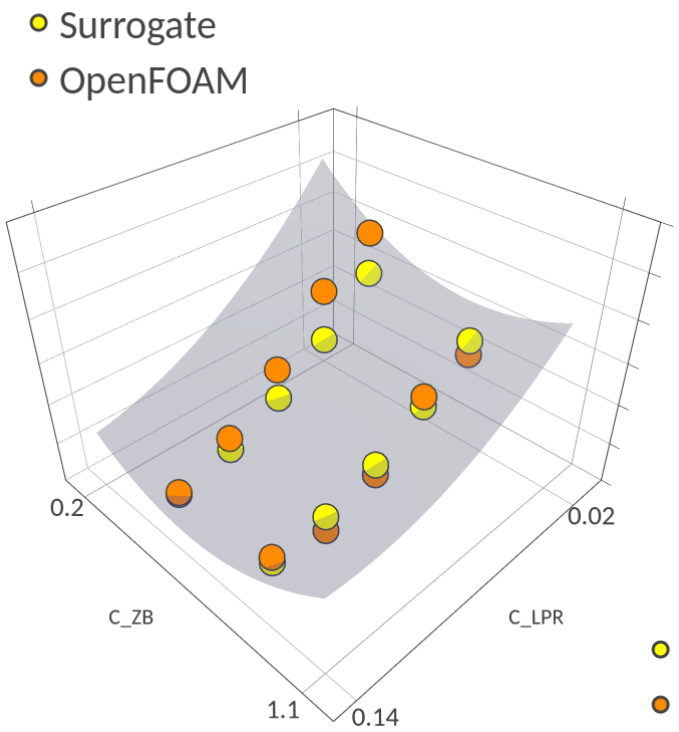


Results

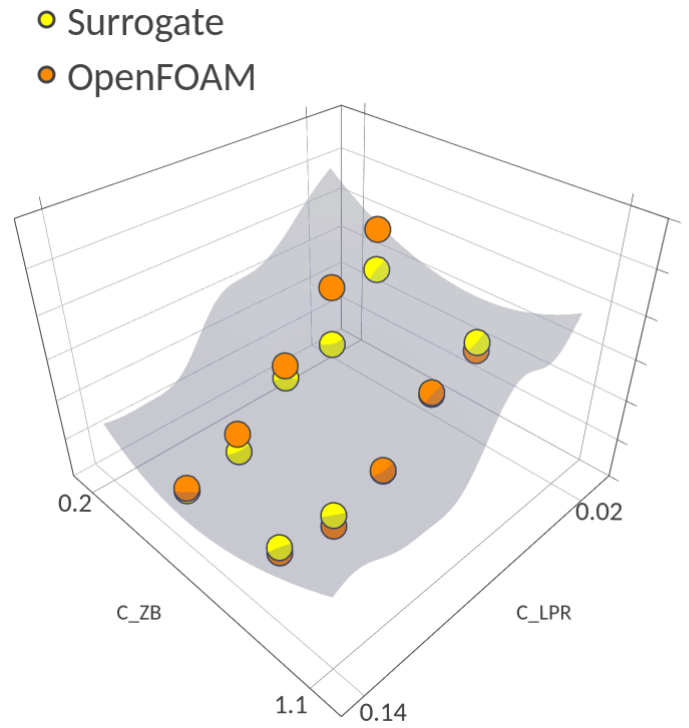
** Numerical values are confidential*



Results



2-order Polynomial



Kriging

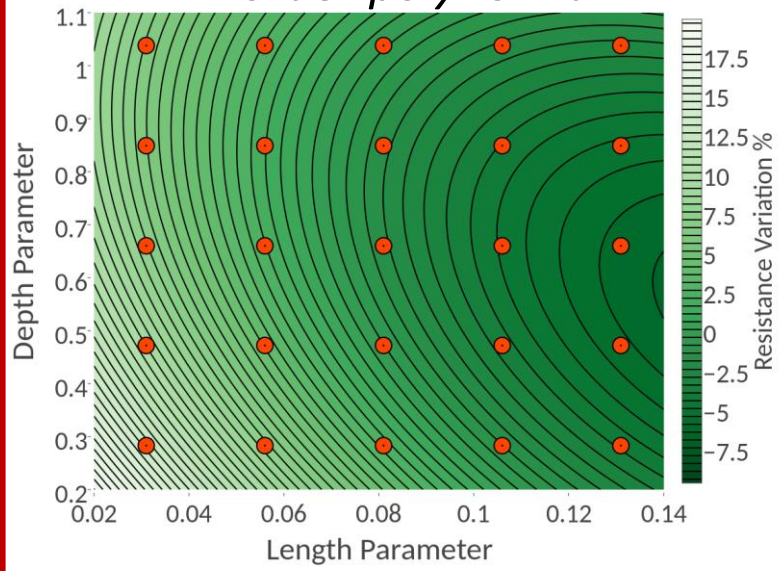
