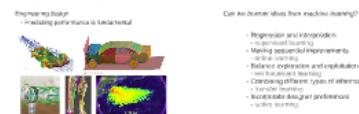
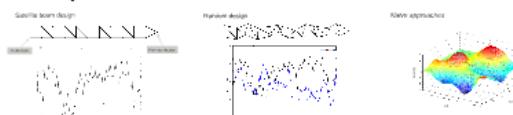


# Deadline Driven Design

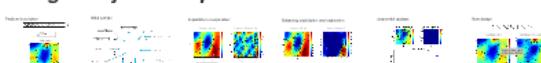
## Engineering Design Problems



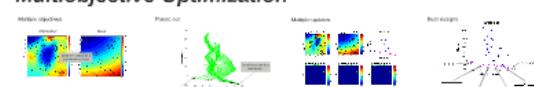
## Example Problem



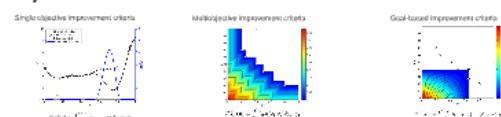
## Single Objective Optimization



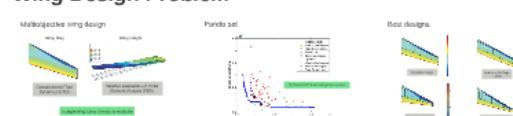
## Multiobjective Optimization



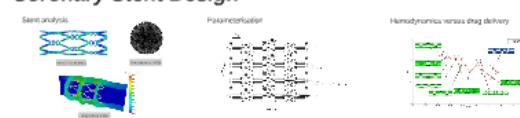
## Improvement Criteria



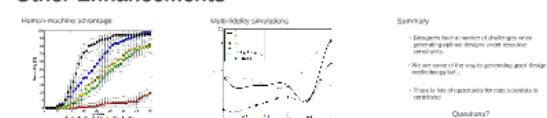
## Wing Design Problem



## Coronary Stent Design

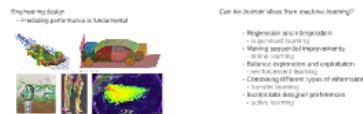


## Other Enhancements

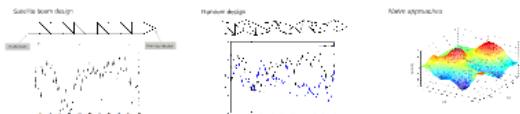


# Deadline Driven Design

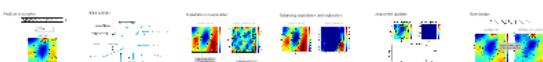
## Engineering Design Problems



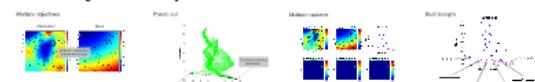
## Example Problem



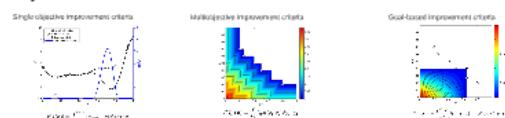
## Single Objective Optimization



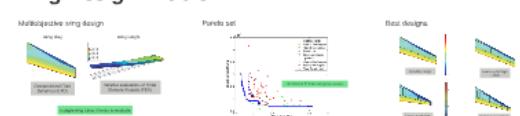
## Multiobjective Optimization



## Improvement Criteria



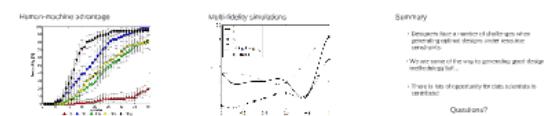
## Wing Design Problem



## Coronary Stent Design



## Other Enhancements

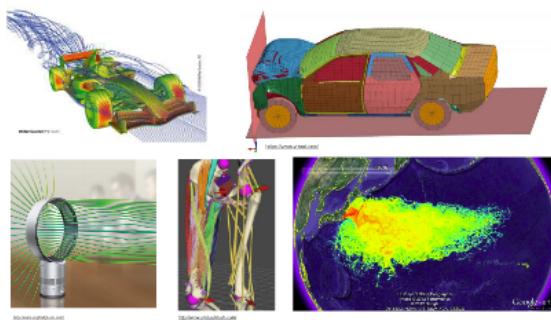


# Deadline Driven Design

## *Engineering Design Problems*

### Engineering design

- Predicting performance is fundamental

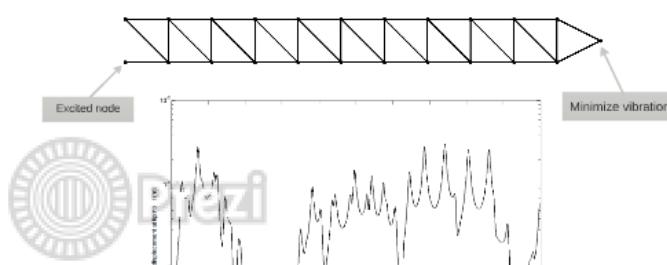


*Can we borrow ideas from machine learning?*

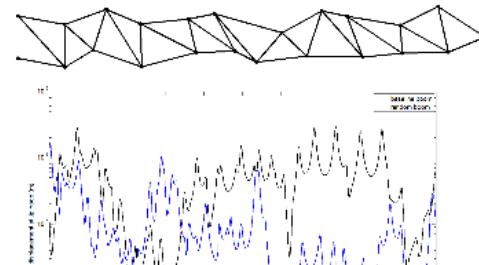
- Regression and interpolation
  - supervised learning
- Making sequential improvements
  - online learning
- Balance exploration and exploitation
  - reinforcement learning
- Combining different types of information
  - transfer learning
- Incorporate designer preferences
  - active learning

## *Example Problem*

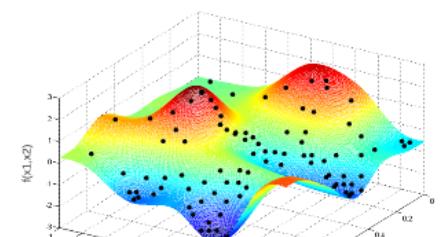
### Satellite boom design



### Random design

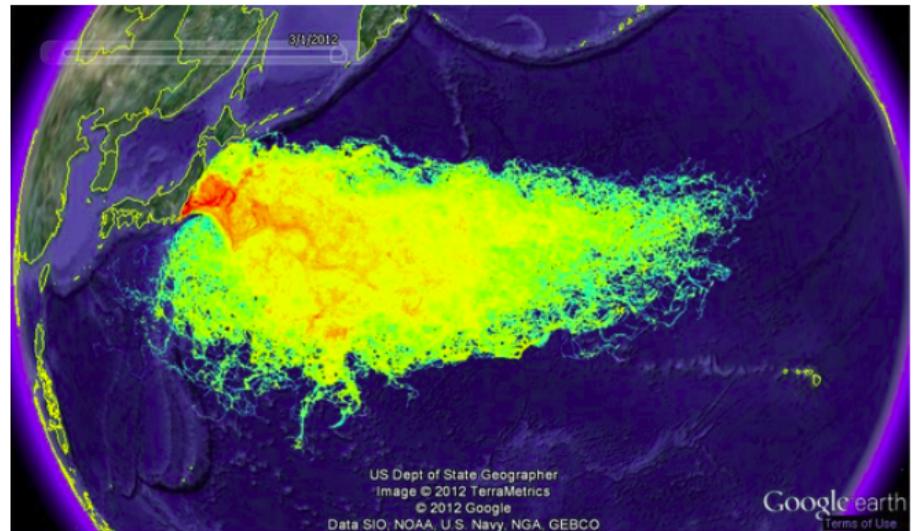
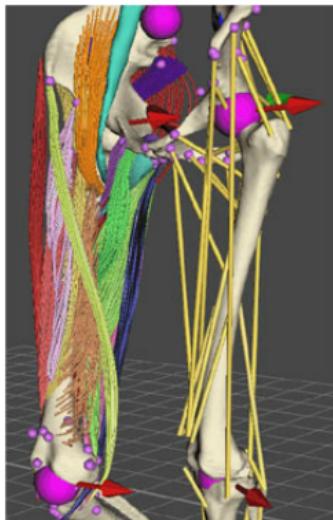
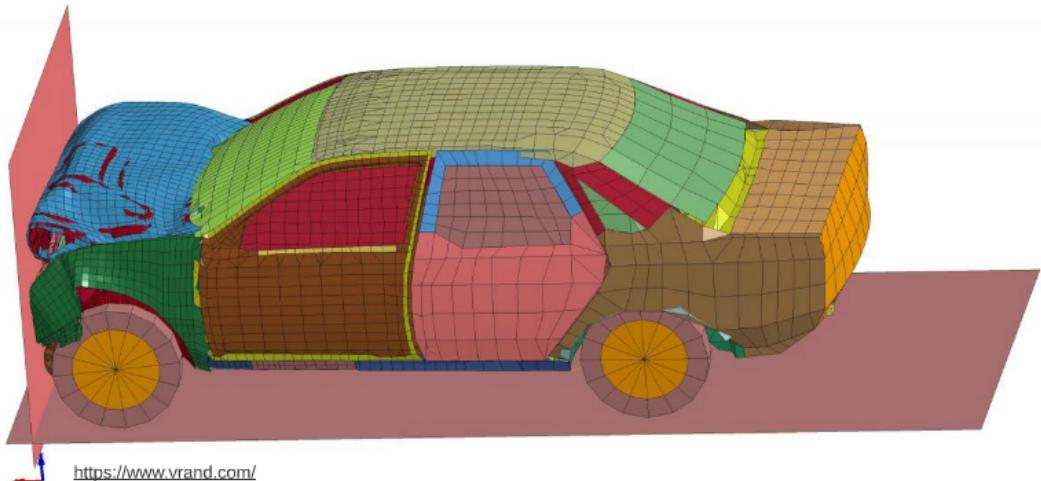
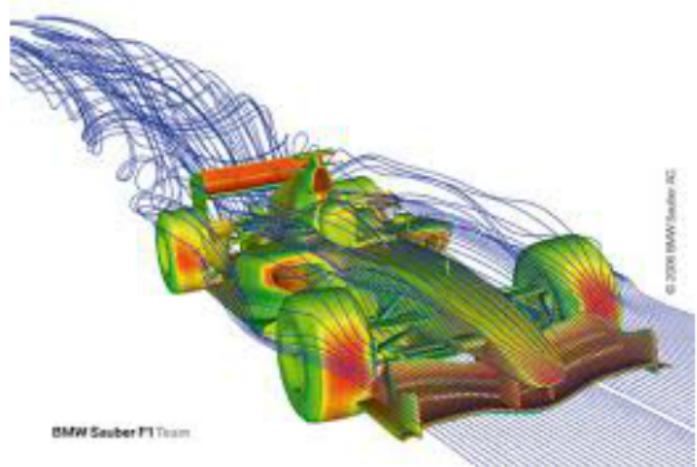


### Naive approaches



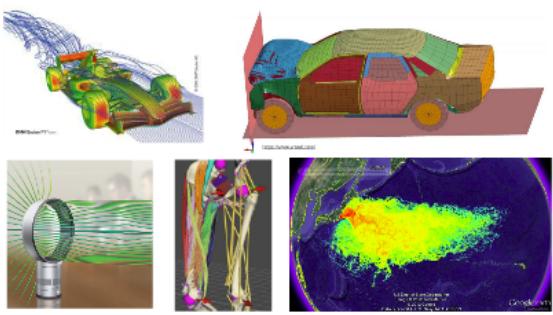
# Engineering design

- Predicting performance is fundamental



# *Can we borrow ideas from machine learning?*

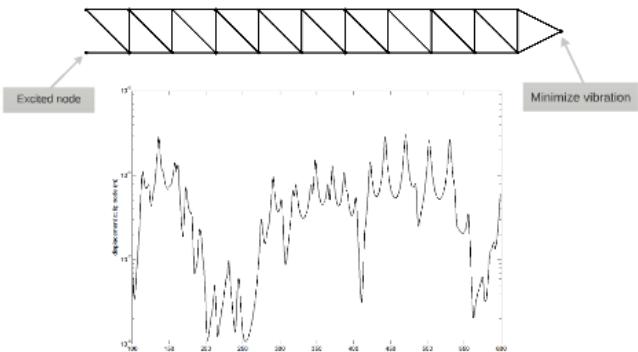
- Regression and interpolation
  - supervised learning
- Making sequential improvements
  - online learning
- Balance exploration and exploitation
  - reinforcement learning
- Combining different types of information
  - transfer learning
- Incorporate designer preferences
  - active learning



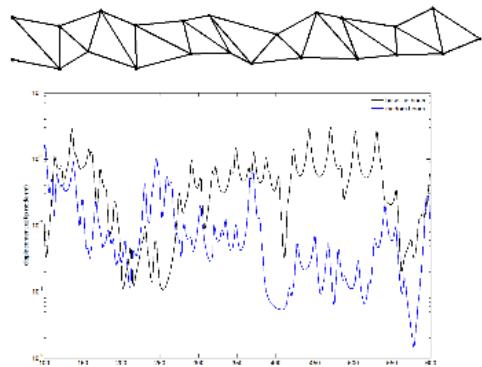
- Regression and interpolation
  - supervised learning
- Making sequential improvements
  - online learning
- Balance exploration and exploitation
  - reinforcement learning
- Combining different types of information
  - transfer learning
- Incorporate designer preferences
  - active learning

