UNIVERSITEIT GENT

FACULTEIT INGENIEURSWETENSCHAPPEN

Grid-Enabled Adaptive Surrogate Modeling for Computer-Based Design

SUMO Lab

INTEC Broadband Communication Networks Research Group (IBCN)

Outline

- Who are we ?
- Introduction
- Surrogate modeling
- SUMO Toolbox
- Examples
- Conclusions

Outline

- **Who are we ?**
  - who are we
  - what do we do
- **Introduction**
- **Surrogate modeling**
- **SUMO Toolbox**
- **Examples**
- **Conclusions**

Who are we ?

Ghent University

Faculty of Engineering

Department of Information Technology (INTEC)

INTEC Broadband and Communications Networks (IBCN)

Who are we ?

UNIVERSITEIT GENT

FACULTY OF ENGINEERING

INTEC

IBCN

SUMO

Universiteit Antwerpen

...

PATS

KATHOLIEKE UNIVERSITEIT LEUVEN

...

DistriNet Research Group

...

IBBT

Who are we ?

- IBCN members
  - 10 professors
  - ~12 postdocs
  - ~85 research members

- SUMO Lab – (surrogate modeling)
  - Professor
    - Tom Dhaene
    - Eric Laermans
  - Postdoc
    - Dirk Deschrijver

    associated members (UA)
    - Luciano De Tommasi
  - PhD students
    - Ivo Couckuyt
    - Dirk Gorissen
    - Francesco Ferranti
    - Adam Narbudowicz

    associated members (UA)
    - Karel Crombecq
    - Wouter Hendrickx

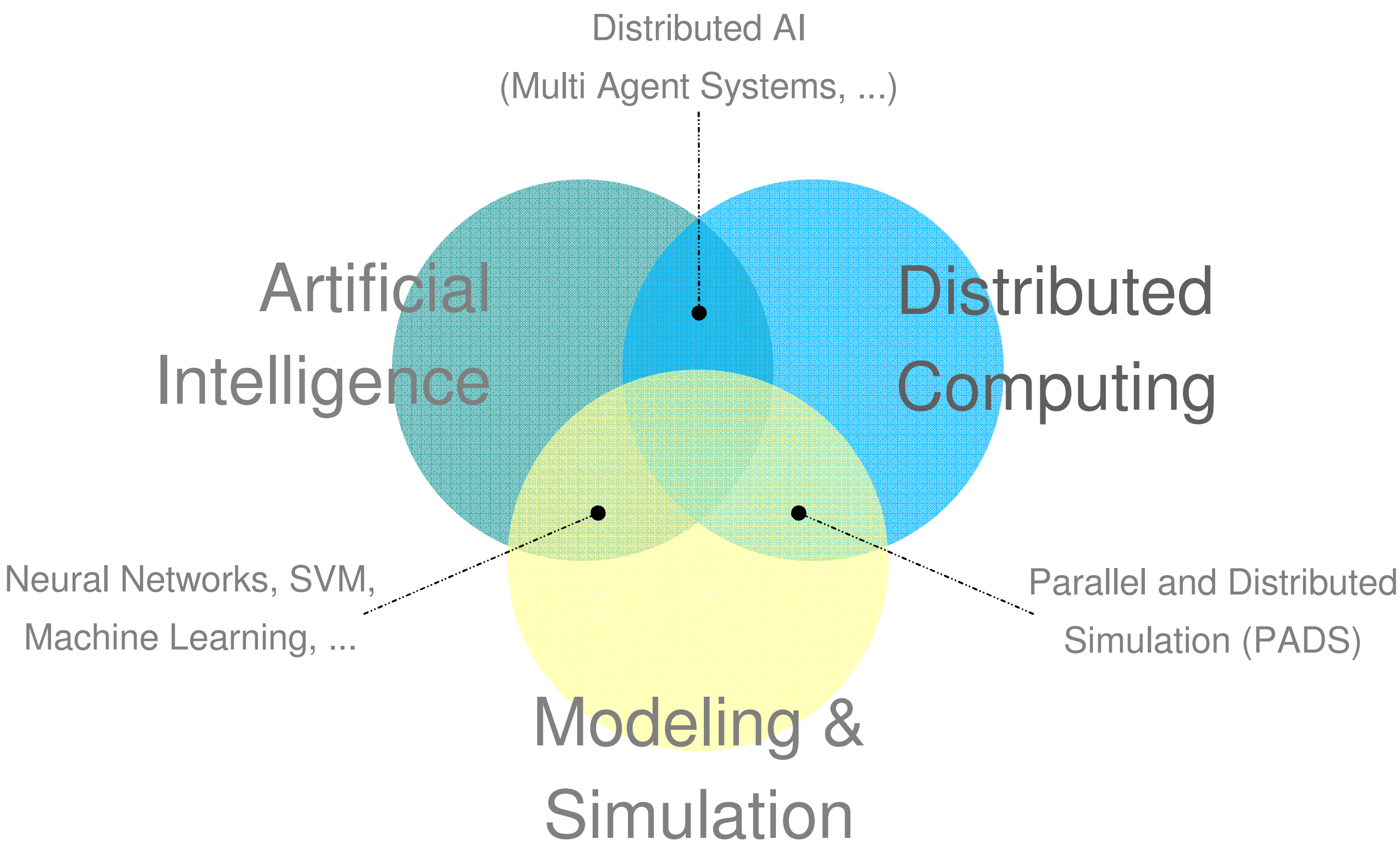
Research topics

- **Surrogate models of complex systems**
  - replacement metamodels
- **Surrogate based optimization**
  - EGO based approaches
- **Machine learning and Experimental design**
- **High Performance Computing (HPC)**
- **(Parametric) Macromodels of electronic systems**
- **(Parametric) Model Order Reduction**