** Numerical values are confidential*

Results

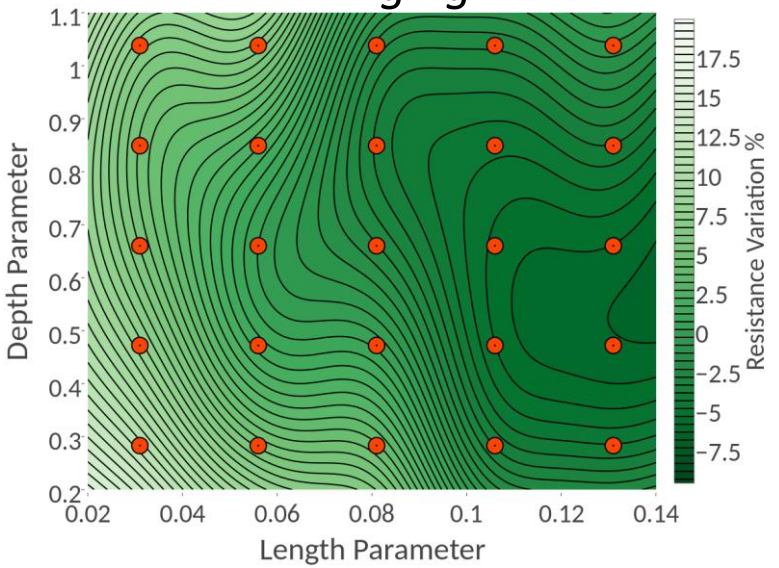
** Numerical values are confidential*

Two-design-variables: infilling

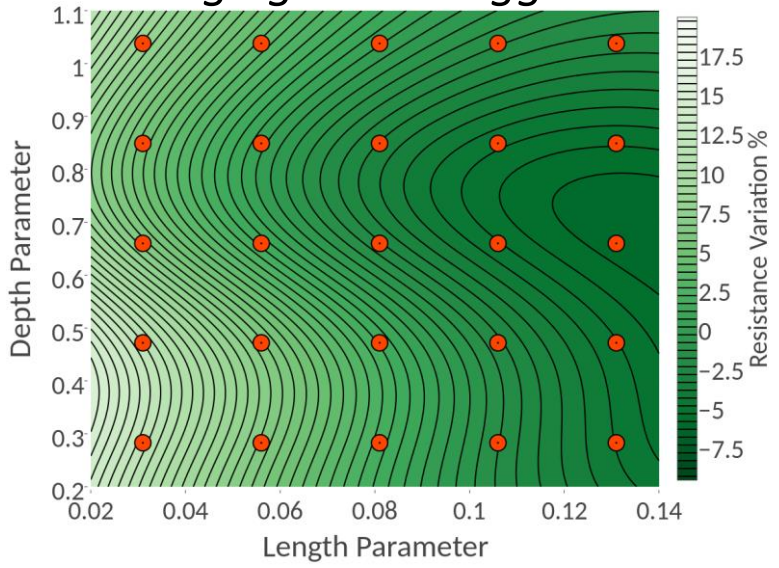
2-order polynomial



Kriging



Kriging with "nugget"