## Example Problem

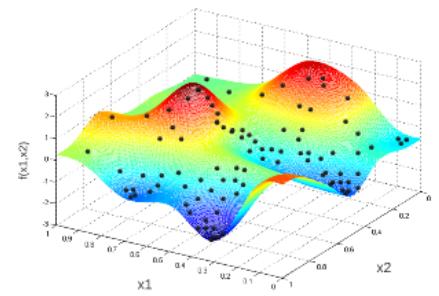
Satellite boom design



Random design

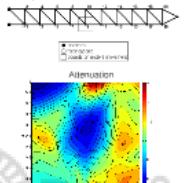


Naive approaches

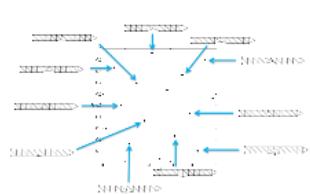


## Single Objective Optimization

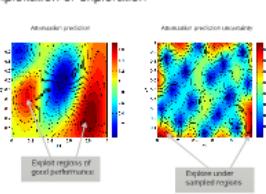
Problem description



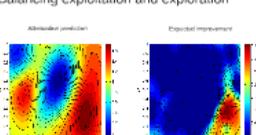
Initial sample



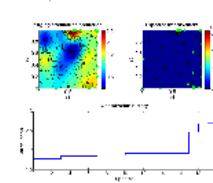
Exploitation or exploration



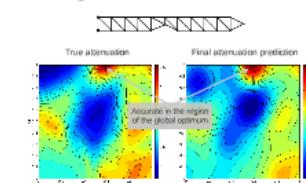
Balancing exploitation and exploration



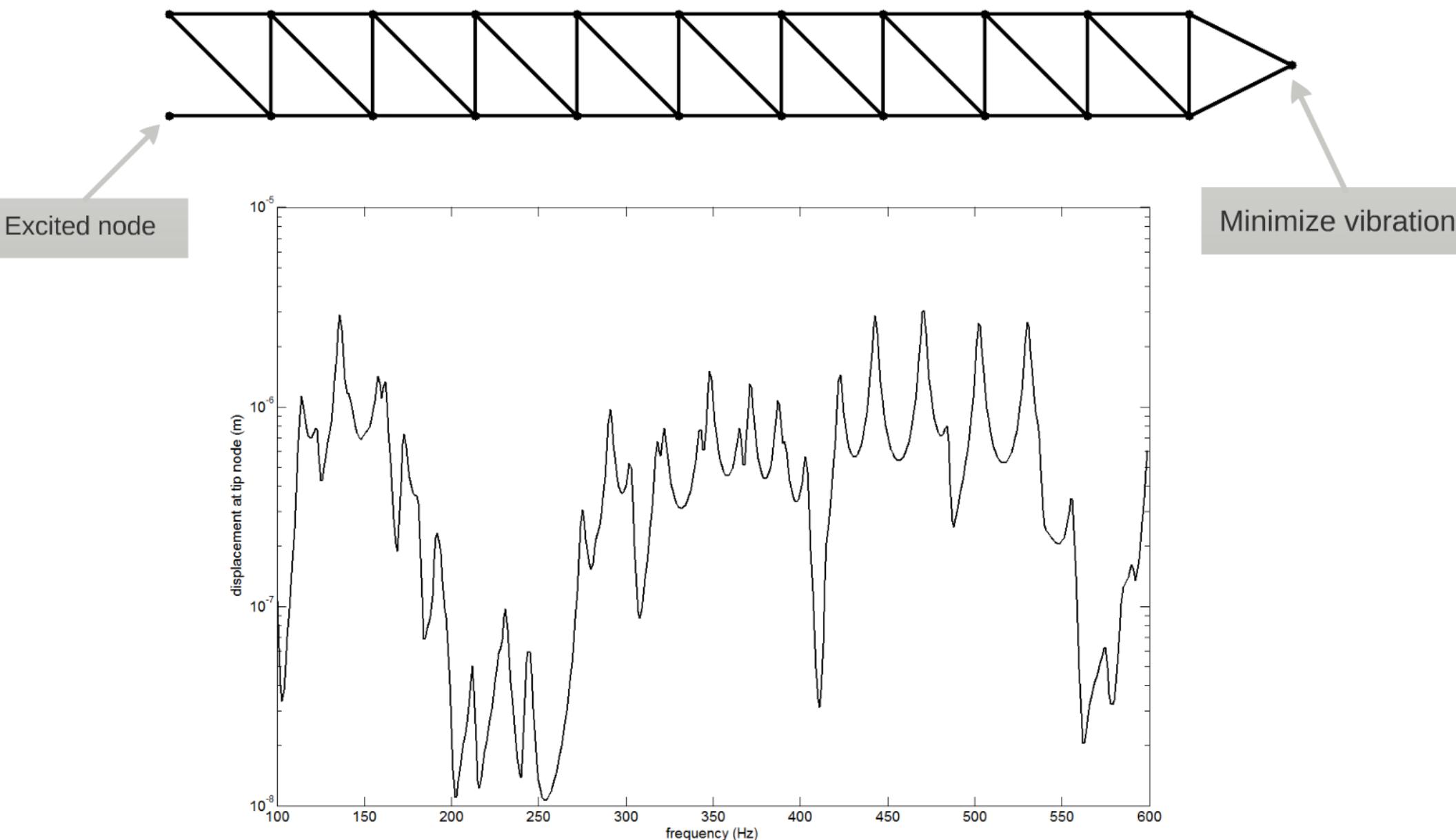
Sequential updates



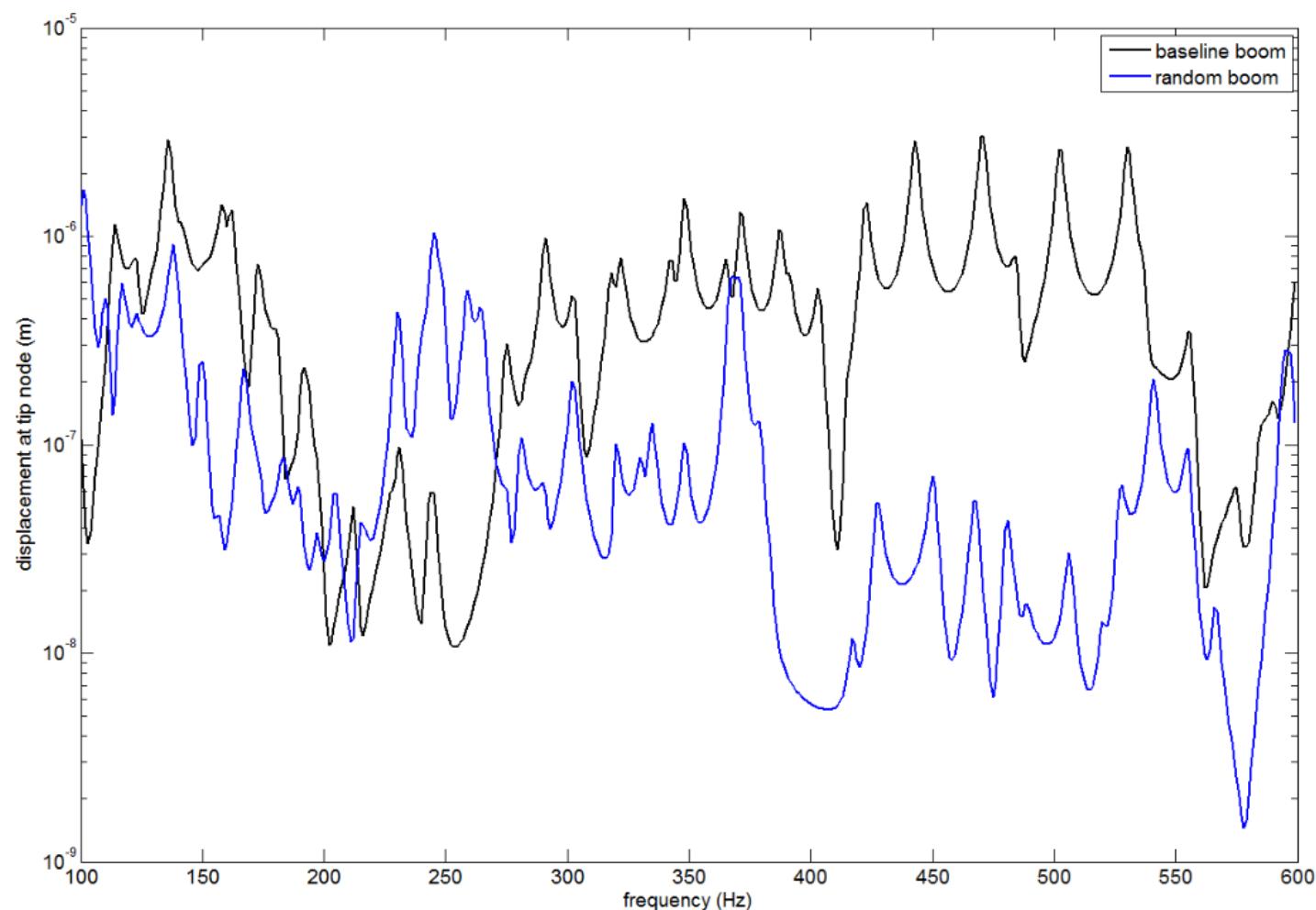
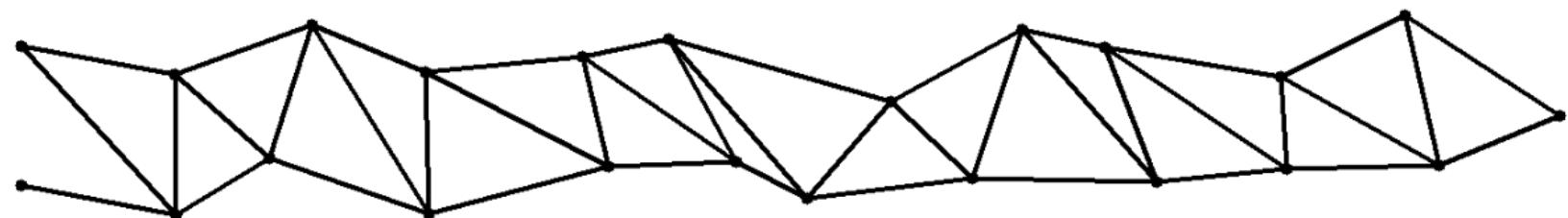
Best design



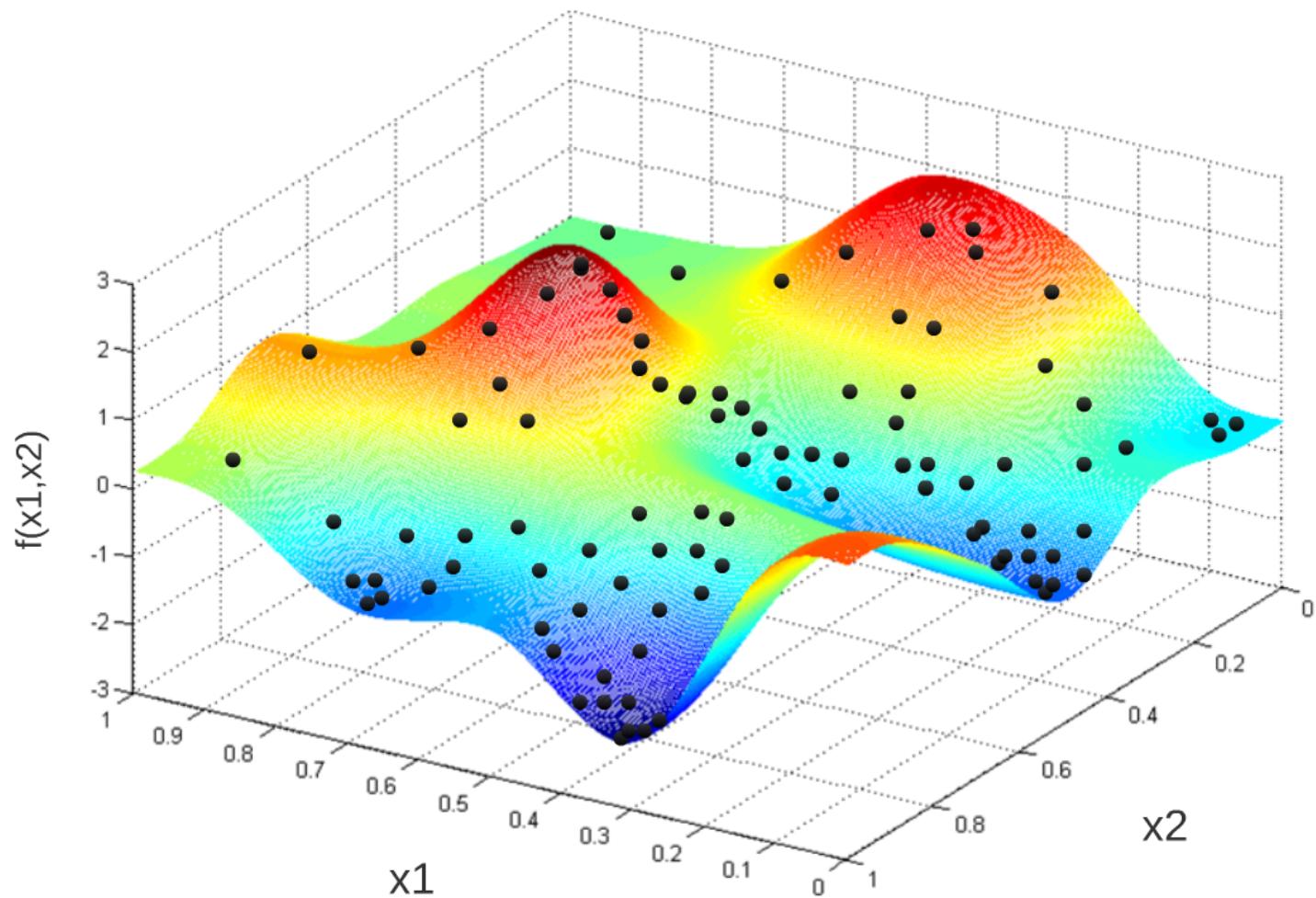
# Satellite boom design



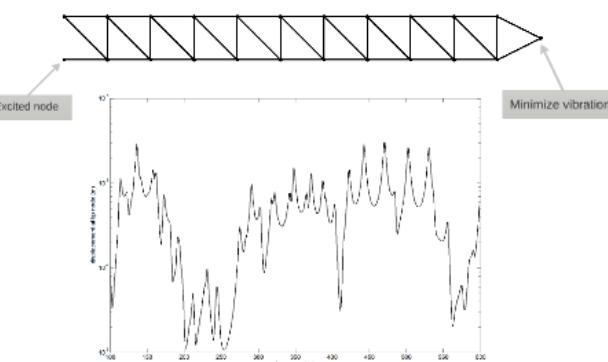
# Random design



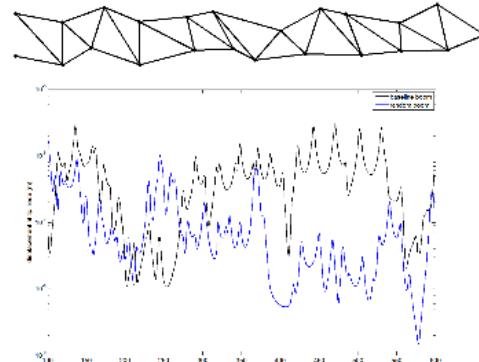
# *Naive approaches*



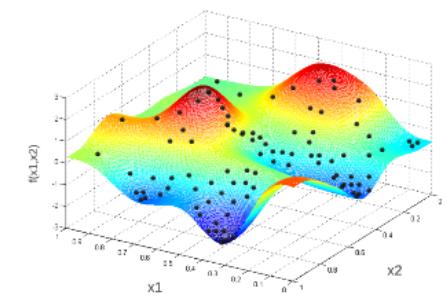
## Satellite boom design



## Random design

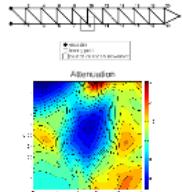


## Naive approaches

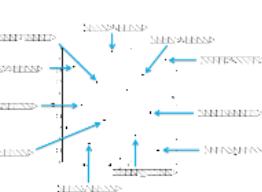


# Single Objective Optimization

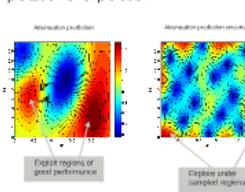
## Problem description



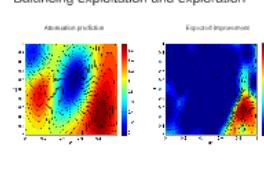
## Initial sample



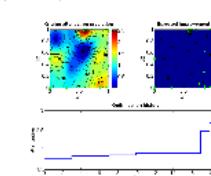
## Exploitation or exploration



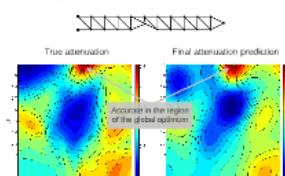
## Balancing exploitation and exploration