Research topics

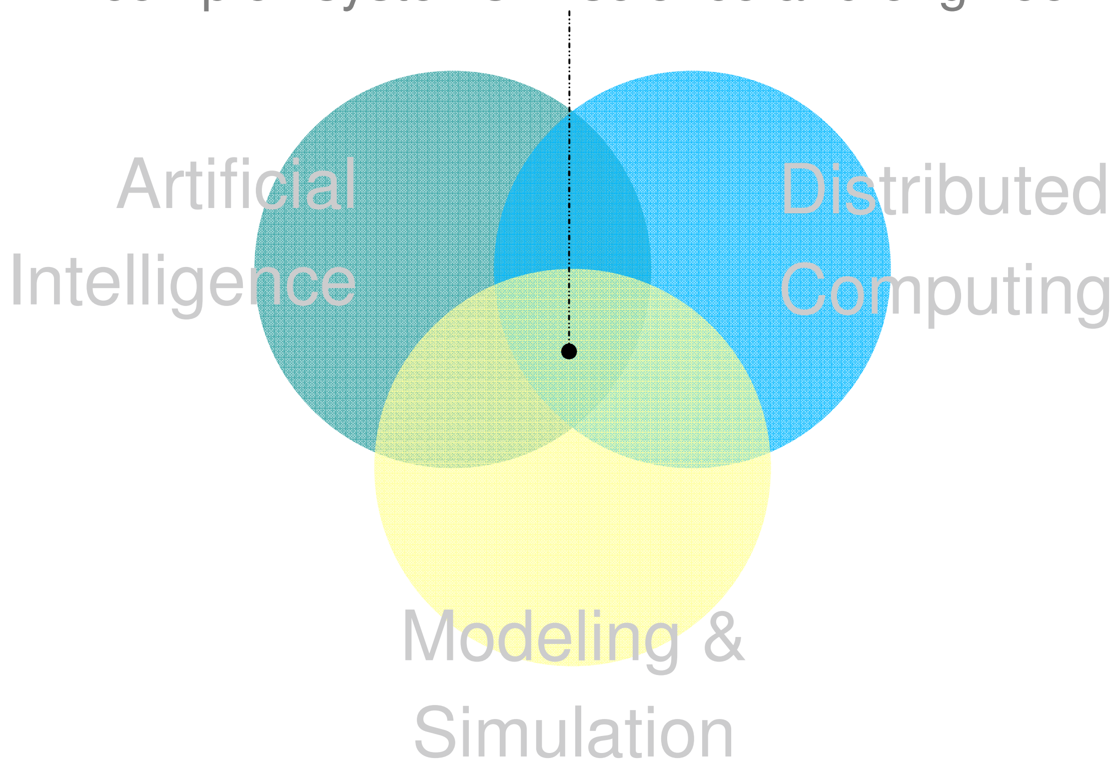
- **Surrogate models of complex systems**
  - replacement metamodels
- **Surrogate based optimization**
  - EGO based approaches
- **Machine learning and Experimental design**
- **High Performance Computing (HPC)**
- **(Parametric) Macromodels of electronic systems**
- **(Parametric) Model Order Reduction**

What do we do


Distributed AI
(Multi Agent Systems, ...)
Artificial Intelligence
Distributed Computing
Neural Networks, SVM,
Machine Learning, ...
Parallel and Distributed
Simulation (PADS)
Modeling & Simulation

Adaptive Surrogate Modeling

efficient and accurate characterization, modeling and simulation of complex systems in science and engineering



Outline

- **Who are we ?**
- **Introduction**
  - Surrogate model ?
  - What are we looking for ?
  - Existing approaches and techniques
- **Surrogate modeling**
- **SUMO Toolbox**
- **Examples**
- **Conclusions**

A New Science Paradigm

A New Science Paradigm

- thousand years ago : experimental science
  - description of natural phenomena

A New Science Paradigm

- thousand years ago : experimental science
  - description of natural phenomena

- last few hundred years : theoretical science
  - Newton’s laws, Maxwell’s equations …

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - K\frac{c^2}{a^2}$$

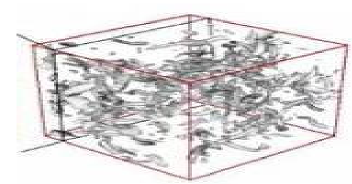
A New Science Paradigm

- thousand years ago : experimental science
  - description of natural phenomena

- last few hundred years : theoretical science
  - Newton's laws, Maxwell's equations …

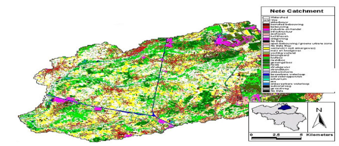
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - K\frac{c^2}{a^2}$$

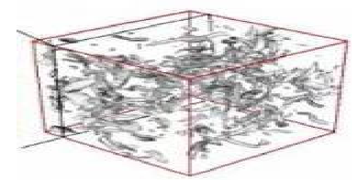
- last few decades : computational science
  - simulation of complex phenomena



A New Science Paradigm

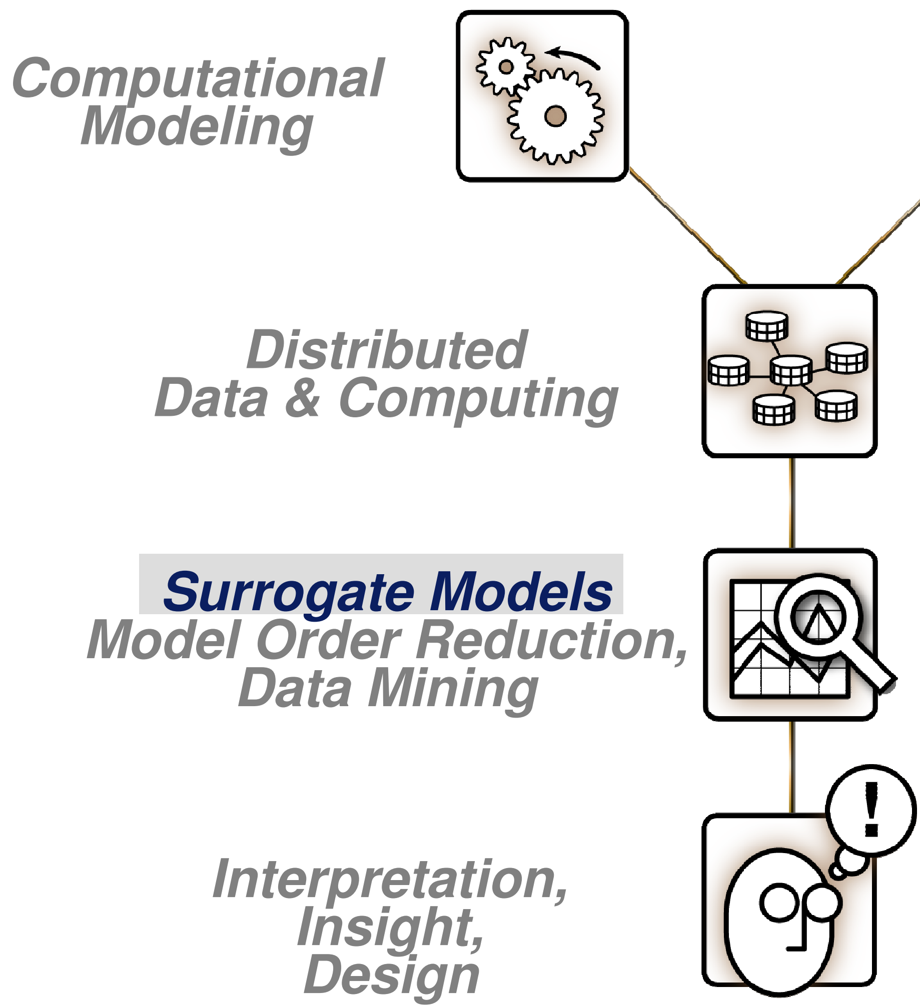
- thousand years ago : **experimental science**
  - description of natural phenomena
- last few hundred years : **theoretical science**
  - Newton’s laws, Maxwell’s equations …
- last few decades : **computational science**
  - simulation of complex phenomena
- today : **e-Science or data-centric science**
  - massive computing
  - large data exploration and mining
  - unify : theory, experiment, and simulation





(With thanks to Jim Gray)