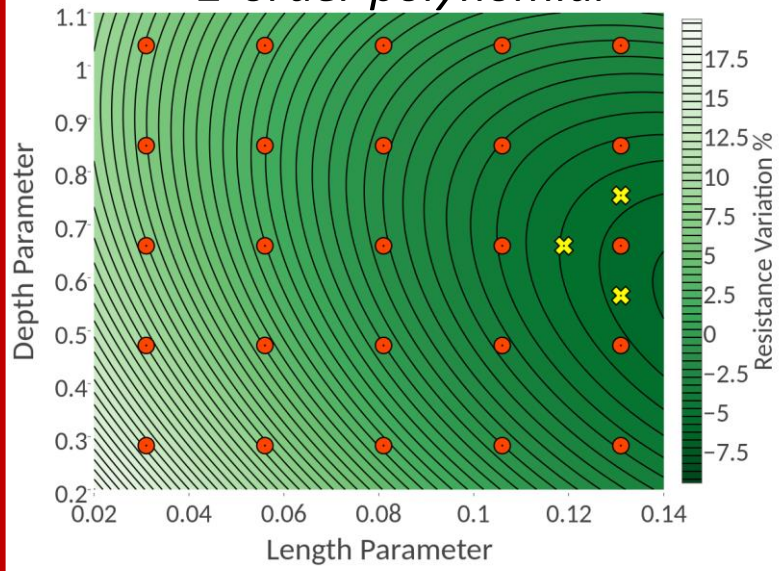


Results

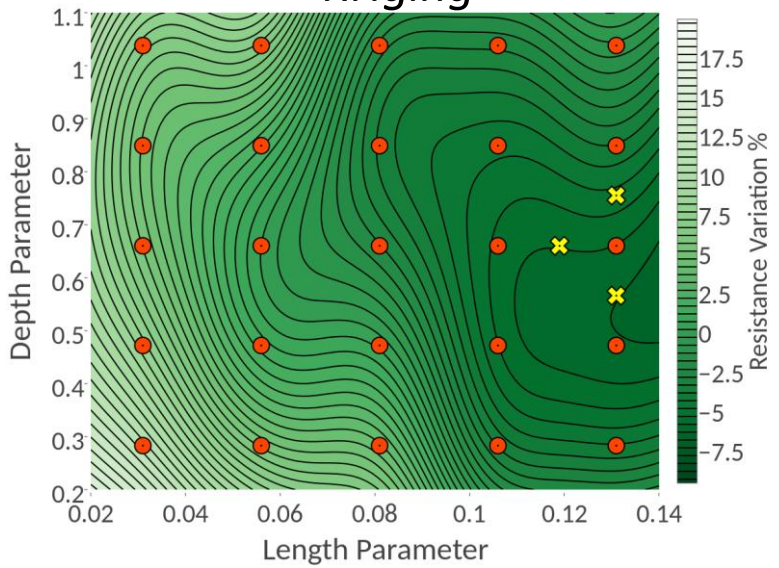
** Numerical values are confidential*

Two-design-variables: infilling

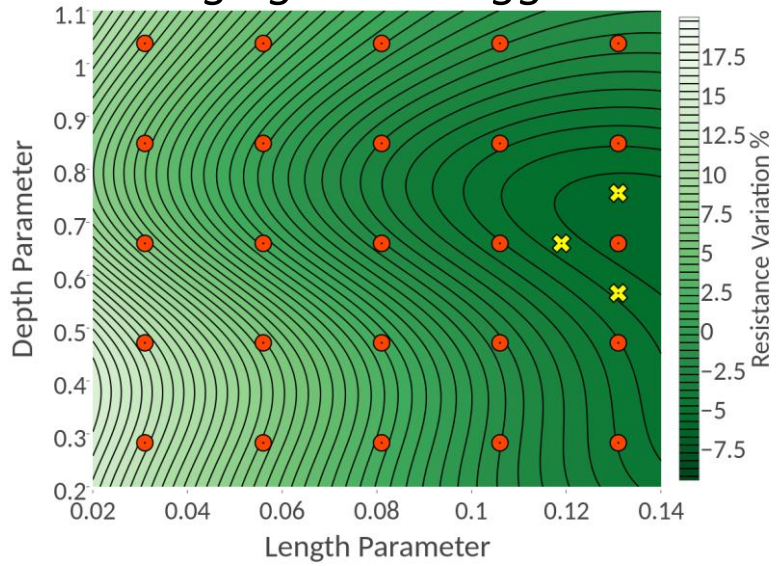
2-order polynomial



Kriging



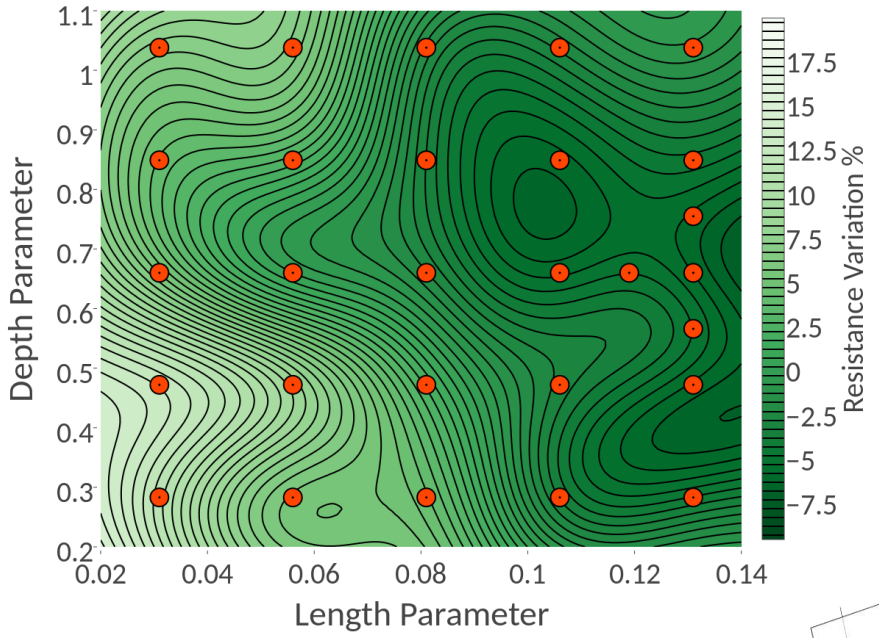