## Sequential updates

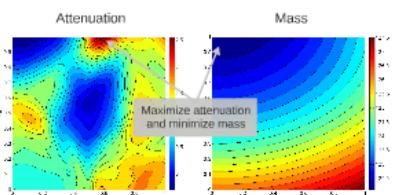


## Best design

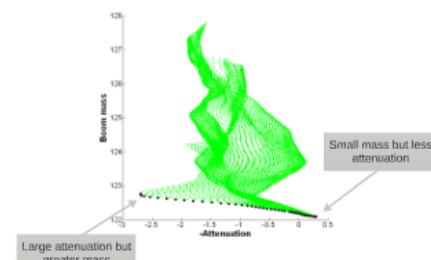


# Multiobjective Optimization

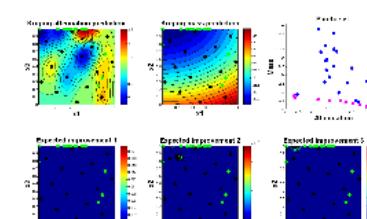
## Multiple objectives



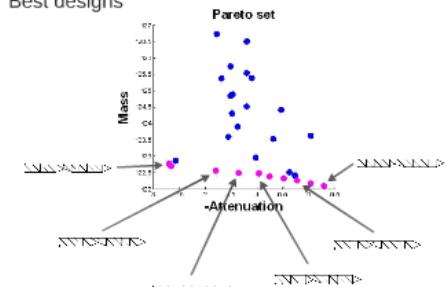
## Pareto set



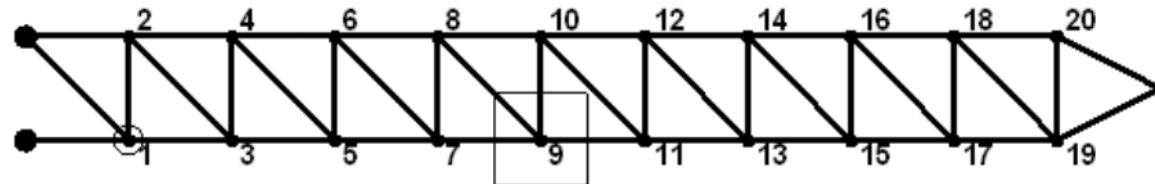
## Multiple updates



## Best designs

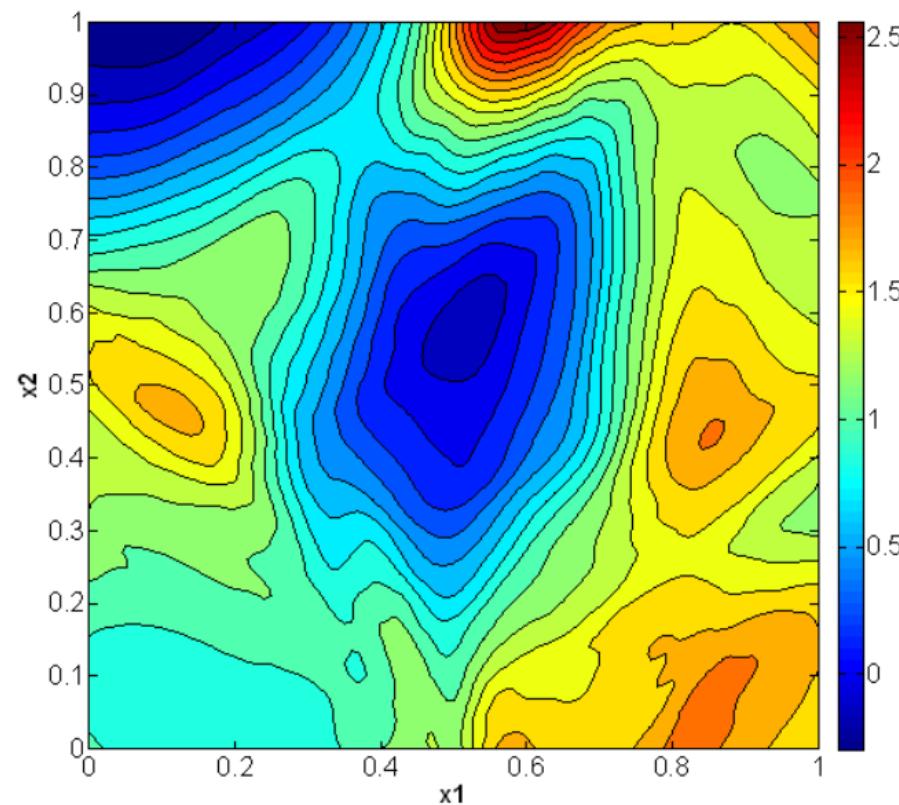


# Problem description

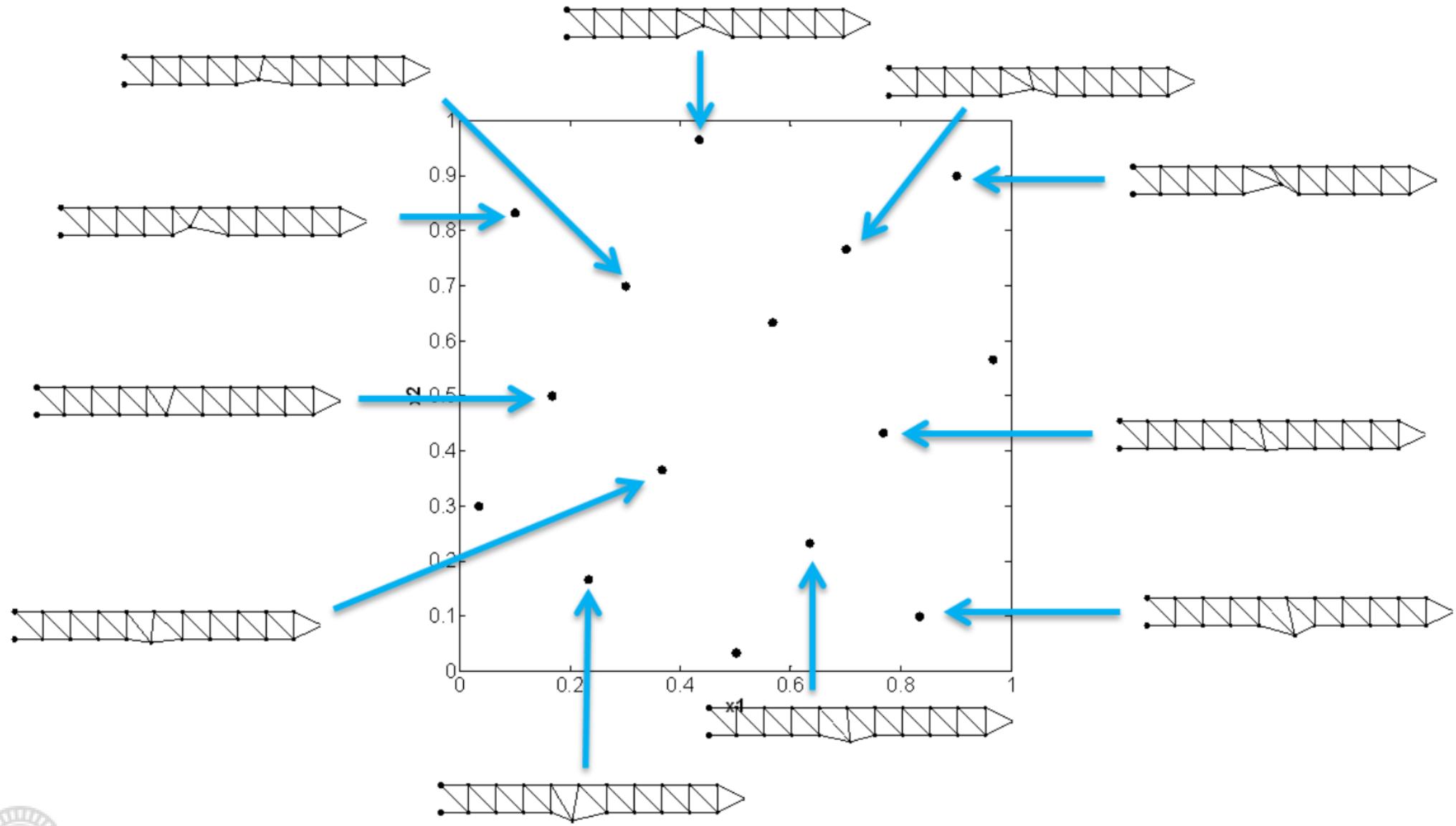


● encastre  
○ forcing point  
□ bounds on node 9 movement

## Attenuation

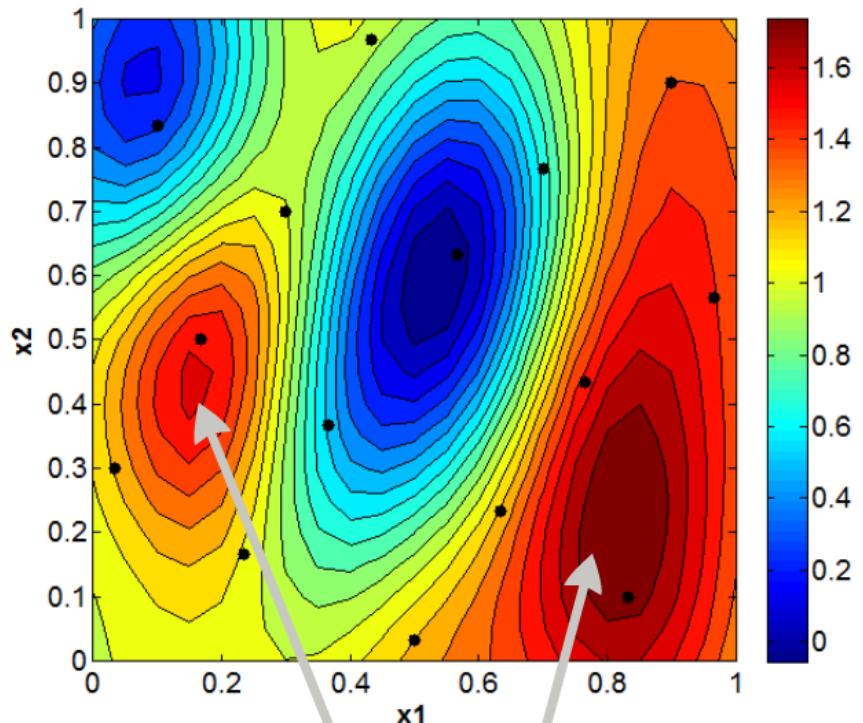


# Initial sample



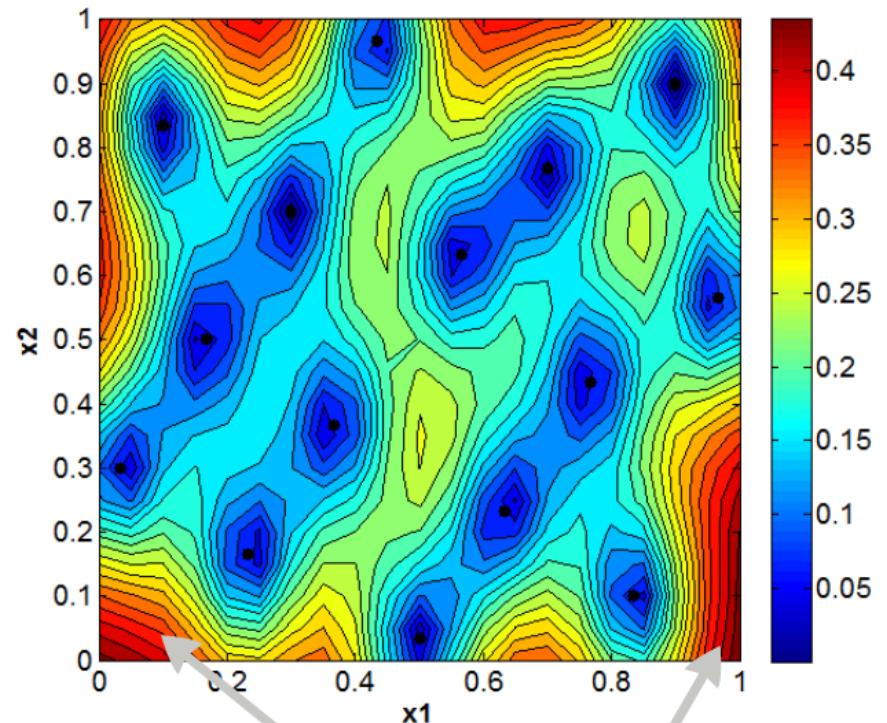
# Exploitation or exploration

Attenuation prediction



Exploit regions of  
good performance

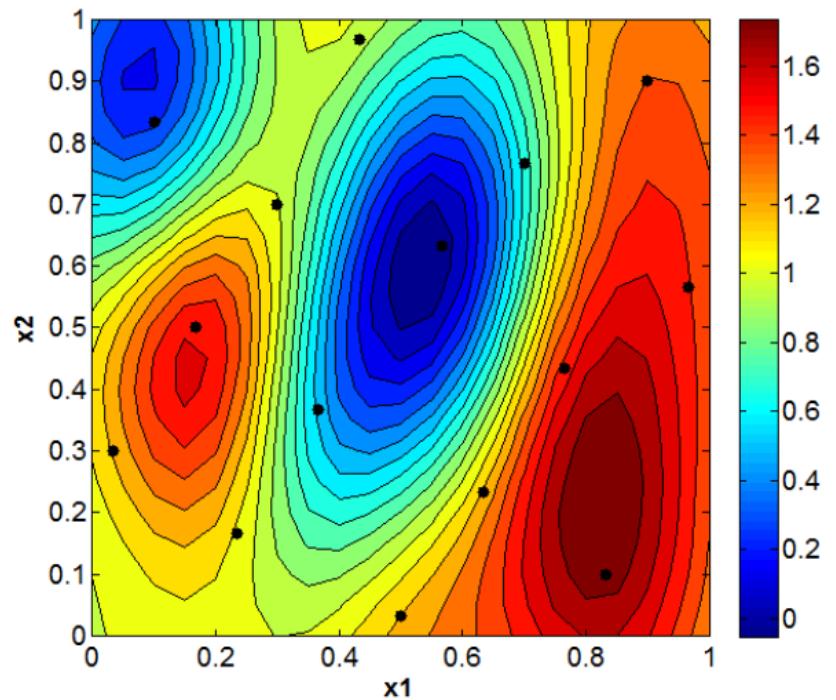