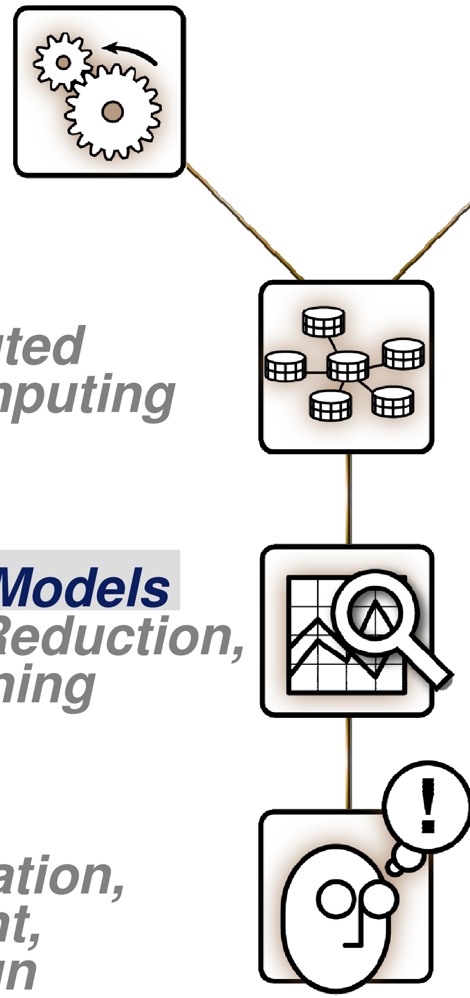
A New Science Paradigm



A New Science Paradigm

Computational Modeling

Real-world Data



Distributed Data & Computing

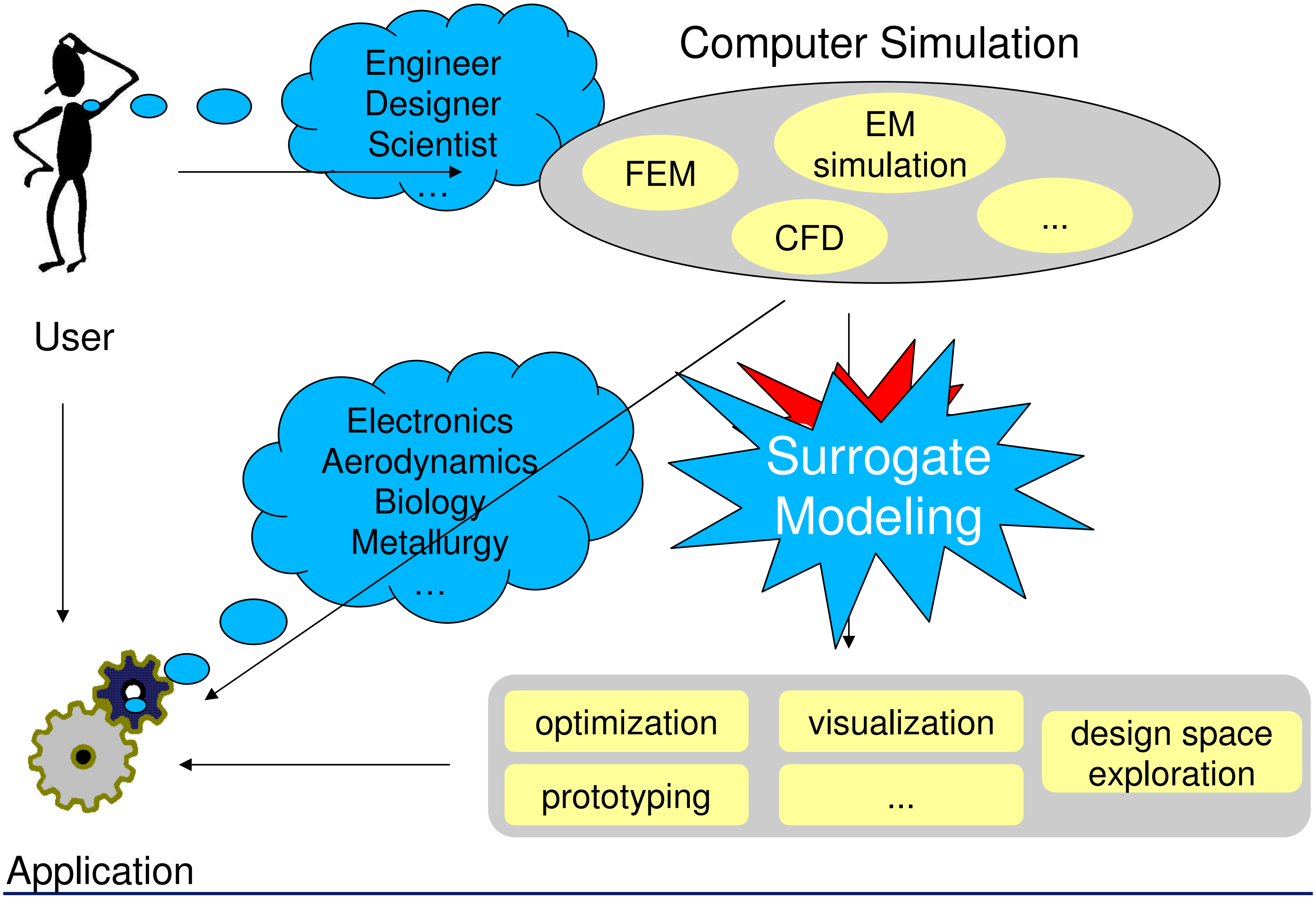
Surrogate Models
Model Order Reduction, Data Mining

Interpretation, Insight, Design

data

knowledge

Problem domain



Scope

- **Surrogate modeling is not the only way**
  - Faster hardware, different approach, different solver, simplify problem (MOR, …)
  - Right tool for the right job
- **Focus is on global surrogate modling**
  - Though Surrogate Based Optimization (SBO) is not ignored either
- **Focus is on input-output problems**
  - Static, not dynamic
  - No time series prediction

Surrogate model ?

- **system modeling**
  - **real world**
    - I/O system
    - stimulus / response

    - examples: *mechanical, electrical, optical, electronic, chemical … systems*

Surrogate model ?

system modeling

- real world
  - I/O system
  - stimulus / response

- **simulation model**
  - approximation
  - discretization

- model = *abstraction of a real system*
- simulation = *virtual experiment*

Surrogate model ?

■ system modeling

- real world
  - I/O system
  - stimulus / response

- simulation model
  - approximation
  - discretization

- **surrogate model**
  - metamodel, RSM, emulator
  - scalable analytical model
  - *"model of model"*

Surrogate model ?