Kriging with "nugget"



Results

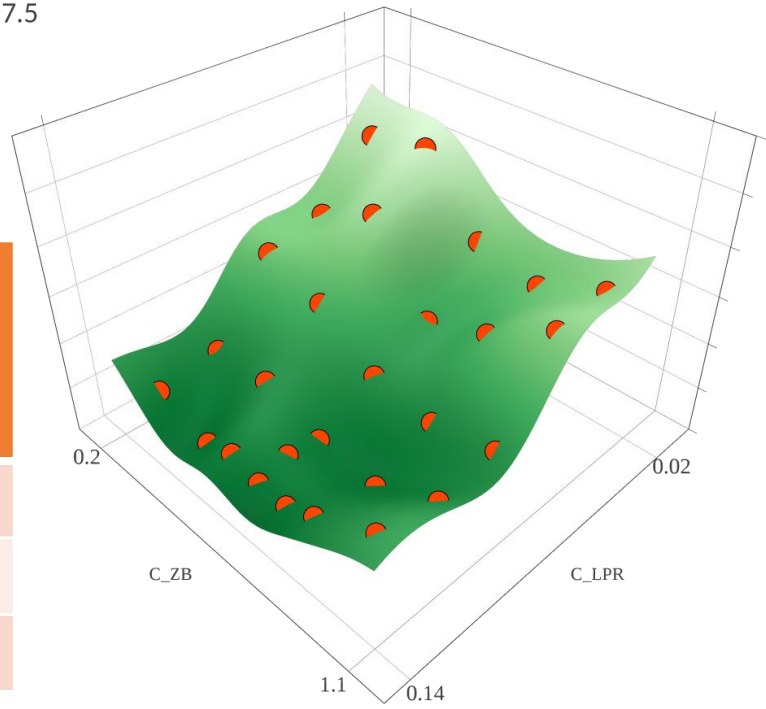
** Numerical values are confidential*

Two-design-variables: infilling



Kriging

C_{LPR}	C_{ZB}	ΔR% Kriging	ΔR% OpenFOAM
0.119	0.660	-5.77	-6.14
0.131	0.566	-6.48	-6.04
0.131	0.755	-6.07	-6.65