Attenuation prediction uncertainty



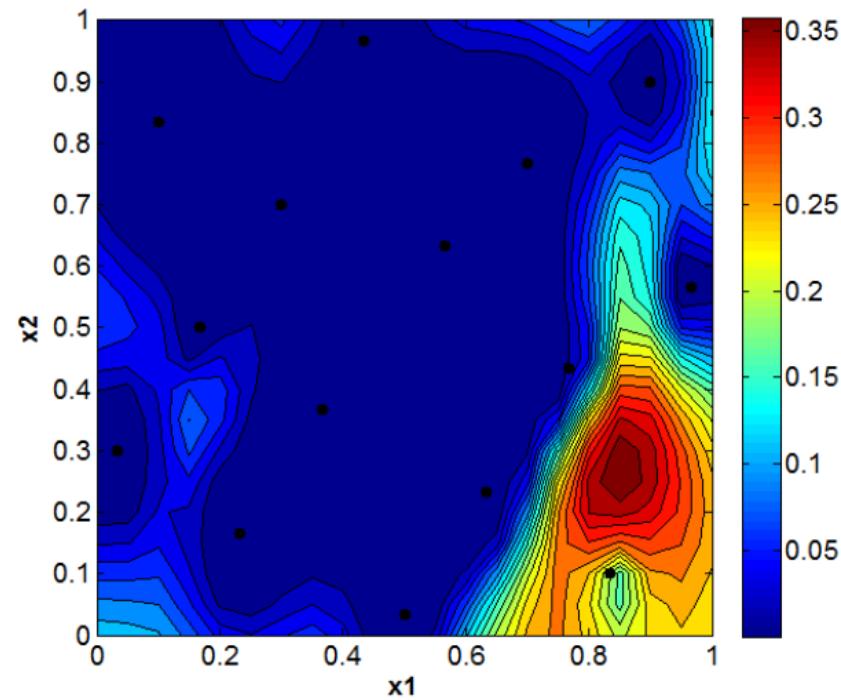
Explore under  
sampled regions

# Balancing exploitation and exploration

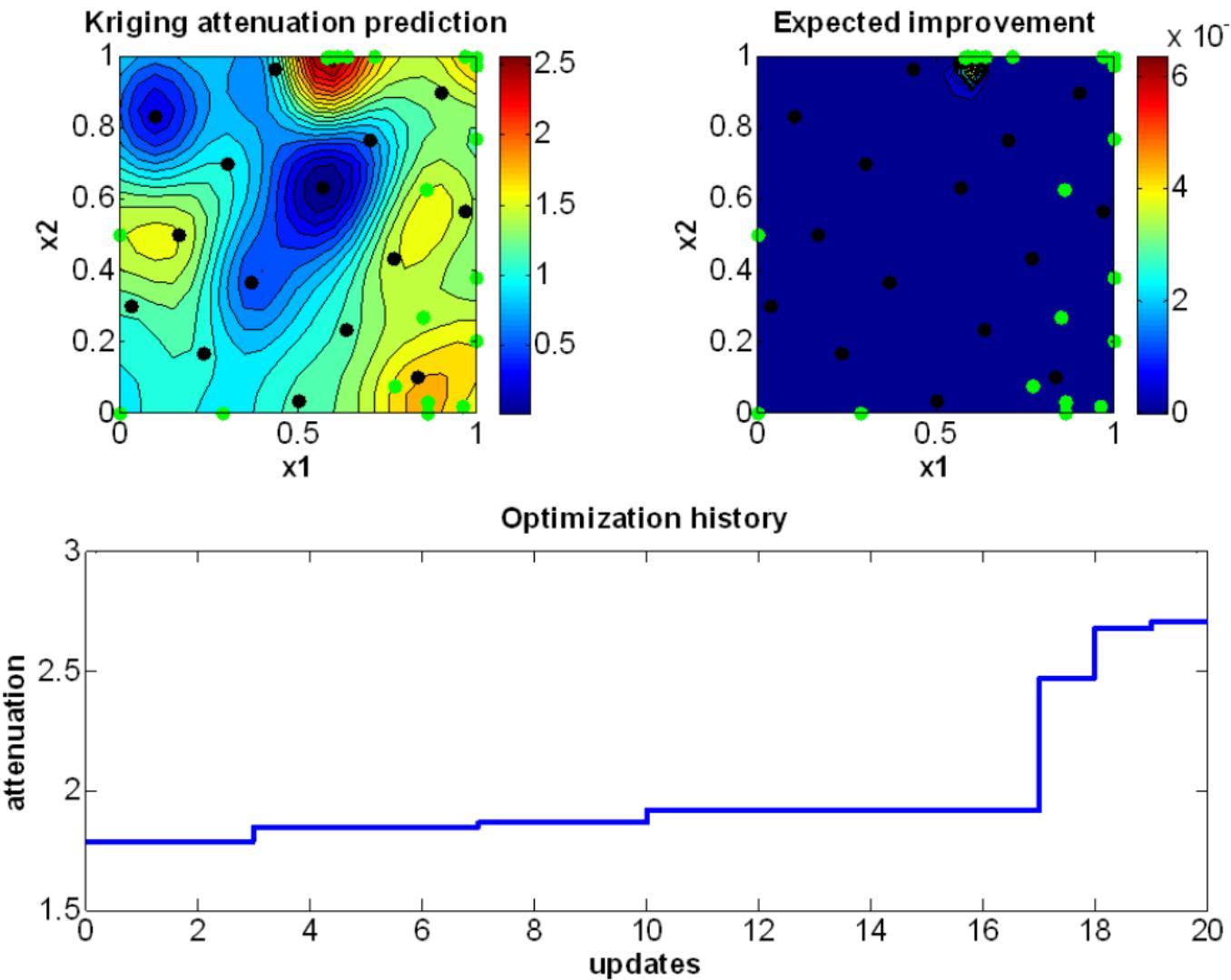
Attenuation prediction



Expected improvement



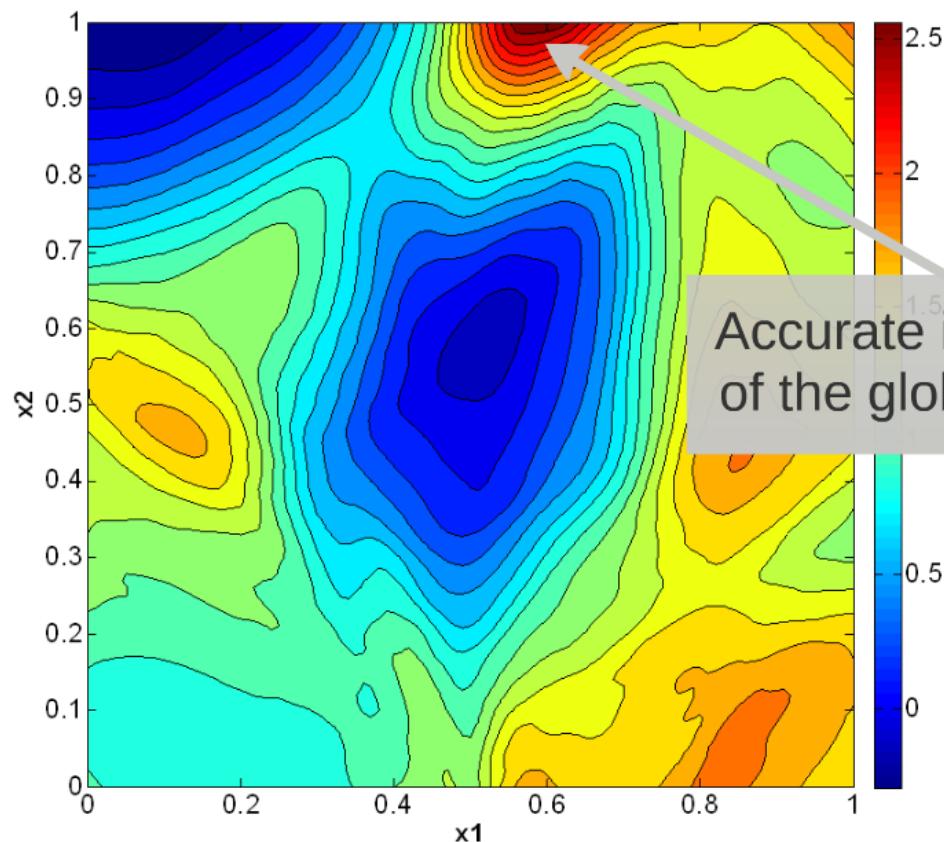
# Sequential updates



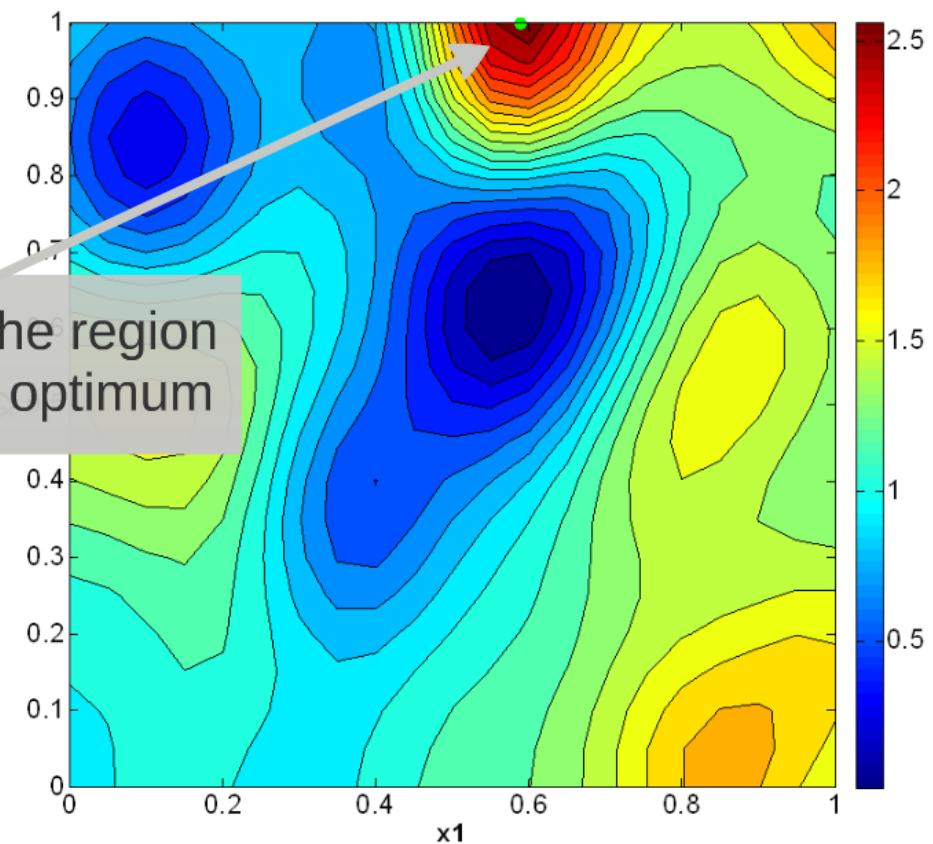
# Best design



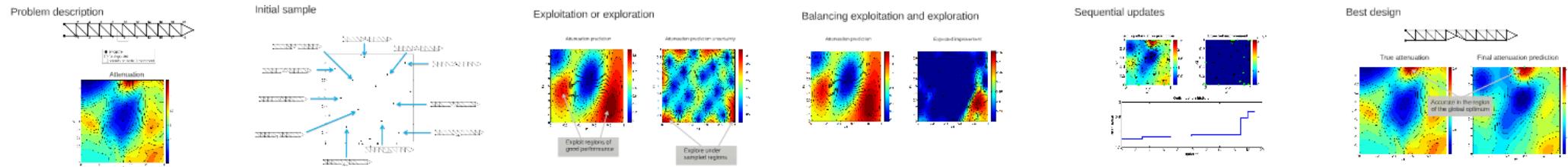
True attenuation



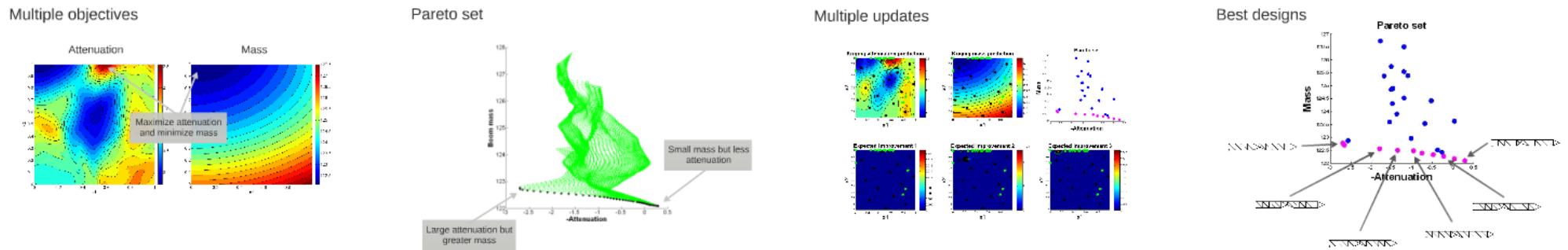
Final attenuation prediction



# Single Objective Optimization

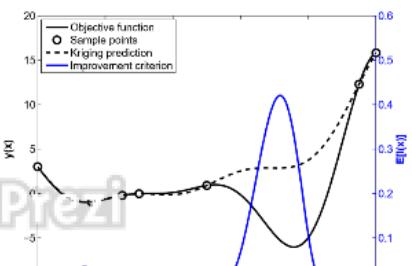


# Multiobjective Optimization

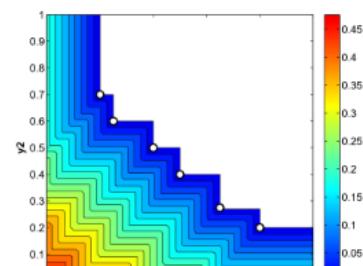


# Improvement Criteria

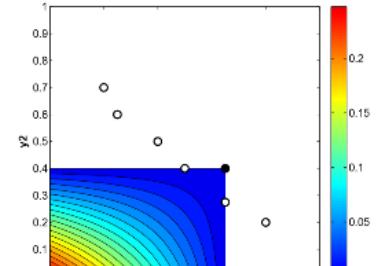
## Single objective improvement criteria