- **simulation model** : widely used in engineering design

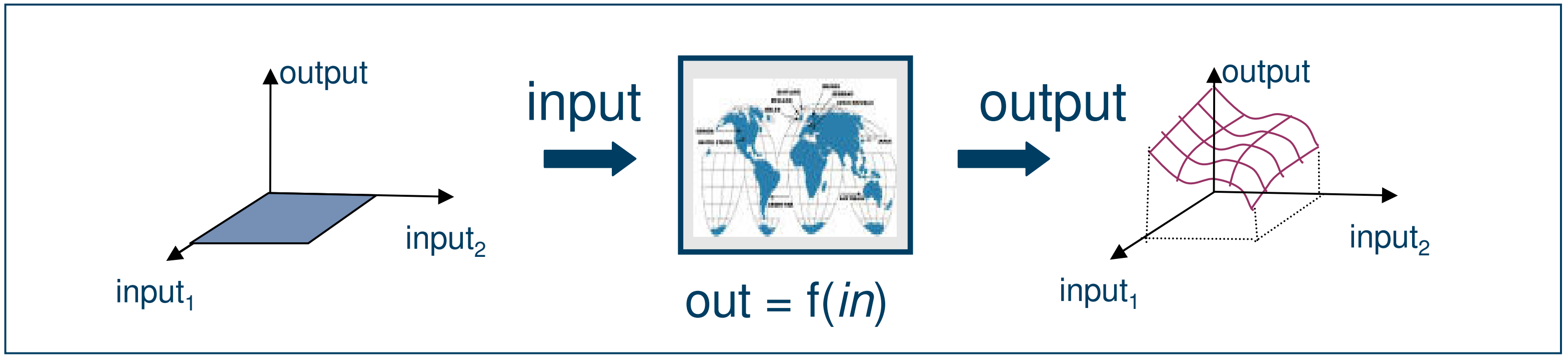
- each new sample in the input design space, requires new computer simulation
- accurate, high fidelity numerical model

Surrogate model ?

- **however, simulation models...**
  - ...complex
  - ...time consuming to run
  - ...optimization is expensive
  - ...not always available
  - ...highly specialized
    - **scalability?**
    - **model chaining?**
    - **integration with other tools?**
    - **hardware / software requirements?**
    - **licensing?**
    - **...**

Surrogate model ?

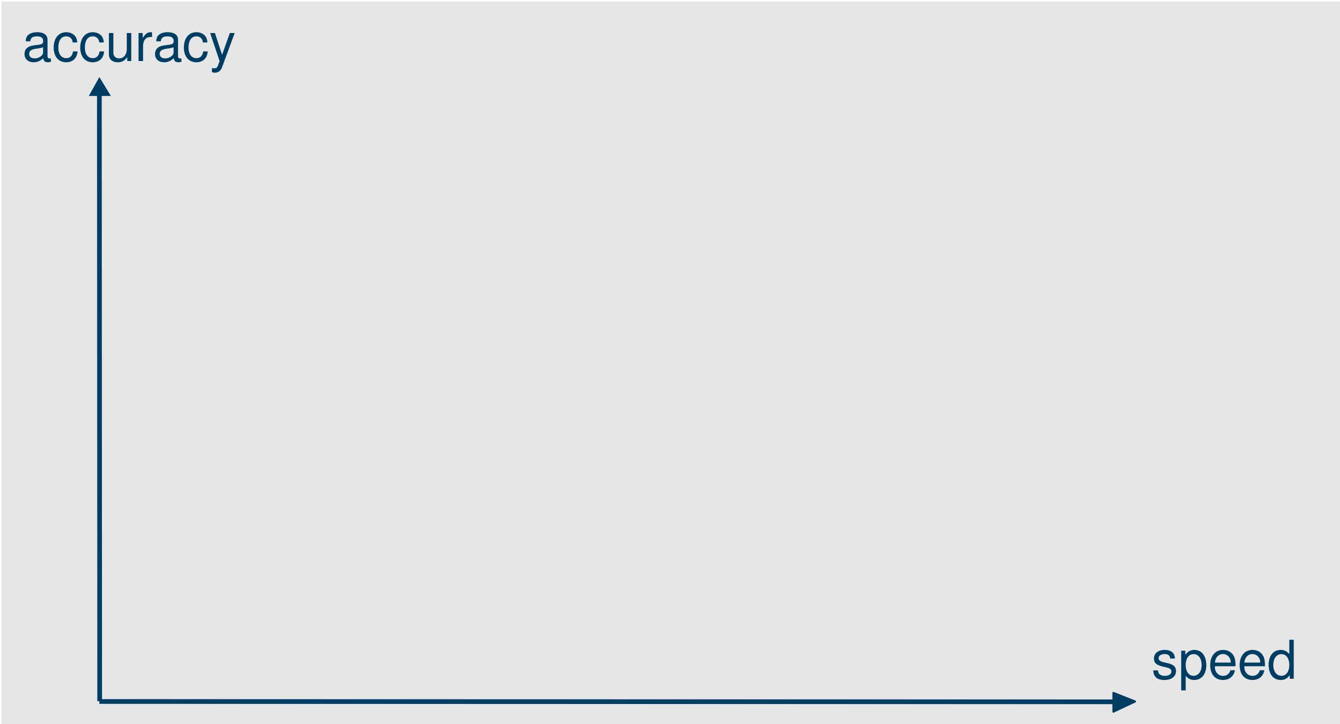
■ surrogate model



- analytical surrogate model
  - one-time upfront time investment
  - harness the power of the grid for simulation execution
  - adaptive sampling
- covers complete design space
  - design optimization, *"what-if"* analysis, sensitivity analysis

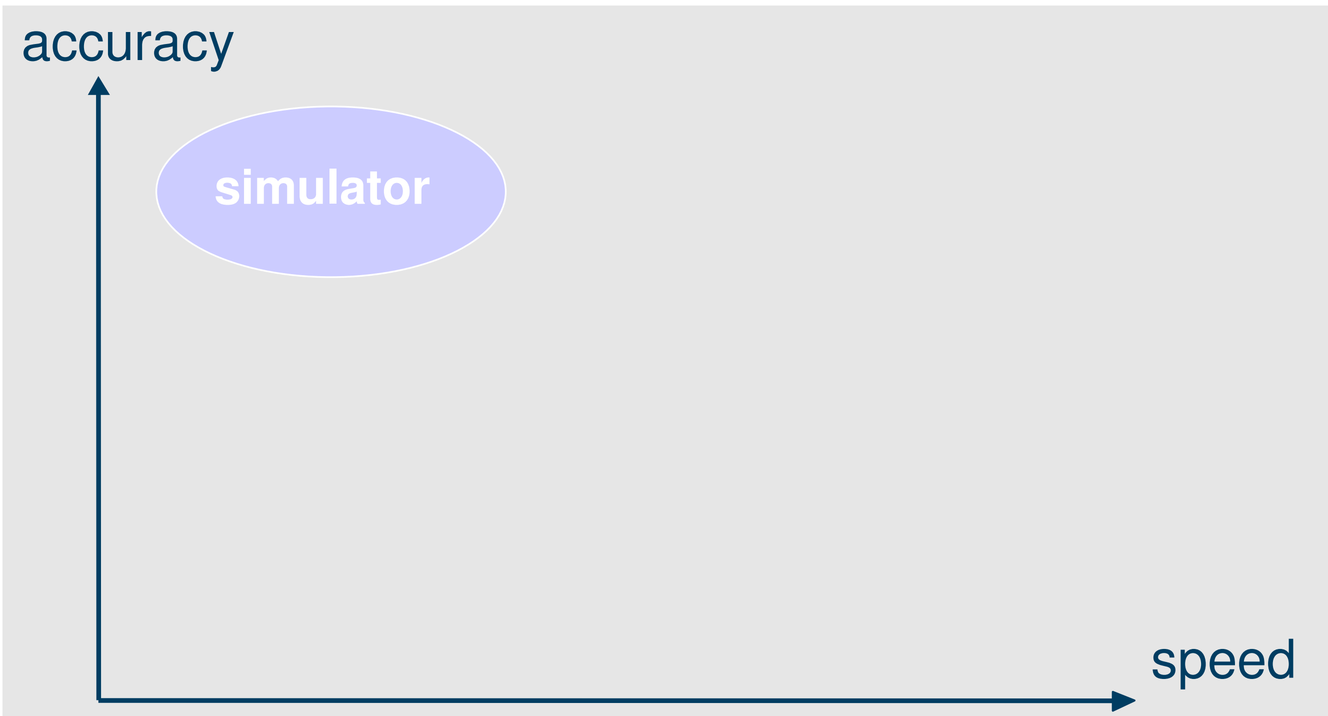
What are we looking for?