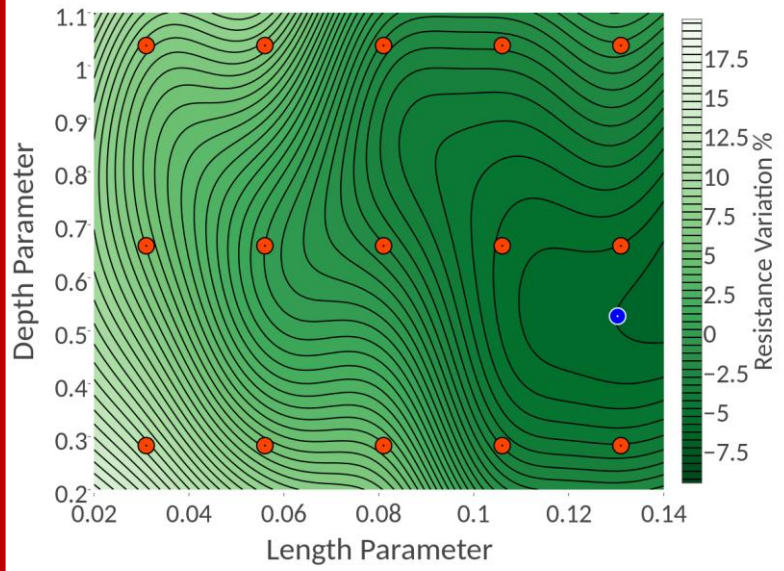


Results

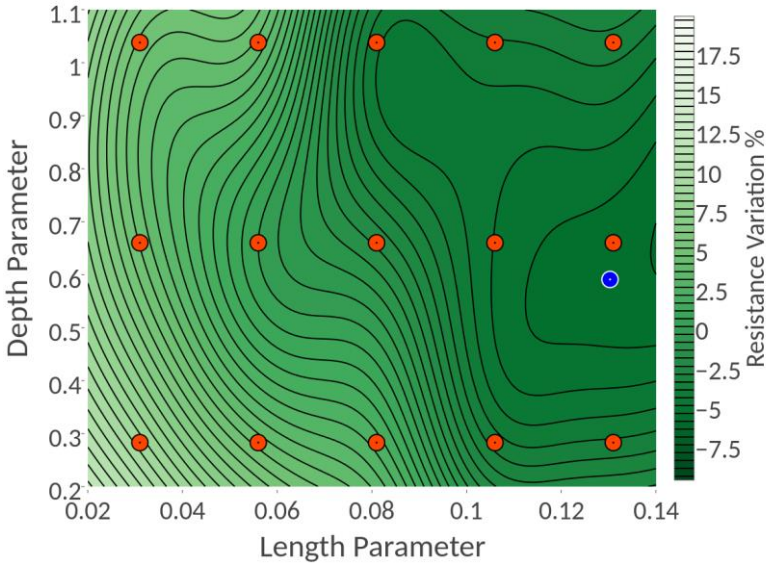
** Numerical values are confidential*

An approach to "robust" solution

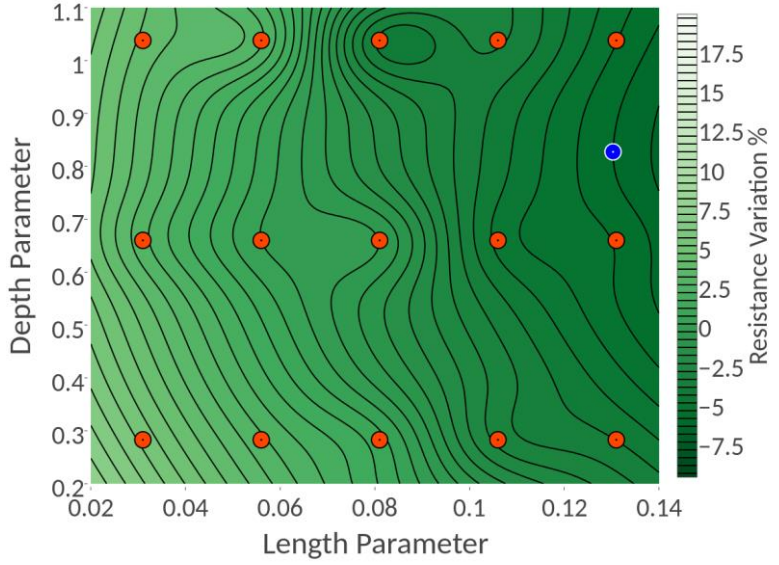
16 knots



18 knots



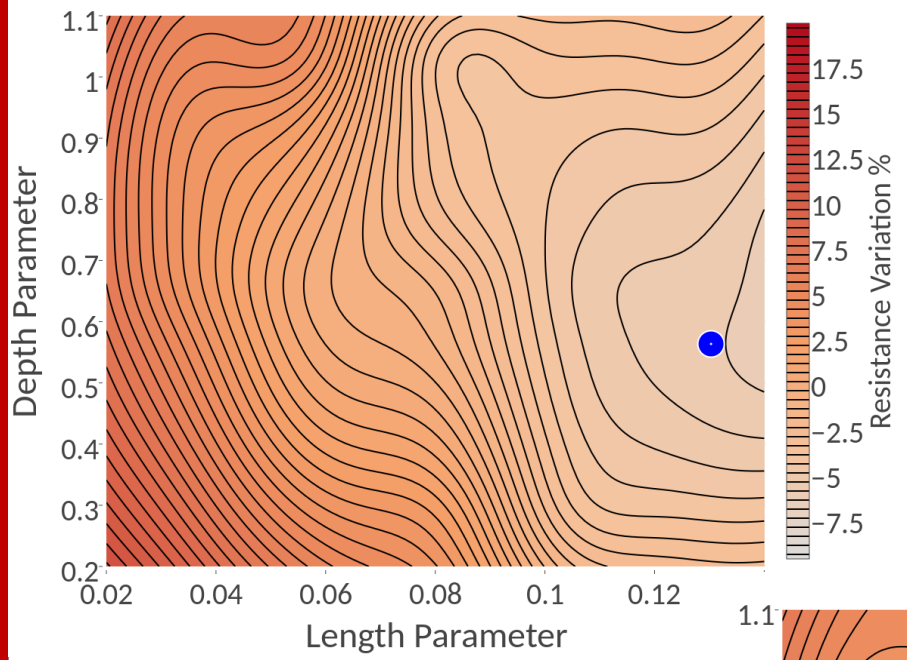
20 knots



Results

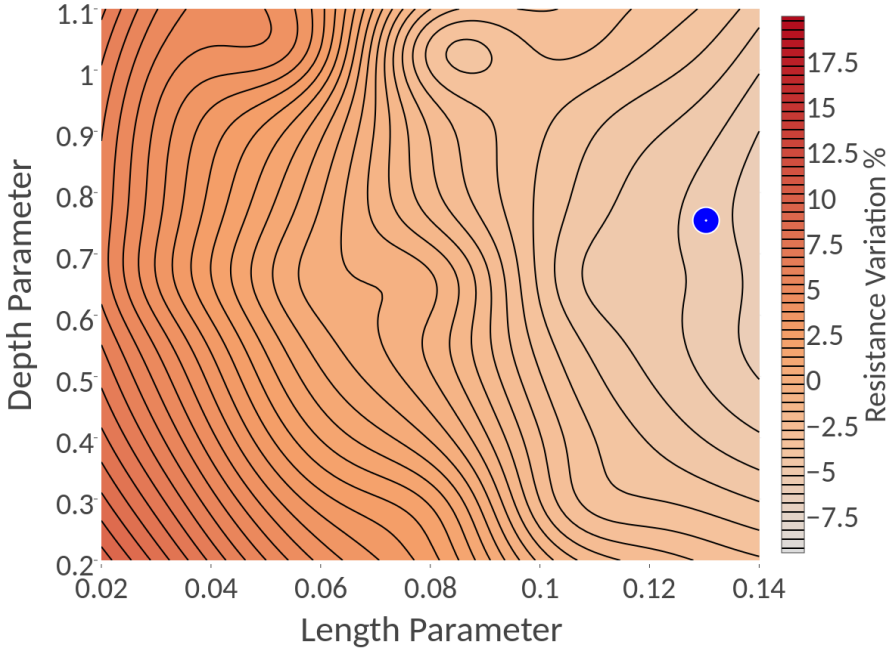
** Numerical values are confidential*

An approach to "robust" solution



Same weights

Preference for 20 knots



Conclusions

- A completely free optimization framework has been built
- The application to a naval case has given interesting and satisfactory results

Future Developments

- Dictionaries improvement
- More than two variables
  - Better parametrization
  - Latin Hypercubes Sampling
- Mesh morphing
- Dynamic simulations
- Multi-objective optimization

That's all

Thanks for attention