## Multiobjective improvement criteria

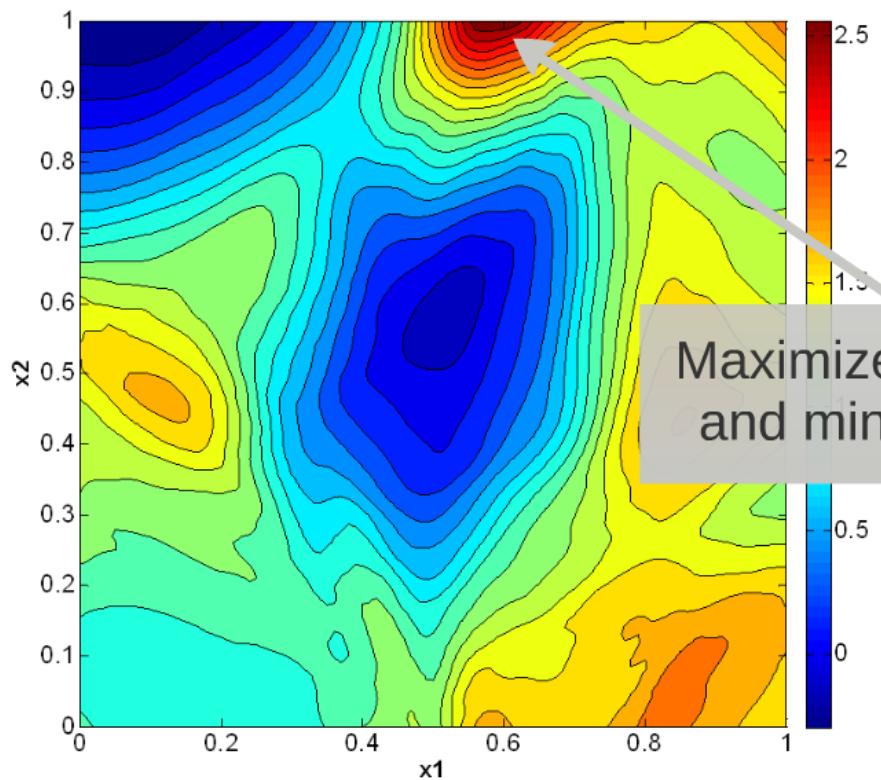


## Goal-based improvement criteria

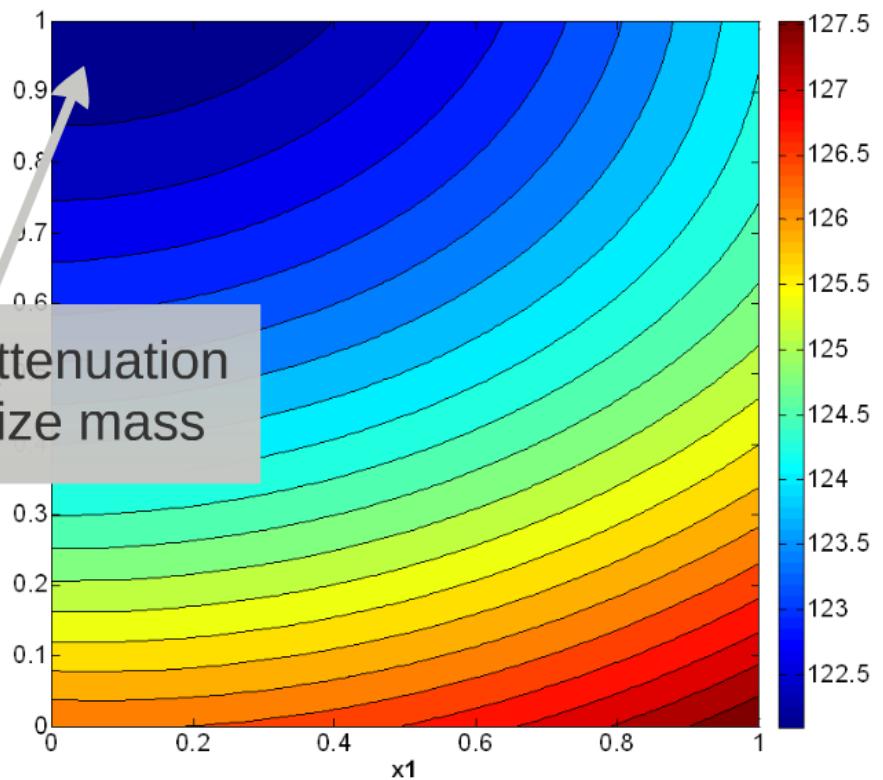


# Multiple objectives

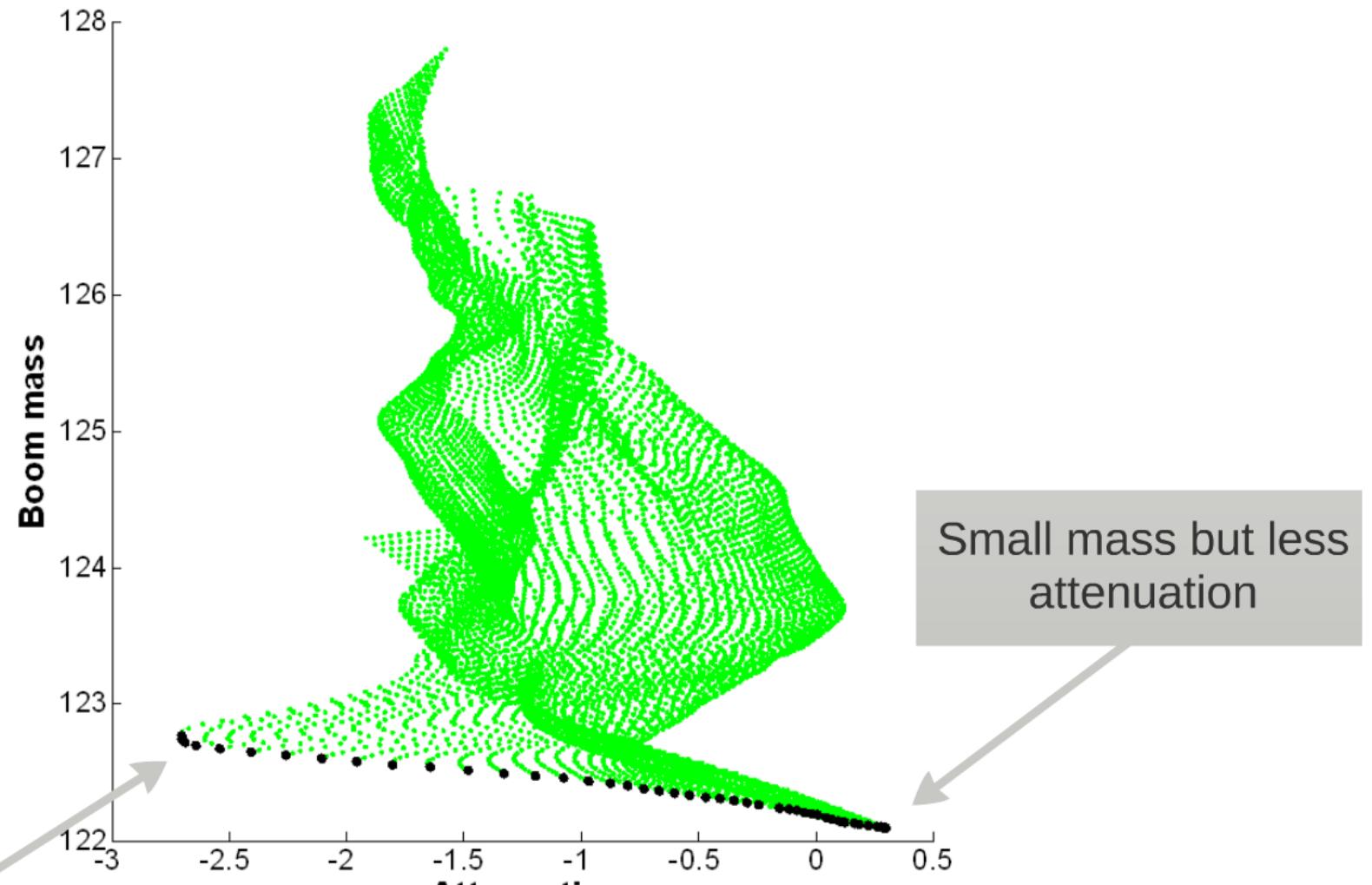
Attenuation



Mass



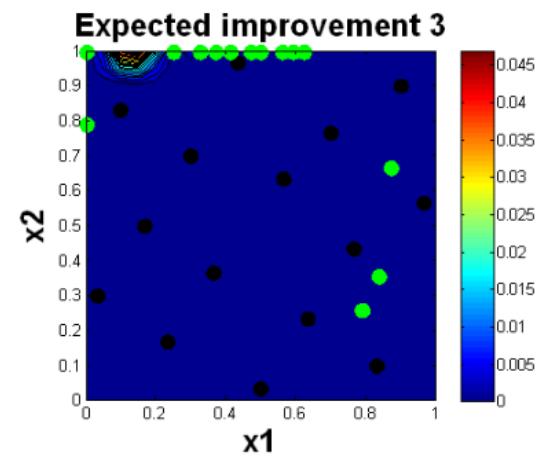
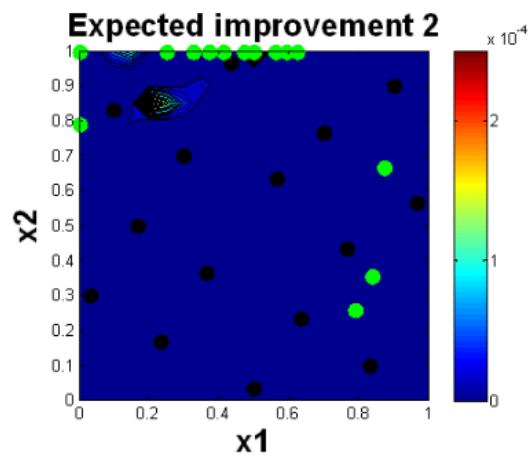
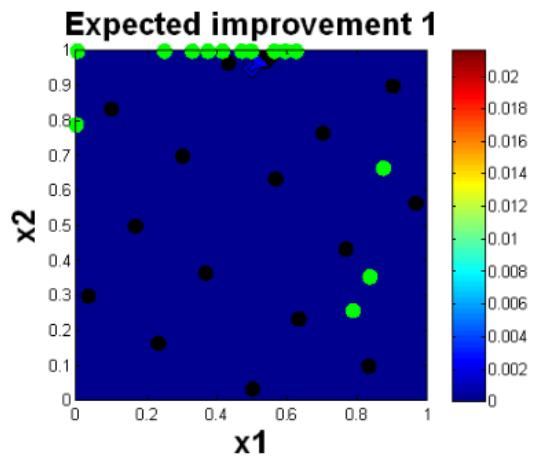
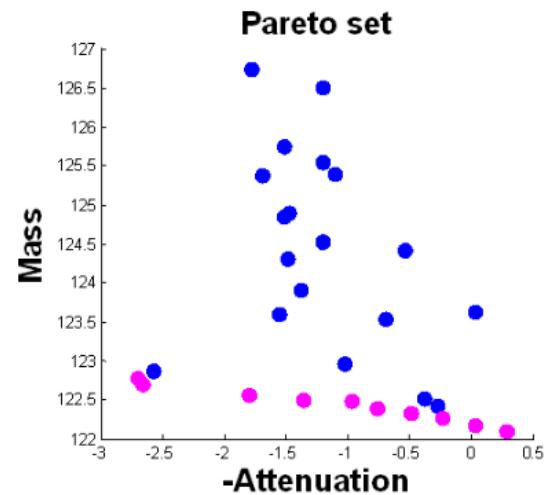
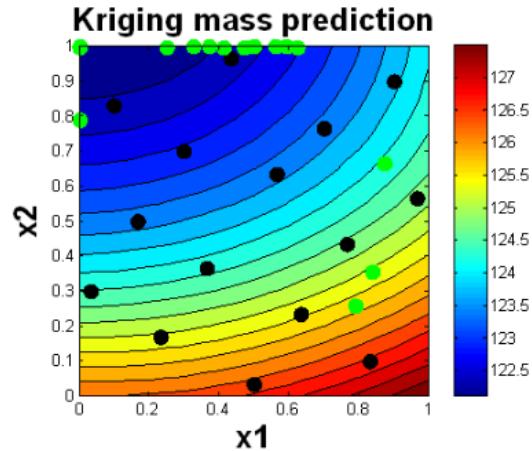
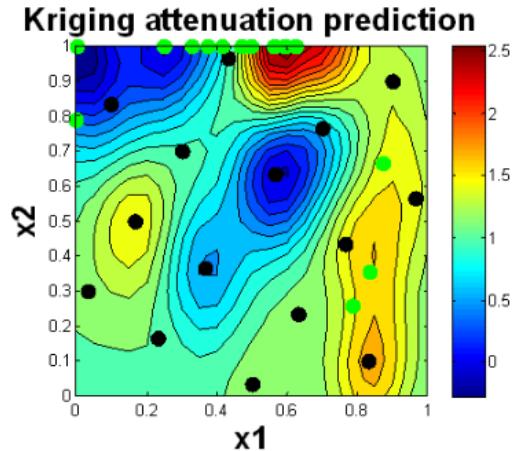
# Pareto set



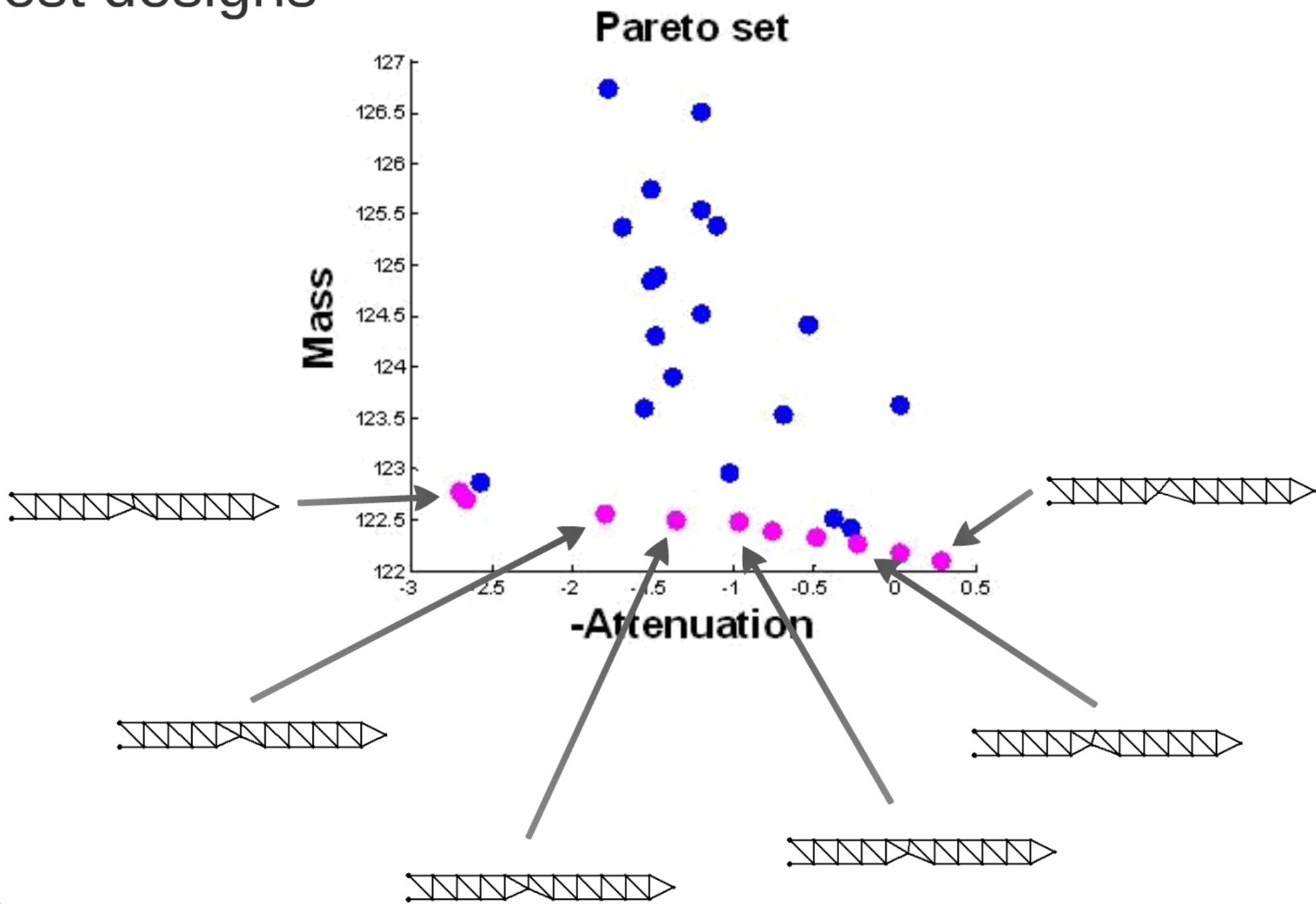
Large attenuation but  
greater mass

Small mass but less  
attenuation

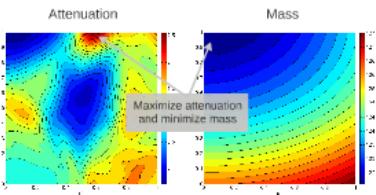
# Multiple updates



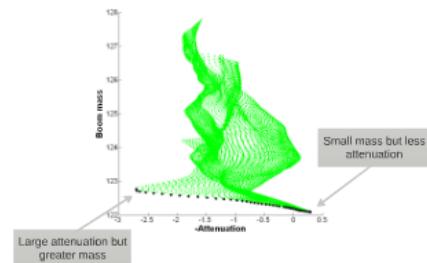
# Best designs



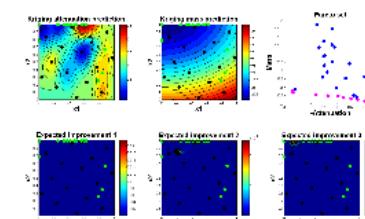
## Multiple objectives



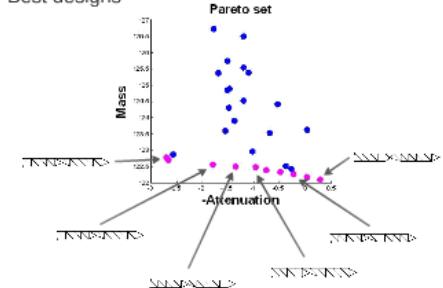
## Pareto set



## Multiple updates

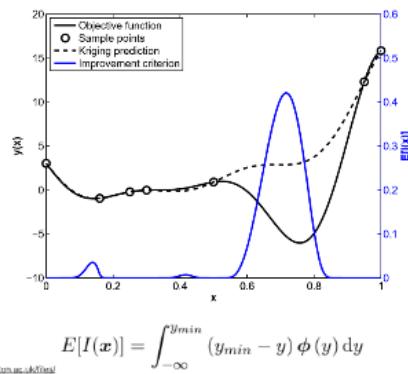


## Best designs

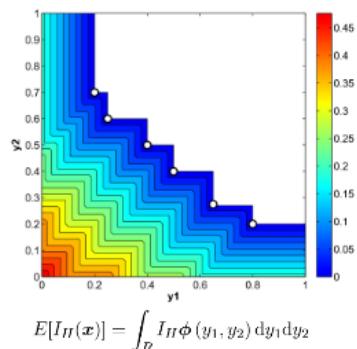


# Improvement Criteria

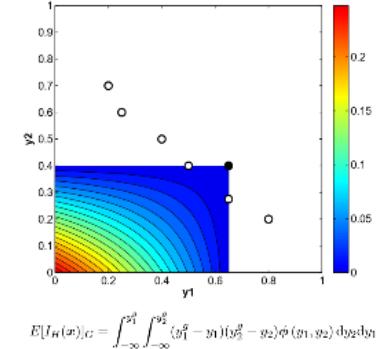
## Single objective improvement criteria