- **accuracy / speed trade-off**



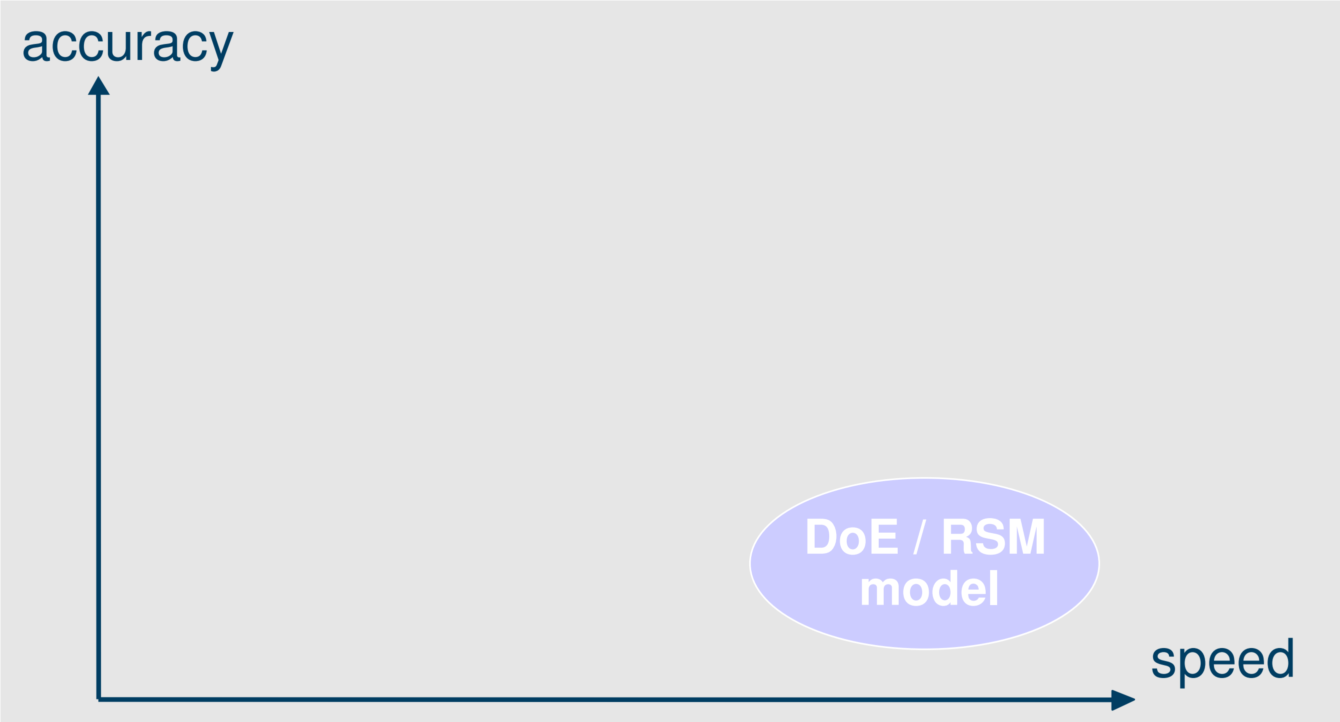
What are we looking for?

- **simulators**
  - domain-specific
  - high-accuracy



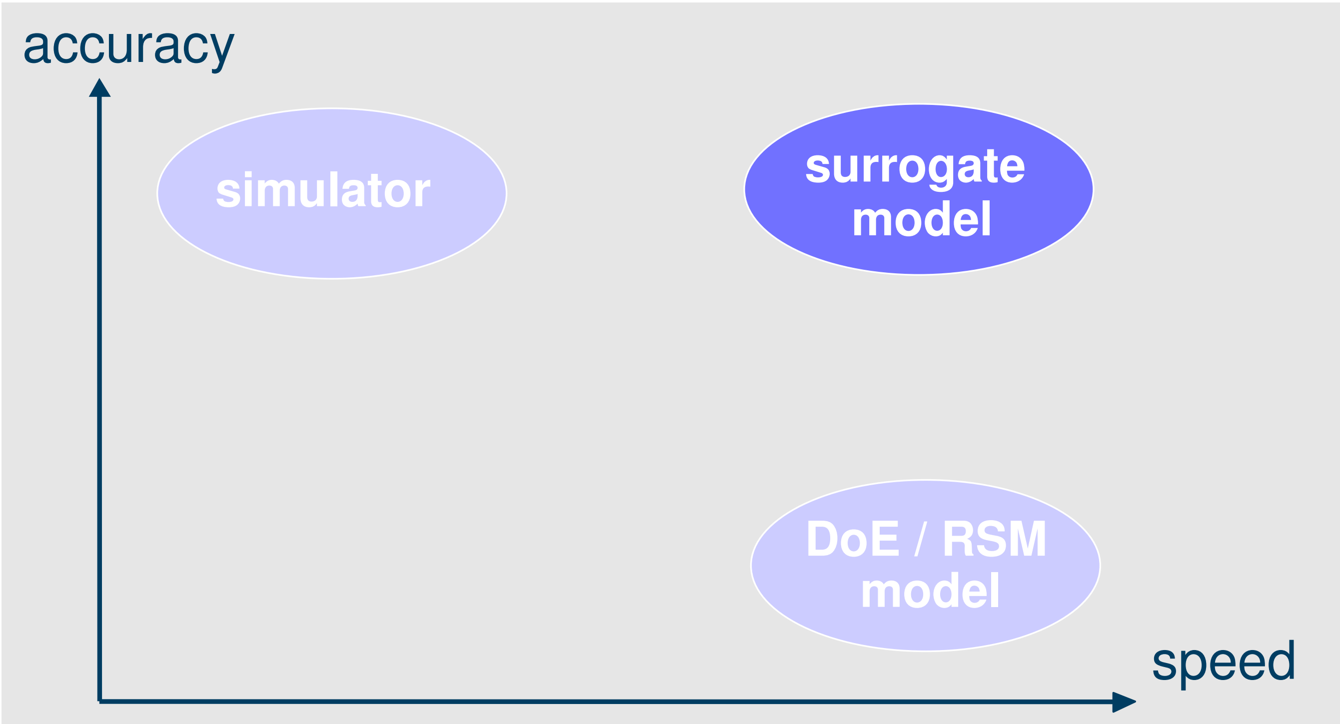
- **models**
  - 2^{nd} order polynomial

  Response Surface Models (RSM)



What are we looking for?