## Multiobjective improvement criteria

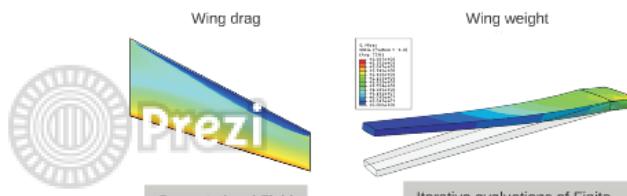


## Goal-based improvement criteria

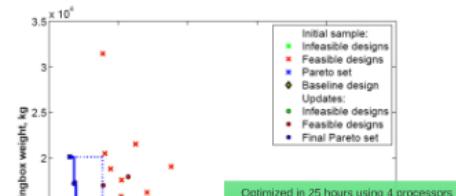


# Wing Design Problem

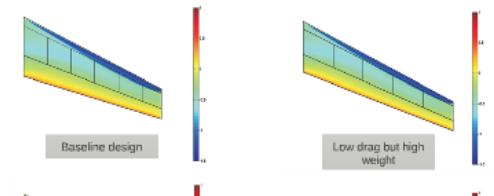
## Multiobjective wing design



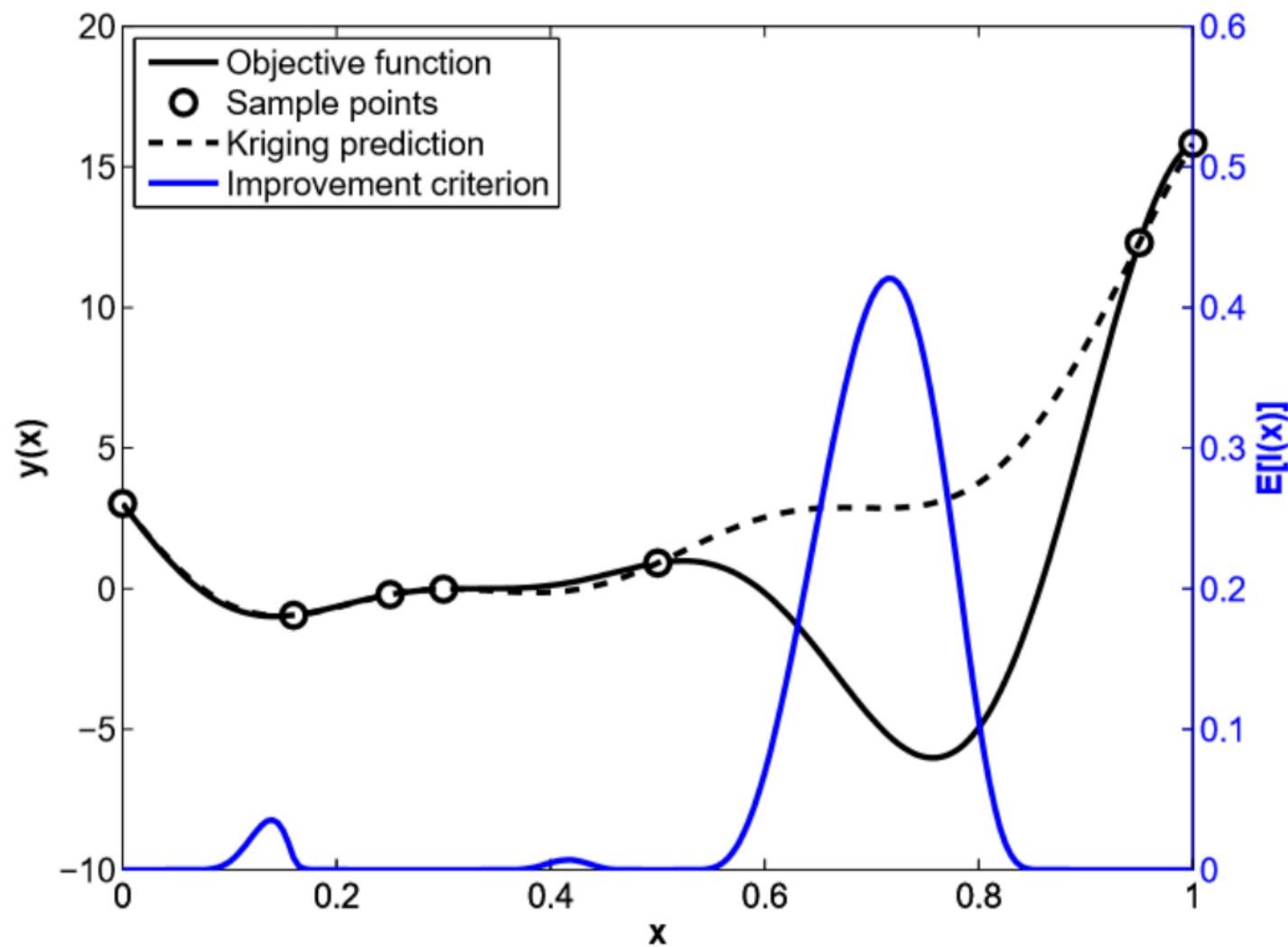
## Pareto set



## Best designs

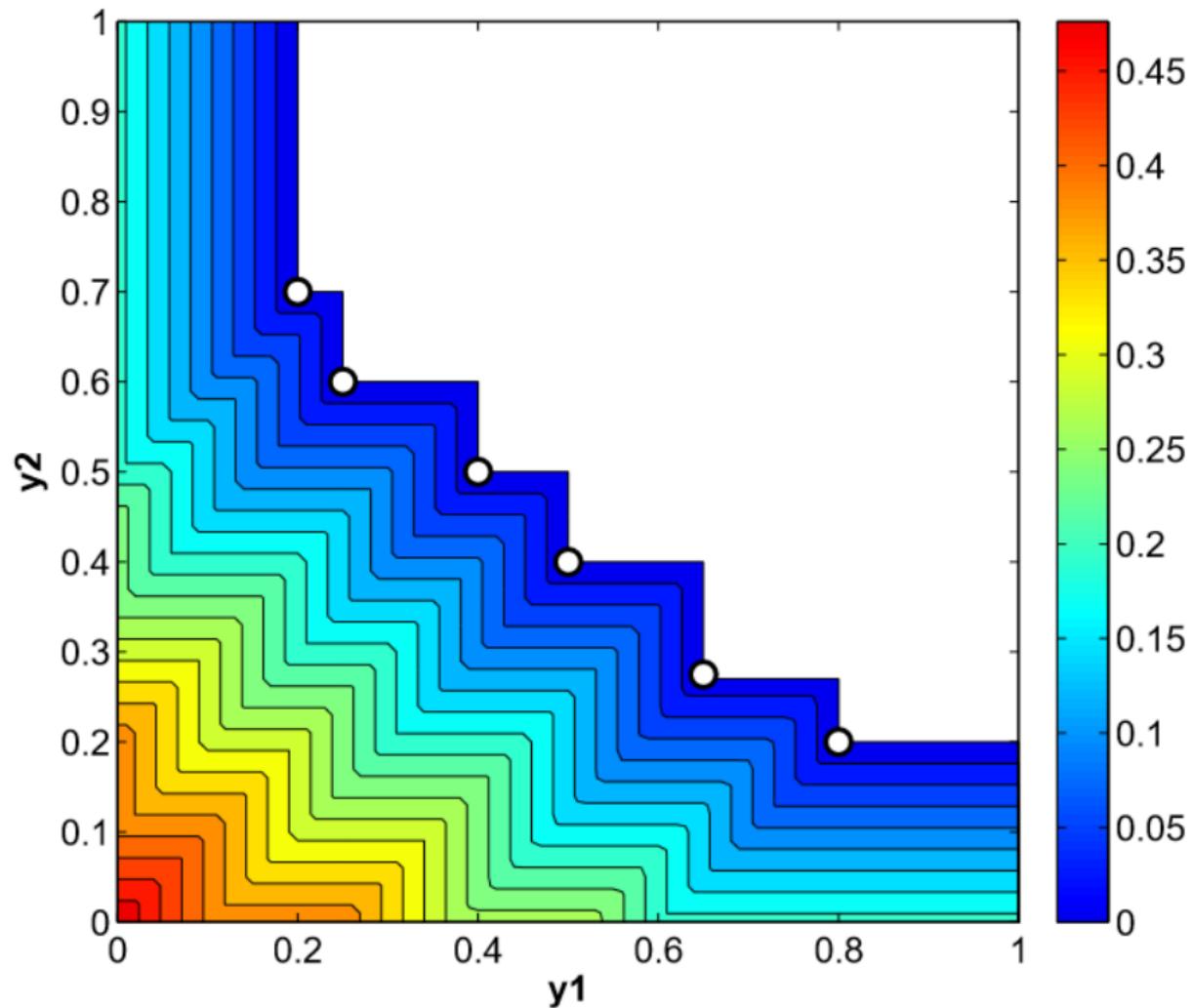


# Single objective improvement criteria



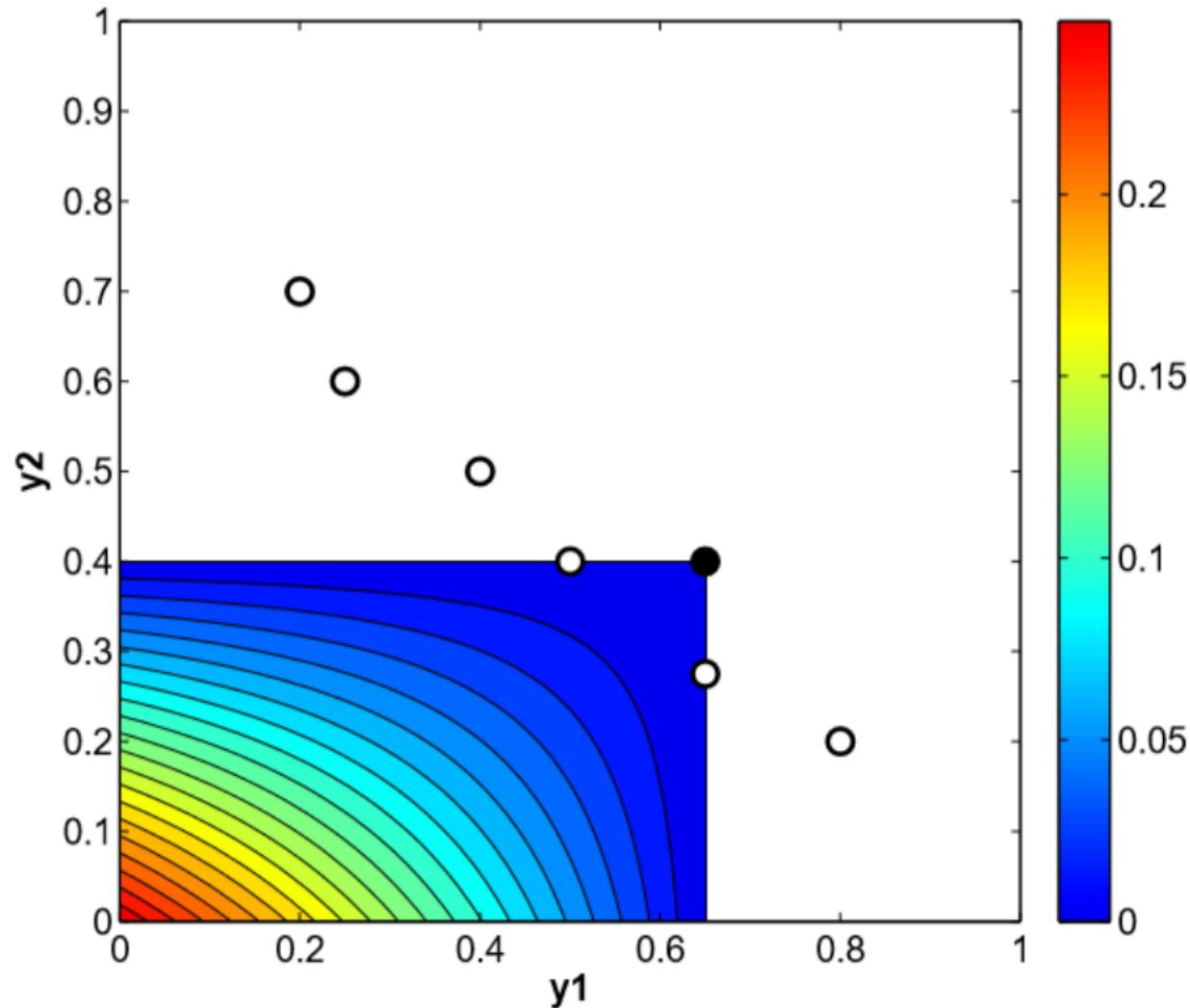
$$E[I(\mathbf{x})] = \int_{-\infty}^{y_{min}} (y_{min} - y) \phi(y) dy$$

# Multiobjective improvement criteria

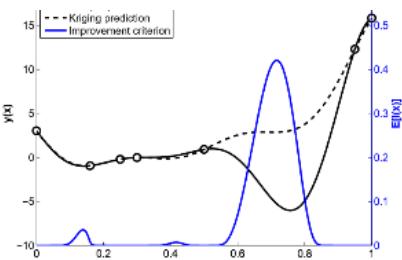


$$E[I_H(\boldsymbol{x})] = \int_R I_H \phi(y_1, y_2) dy_1 dy_2$$

# Goal-based improvement criteria

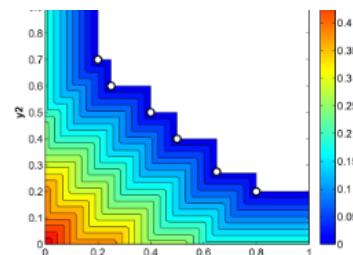


$$E[I_H(\mathbf{x})]_G = \int_{-\infty}^{y_1^g} \int_{-\infty}^{y_2^g} (y_1^g - y_1)(y_2^g - y_2) \phi(y_1, y_2) dy_2 dy_1$$

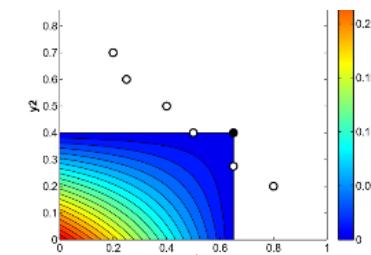


$$E[I(x)] = \int_{-\infty}^{y_{\min}} (y_{\min} - y) \phi(y) dy$$

<https://openreview.net/pdf?id=semrse/20110606143015001-352915.pdf>



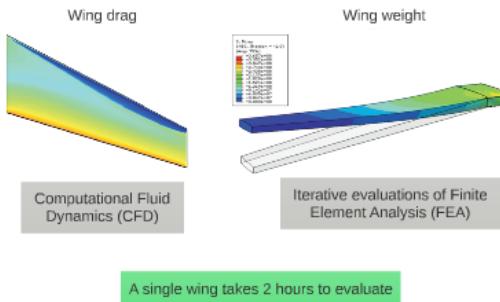
$$E[I_H(x)] = \int_R I_H \phi(y_1, y_2) dy_1 dy_2$$



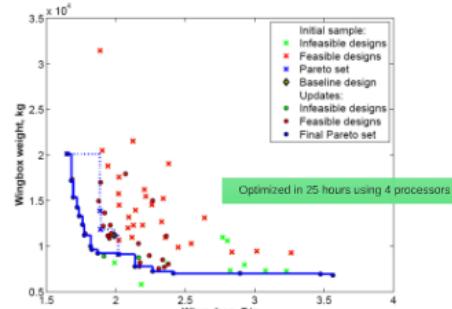
$$E[I_H(x)]_G = \int_{-\infty}^{y_1^*} \int_{-\infty}^{y_2^*} (y_1^* - y_1)(y_2^* - y_2) \phi(y_1, y_2) dy_2 dy_1$$

# Wing Design Problem

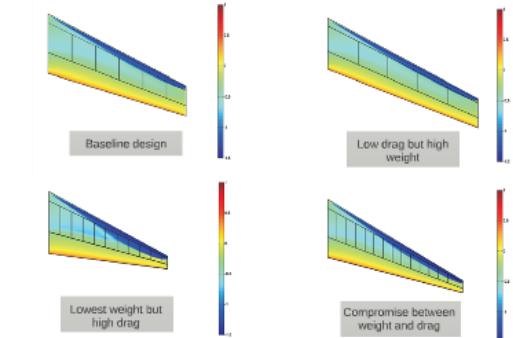
Multiobjective wing design



Pareto set

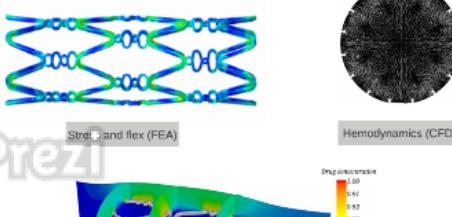


Best designs

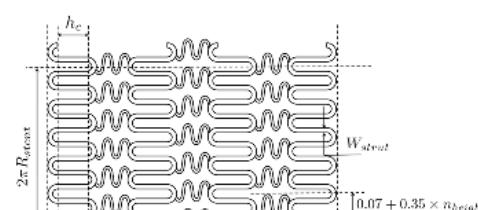


# Coronary Stent Design

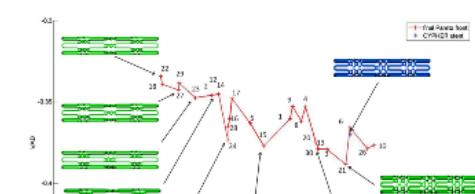
Stent analysis



Parameterisation

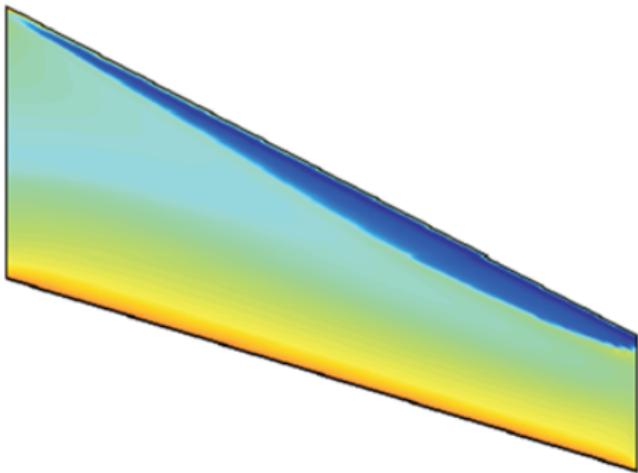


Hemodynamics versus drug delivery



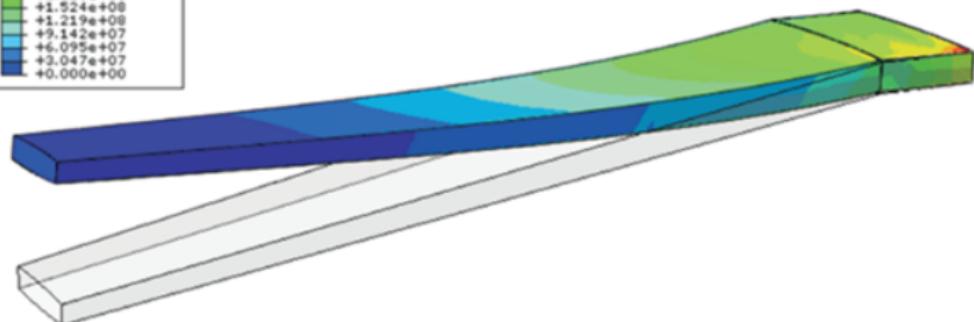
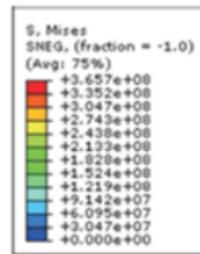
# Multiobjective wing design

Wing drag



Computational Fluid Dynamics (CFD)

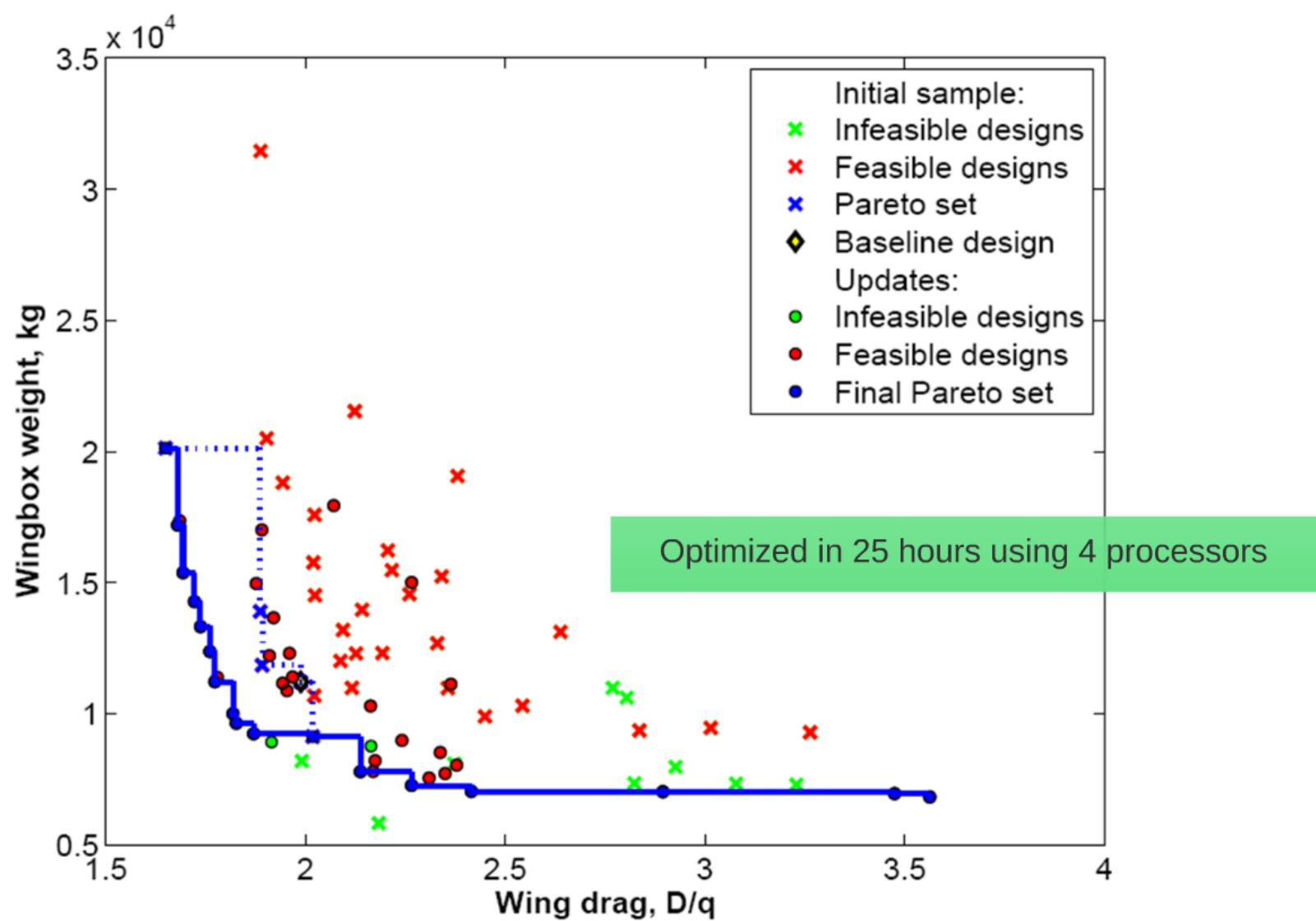
Wing weight



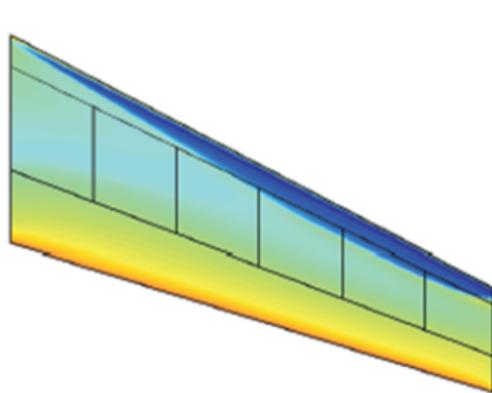
Iterative evaluations of Finite Element Analysis (FEA)

A single wing takes 2 hours to evaluate

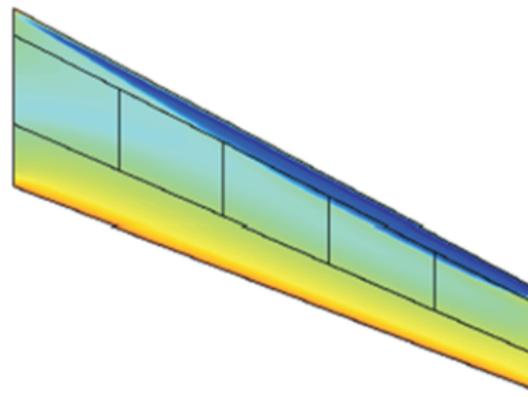
# Pareto set



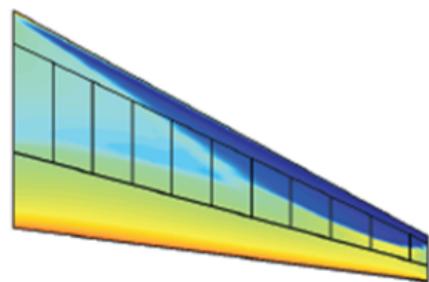
# Best designs



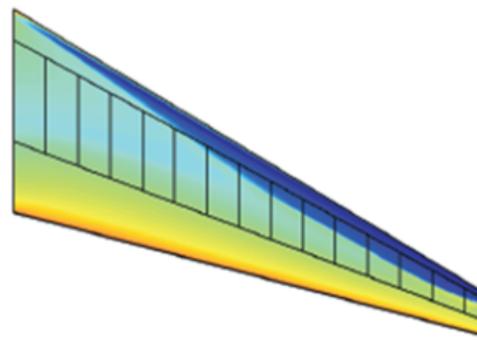
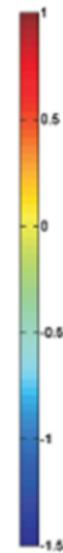
Baseline design



Low drag but high weight

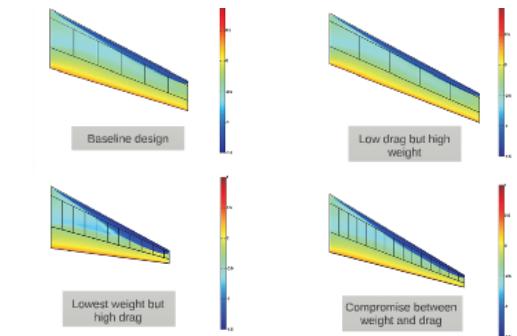
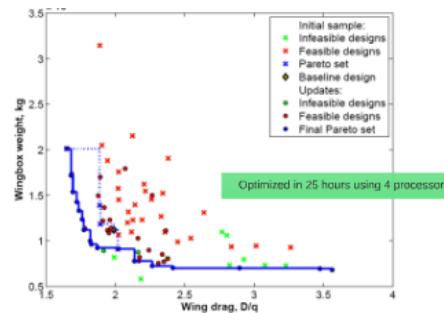
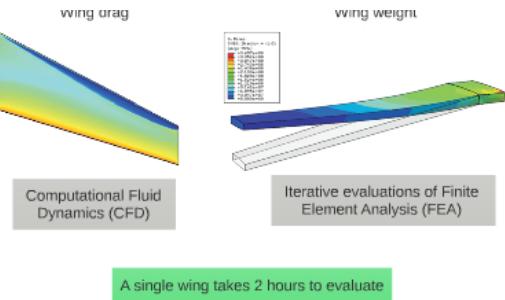


Lowest weight but high drag



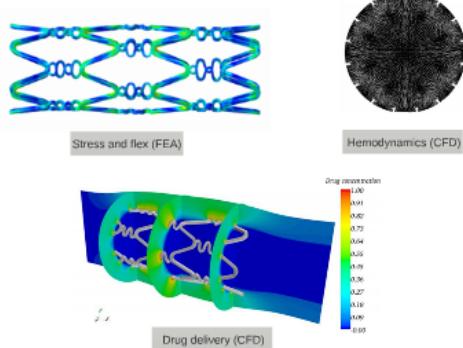
Compromise between weight and drag





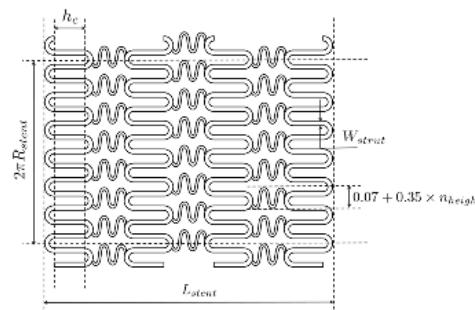
# Coronary Stent Design

Stent analysis

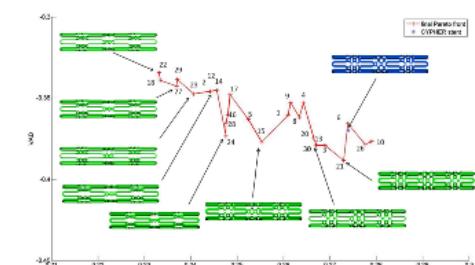


S. Pant (2012): Multidisciplinary and Multiobjective Design Optimization Coronary Stents, University of Southampton, PhD Thesis.

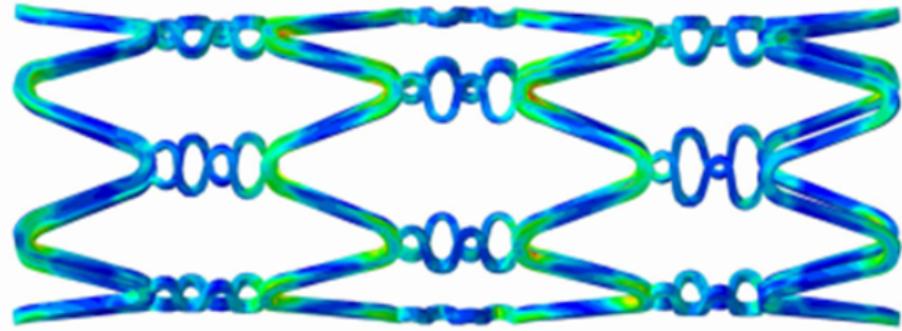
Parameterisation



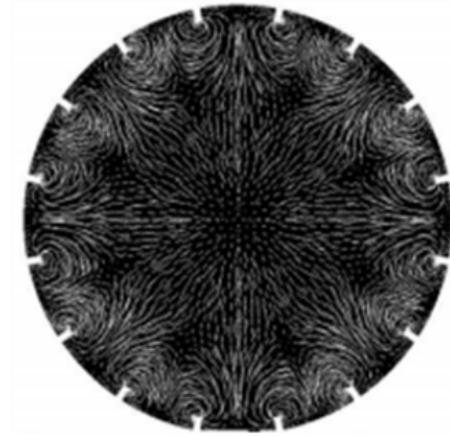
Hemodynamics versus drug delivery



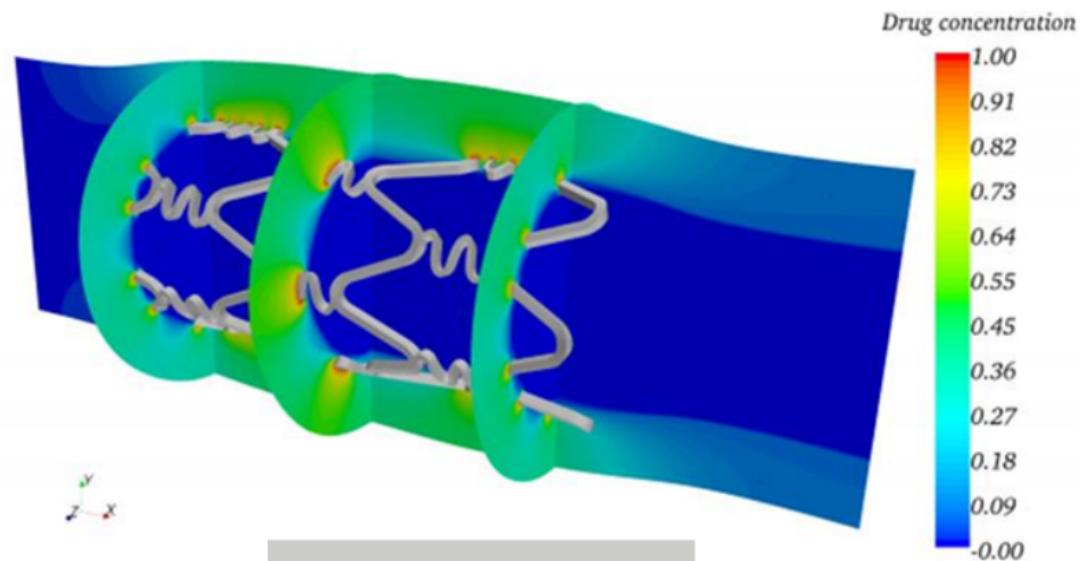
# Stent analysis



Stress and flex (FEA)



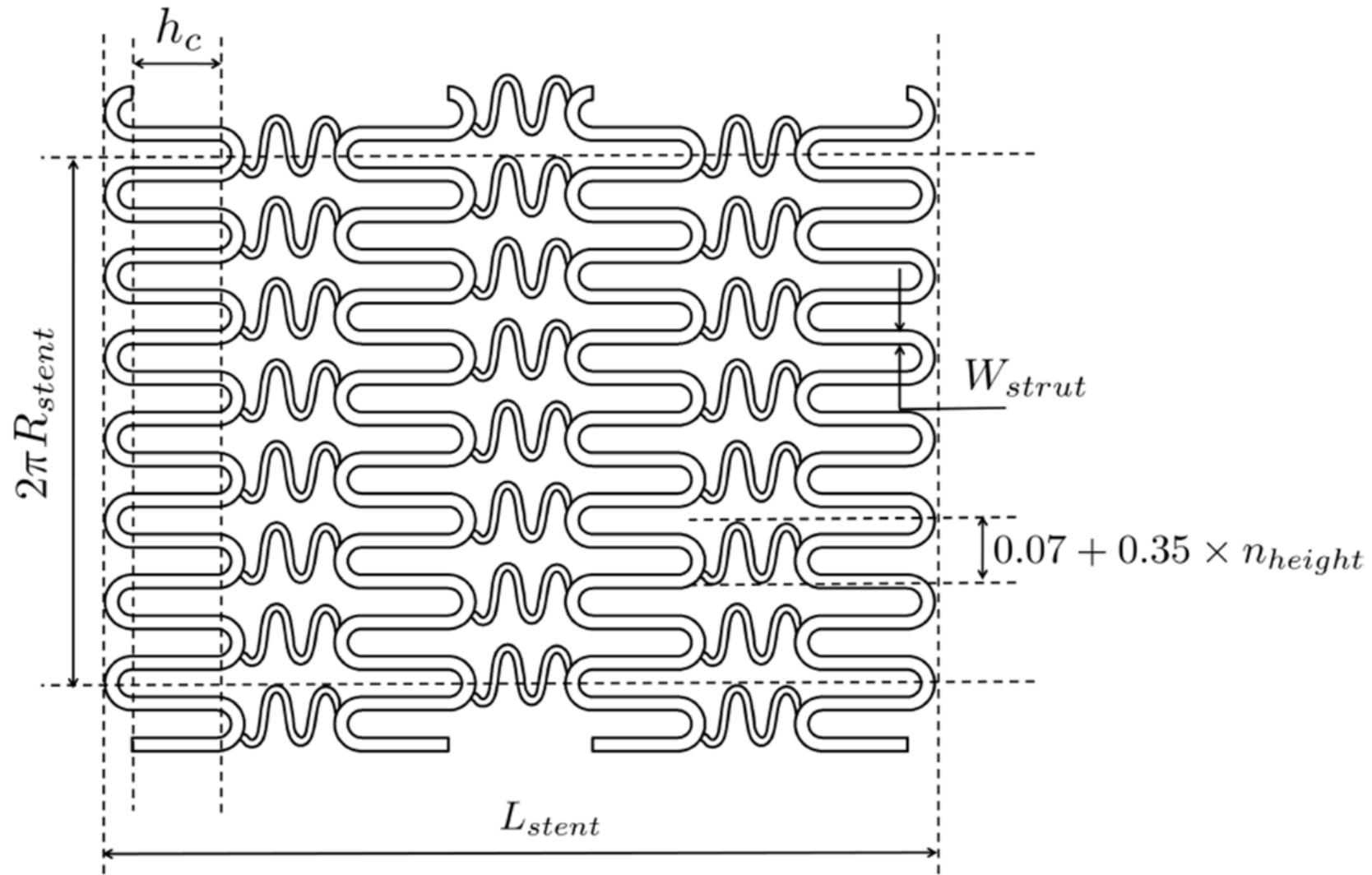
Hemodynamics (CFD)