- **best of both worlds**
  - combining accuracy & generality of **simulators**, with the speed & flexibility of **models**



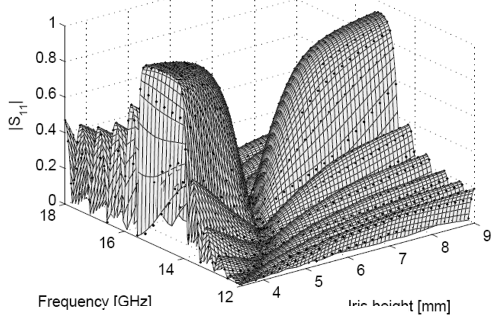
Surrogate model ?

- **advantages**
  - instant evaluation
  - compact formulation (few 100 parameters)

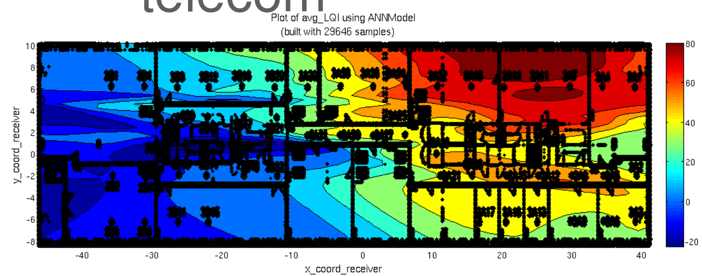
- **applications**
  - prototyping
  - design space exploration
  - design optimization
  - sensitivity analysis
  - *what-if* analysis
  - ...

Applications

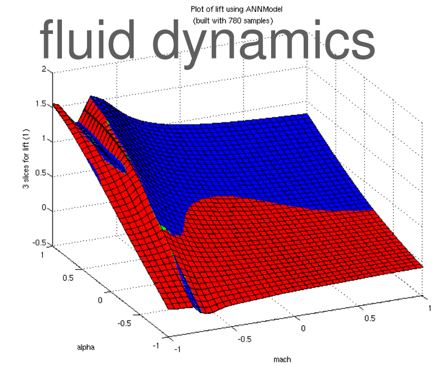
electronics



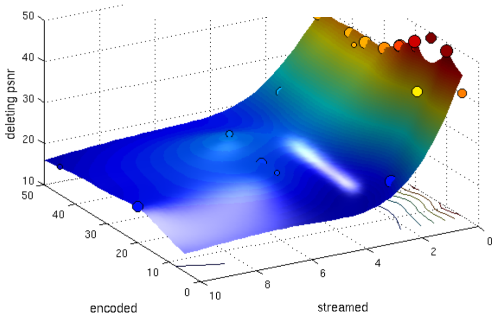
telecom

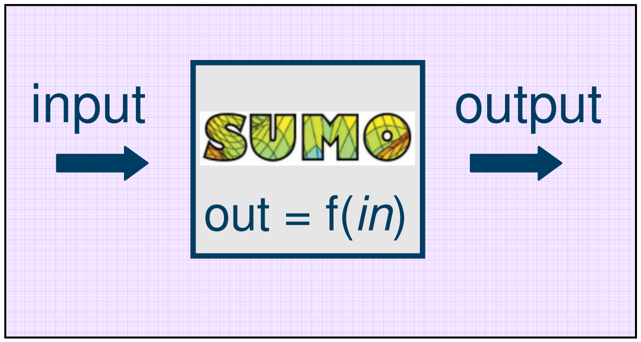


fluid dynamics

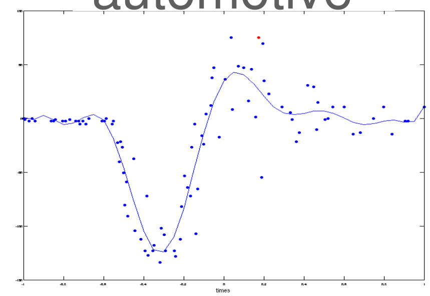


multimedia

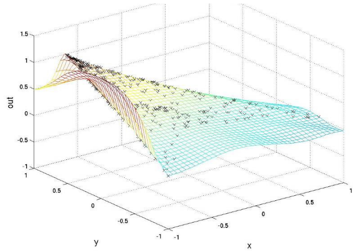




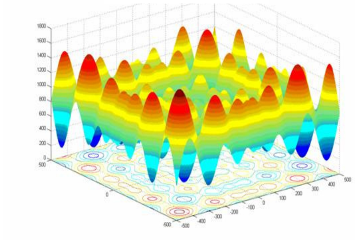
automotive



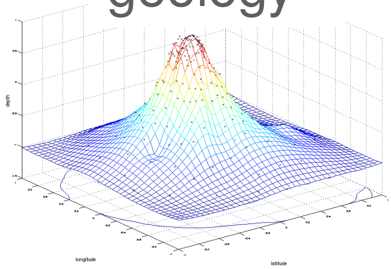
chemistry



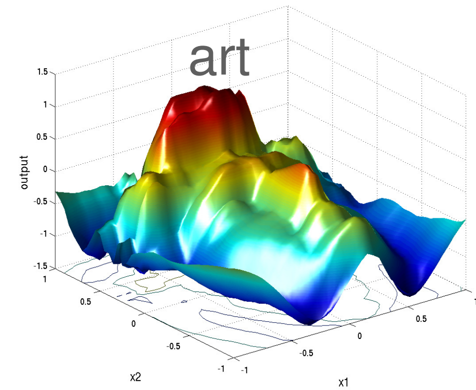
math



geology



art



Surrogate Modeling Lab – www.sumo.intec.ugent.be
Department of Information Technology (INTEC) - IBCN

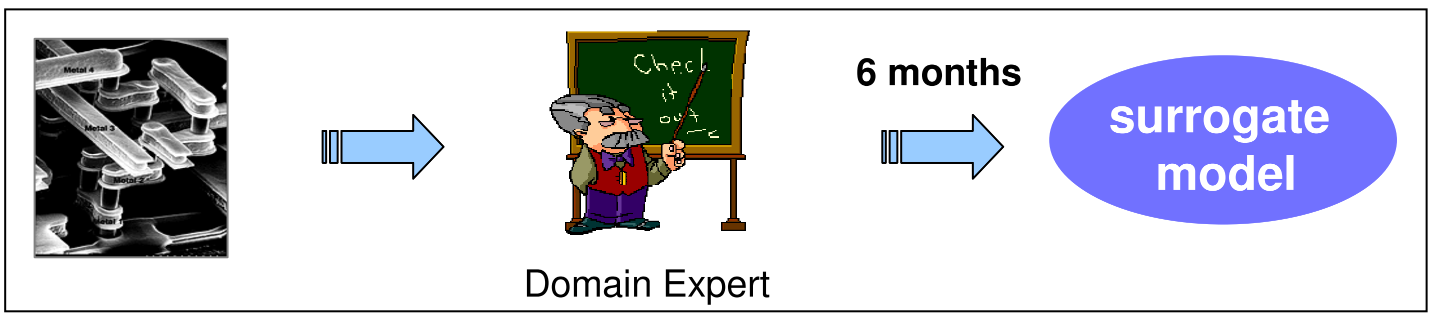
- challenges – research topics
  - experimental design ?
  - sample selection ?
  - model selection, model tuning ?
    - type (e.g. *ANN, SVM, RBF*, …)
    - complexity, hyperparameters (e.g. *#layers, #neurons* of ANN)
    - parameters (e.g. *weights* of ANN)
  - black box – grey box – white box ?

model assessment & selection crucial
only as good as data & designer

What are we looking for?