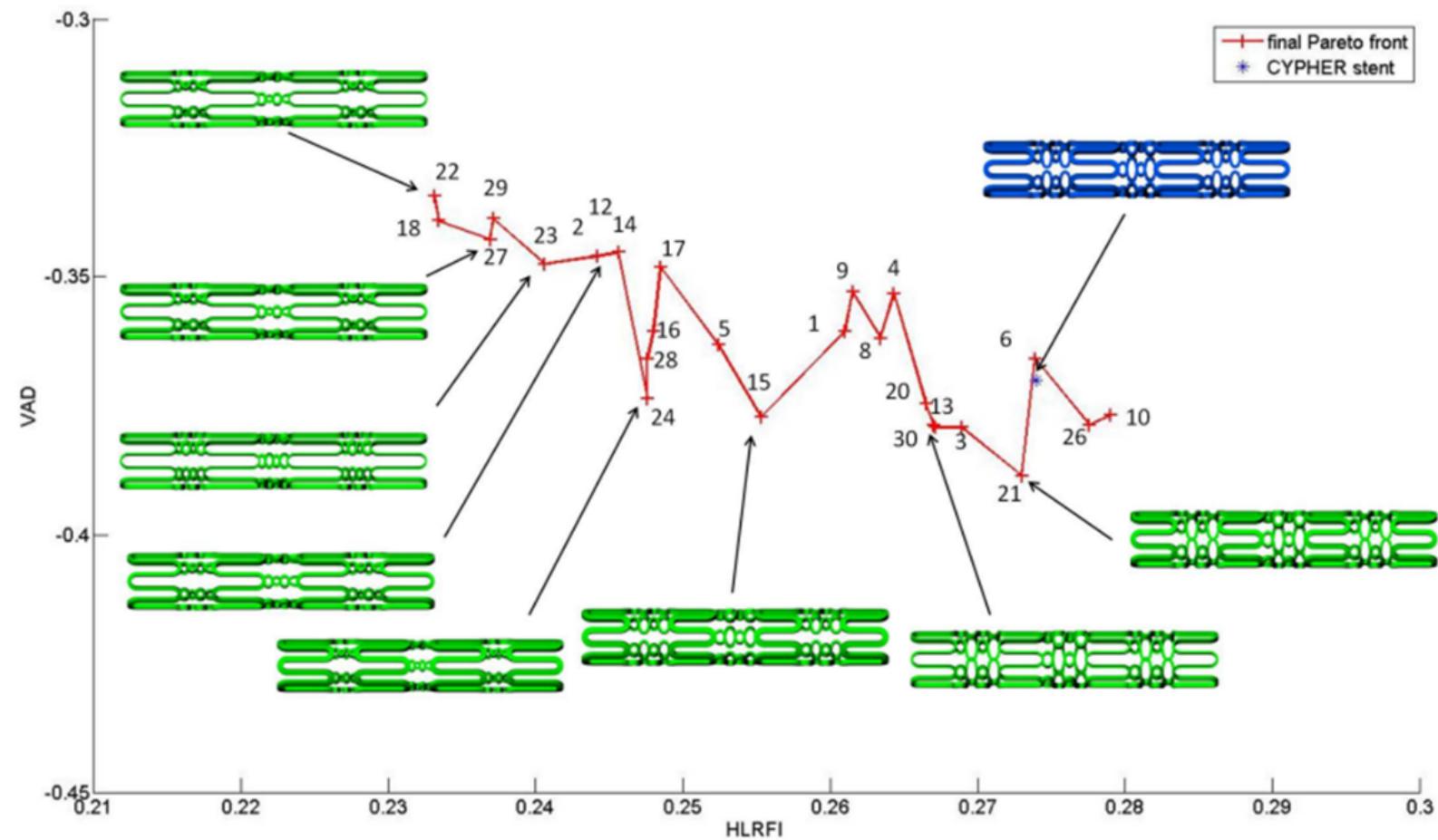
Drug delivery (CFD)

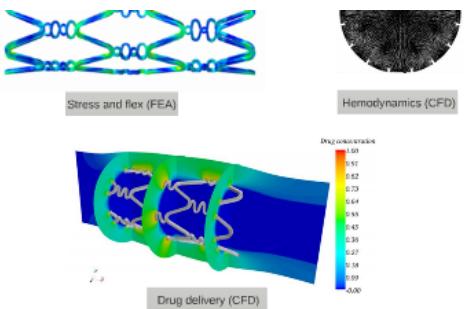
S. Pant (2012): Multidisciplinary and Multiobjective Design Optimization Coronary Stents, University of Southampton, PhD Thesis.

# Parameterisation

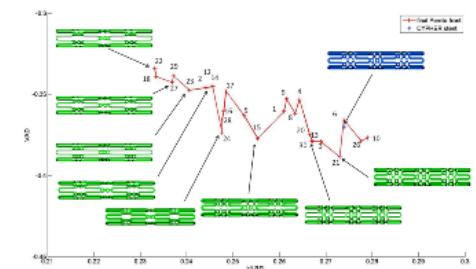
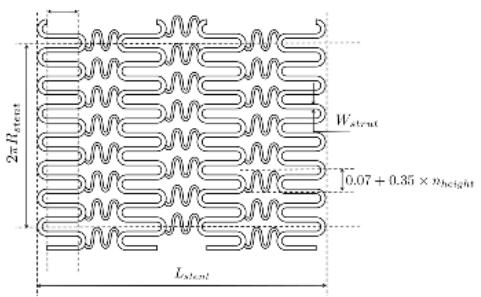


# Hemodynamics versus drug delivery



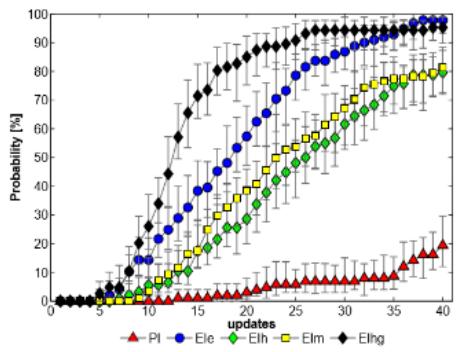


S. Pant (2012): Multidisciplinary and Multiobjective Design Optimization Coronary Stents,  
University of Southampton, PhD Thesis.

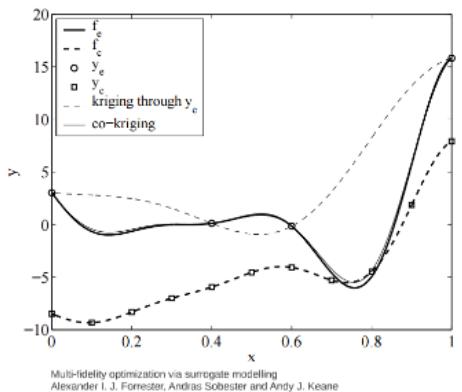


# Other Enhancements

## Human-machine advantage



## Multi-fidelity simulations

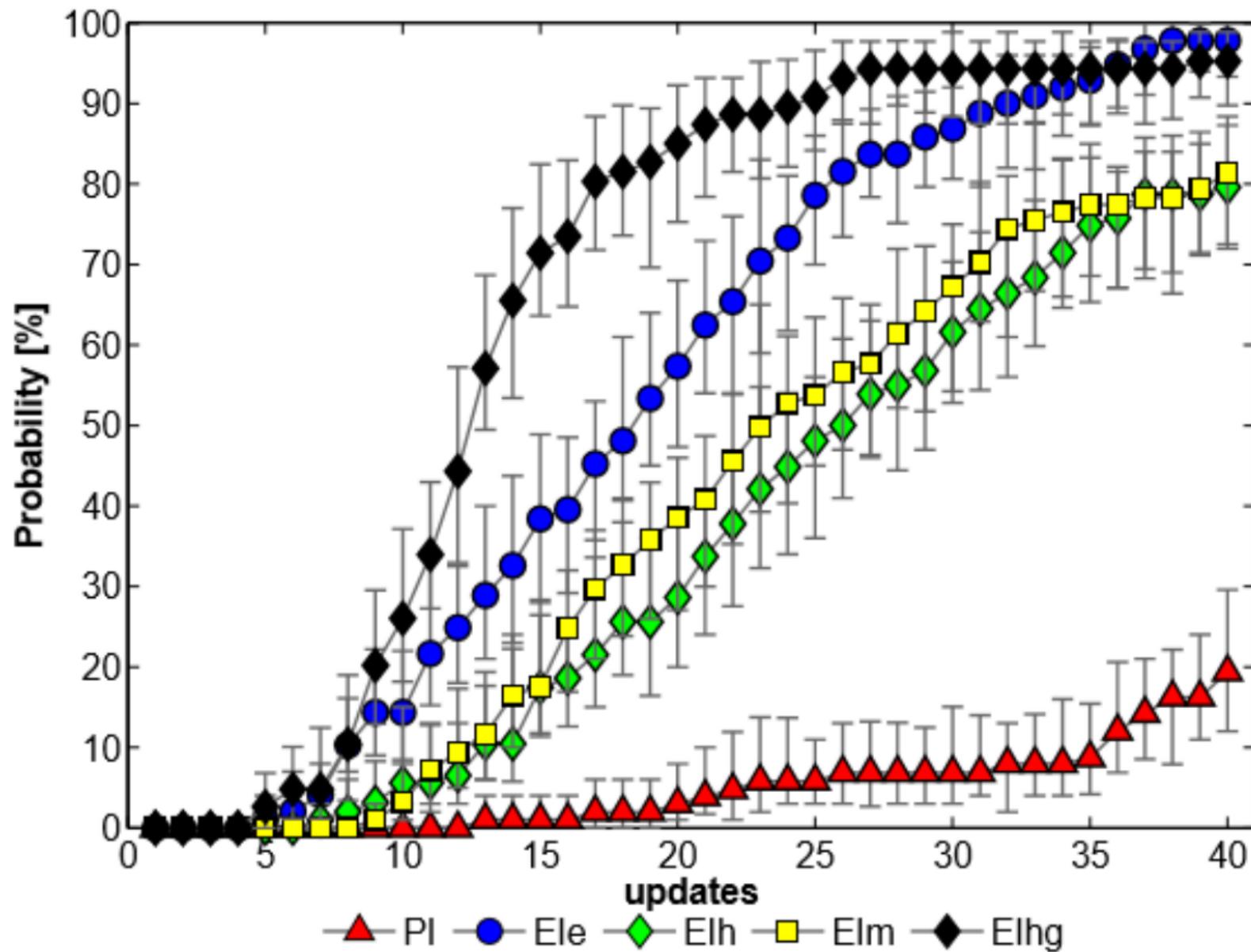


## Summary

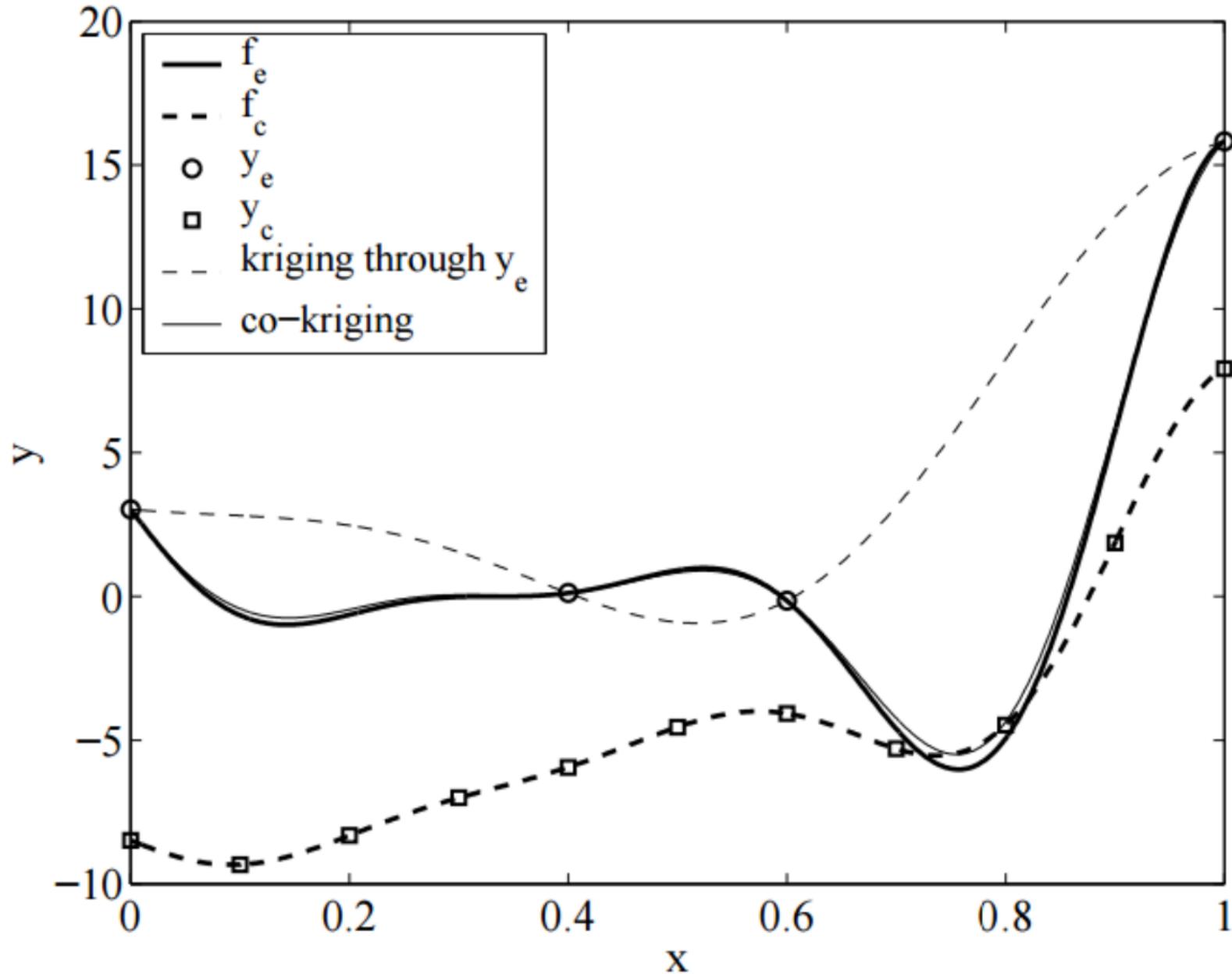
- Designers face a number of challenges when generating optimal designs under resource constraints.
- We are some of the way to generating good design methodology but...
- There is lots of opportunity for data scientists to contribute!

Questions?

# Human-machine advantage



# Multi-fidelity simulations



Multi-fidelity optimization via surrogate modelling  
Alexander I. J. Forrester, Andras Sobester and Andy J. Keane

# Summary

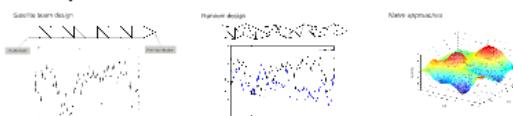
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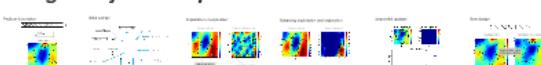
## Deadline Driven Design

## *Engineering Design Problems*

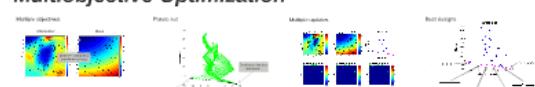
### *Example Problem*



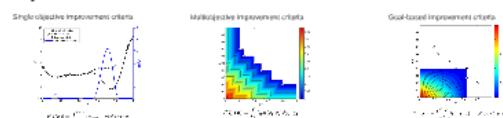
## *Single Objective Optimization*



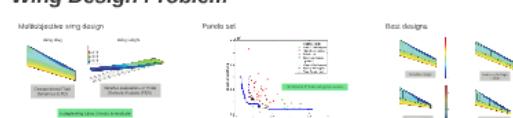
Multiobjective Optimization



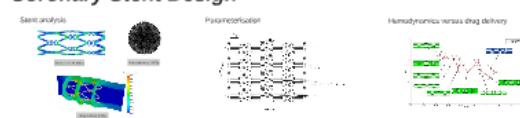
### ***Improvement Criteria***



### *Wing Design Problem*



Coronary Stent Design



### ***Other Enhancements***