- **Grid-enabled adaptive algorithm for automatic surrogate model construction**
  - fully automated
  - minimize prior, problem specific knowledge
    - **trade-off**
  - minimal number of samples
    - **computationally expensive**
  - support for distributed computing
  - pre-defined accuracy
  - pluggable / extensible
    - **no one-size-fits-all**
  - integrate easily into the design process

- traditional approaches
  - discrete model library
    - database
  - look-up tables, combined with local curve fitting
  - hand-made analytical models
  - ...



(With thanks to Luca Daniel (MIT))

Existing approaches and techniques

- common drawbacks
  - oversampling / undersampling
    - waste of resources / important details missed
  - overmodeling / undermodeling
  - accuracy unknown
  - prior knowledge required
  - problem specific
  - "*not invented here*" syndrome

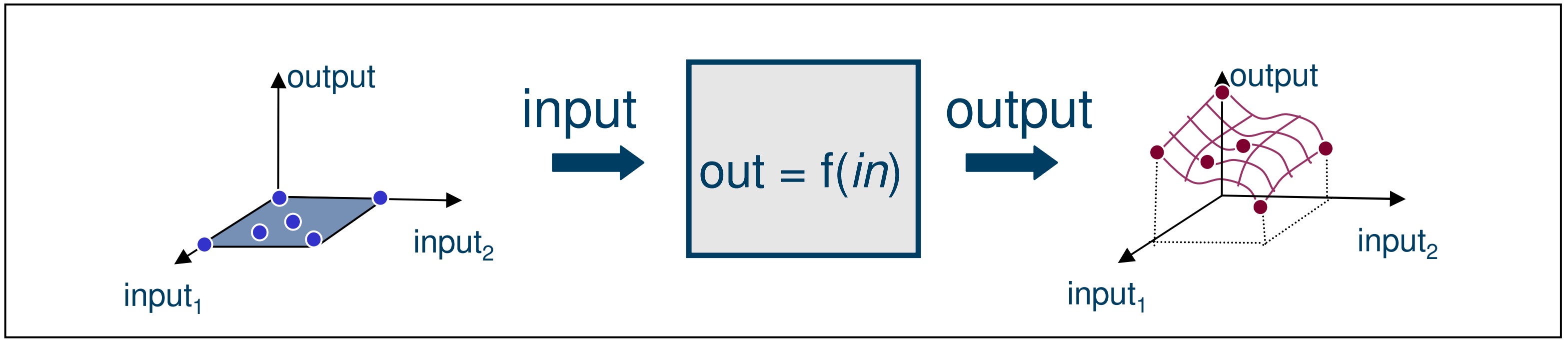
highly skilled modeler

several months of work

- **Who are we ?**
- **Introduction**
- **Surrogate modeling**
  - adaptive modeling
  - adaptive sampling
  - distributed computing
  - adaptive surrogate modeling
- **SUMO Toolbox**
- **Examples**
- **Conclusions**

Surrogate modeling

scalable **surrogate model**, valid over design space

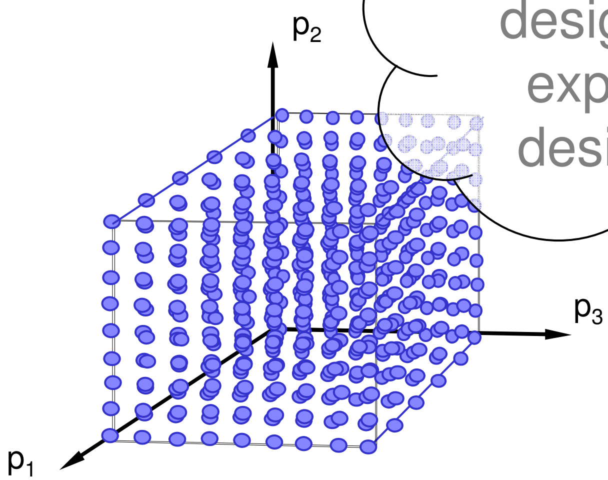


3 key technologies (+ 1 in development)

- adaptive data sampling
- adaptive model building
- distributed computing
- optimization

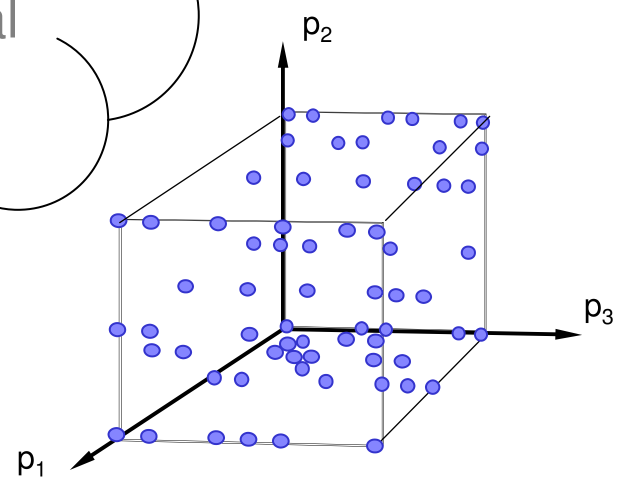
Adaptive Sampling

- traditional approach
  - uniform sampling
  - oversampling
  - undersampling



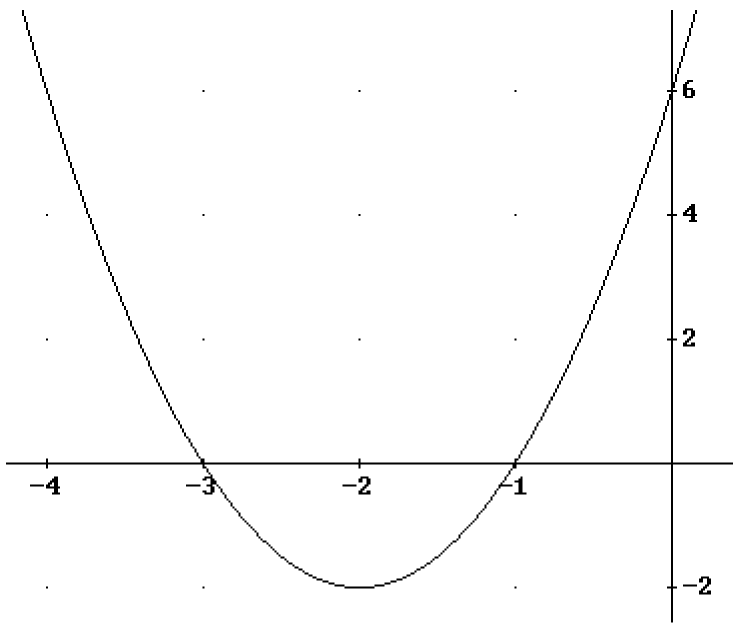
active learning, sequential design, optimal experimental design (OED)

- adaptive sampling
  - “optimal” sample distribution
  - *reflective exploration*

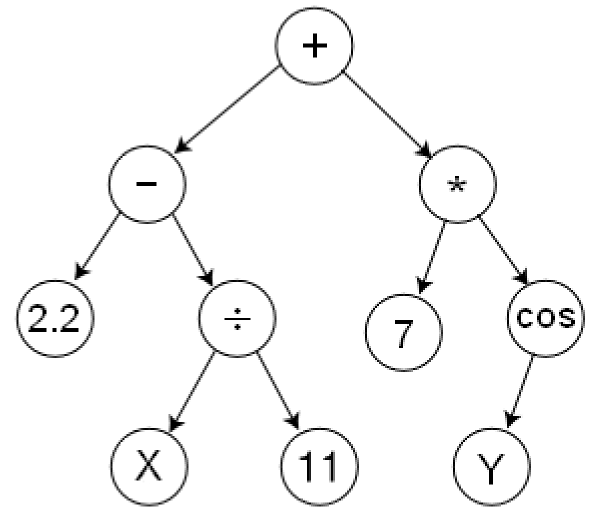


Adaptive modeling

- traditional approach
  - local approximation
  - overmodeling
  - undermodeling



- adaptive modeling
  - global approximation
  - optimal model complexity



$$\left(2.2 - \left(\frac{X}{11}\right)\right) + \left(7 * \cos(Y)\right)$$

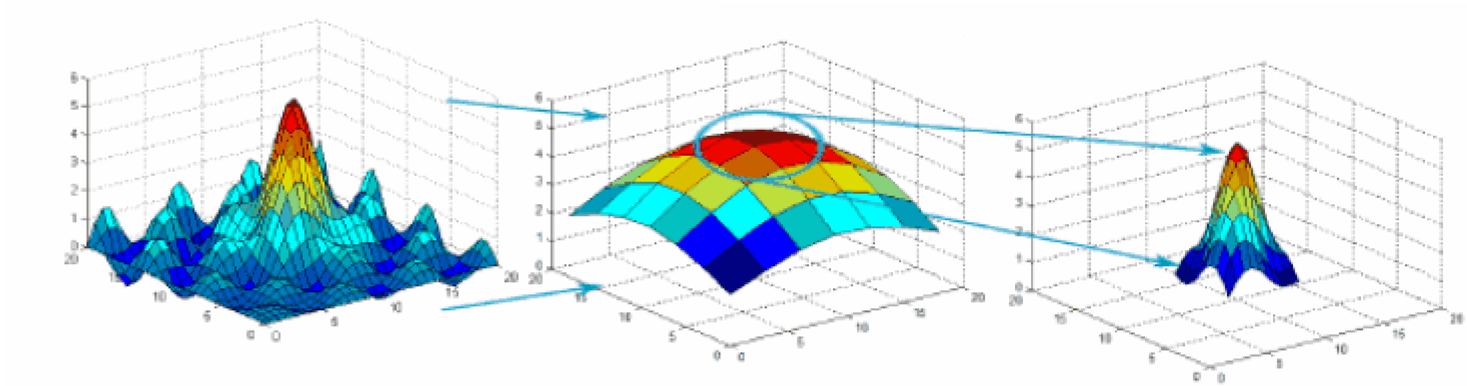
- traditional approach
  - sequential computing

- **distributed computing**
  - cluster
  - grid

Surrogates – *optimization*

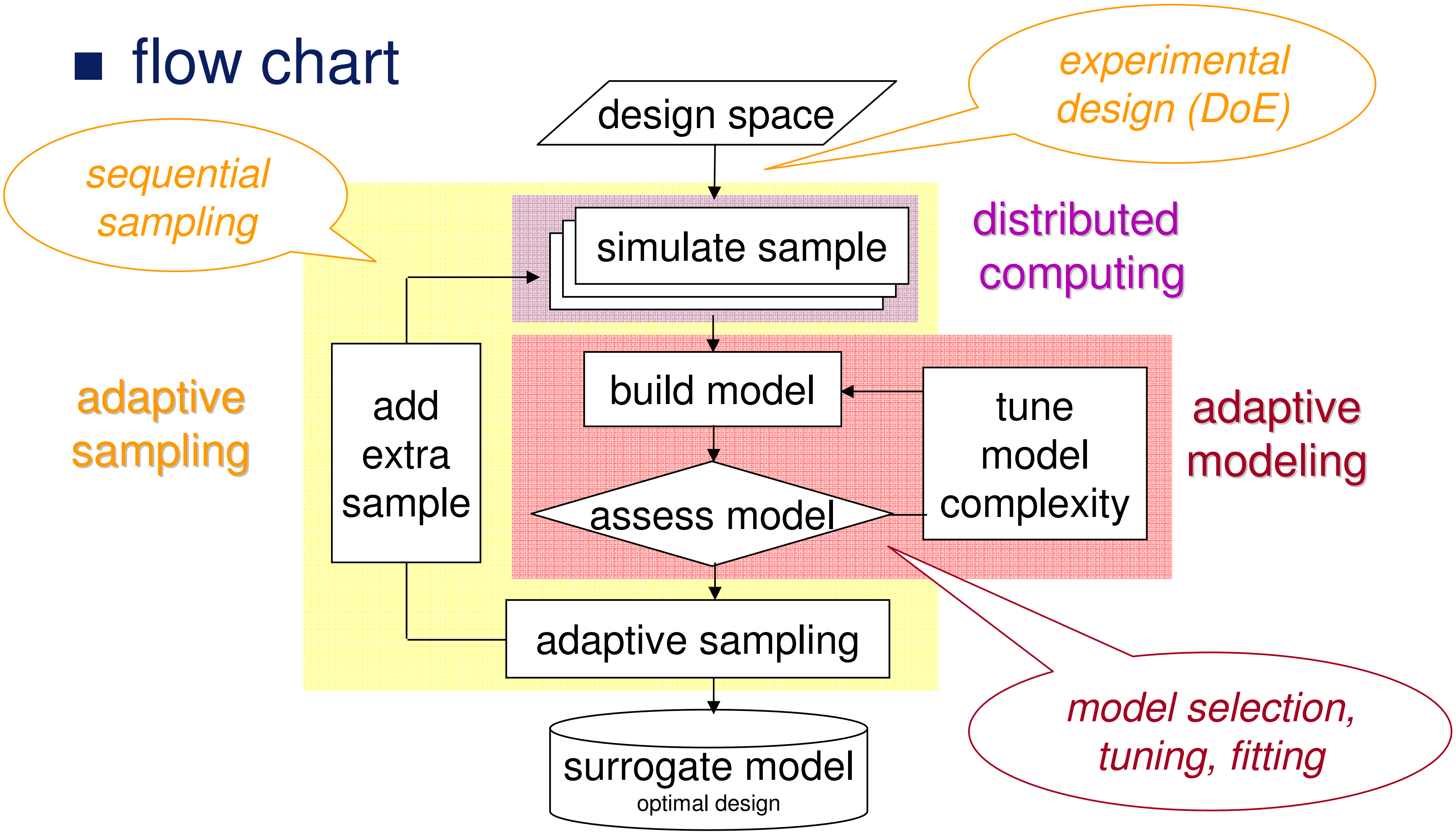
- traditional approach
  - classic optimization
    - not well suited for computational expense simulations

- Optimization
  - surrogate-assisted optimization
    - global surrogate model
    - intermediate surrogate models & zoom-in



Surrogate modeling – *flow chart*

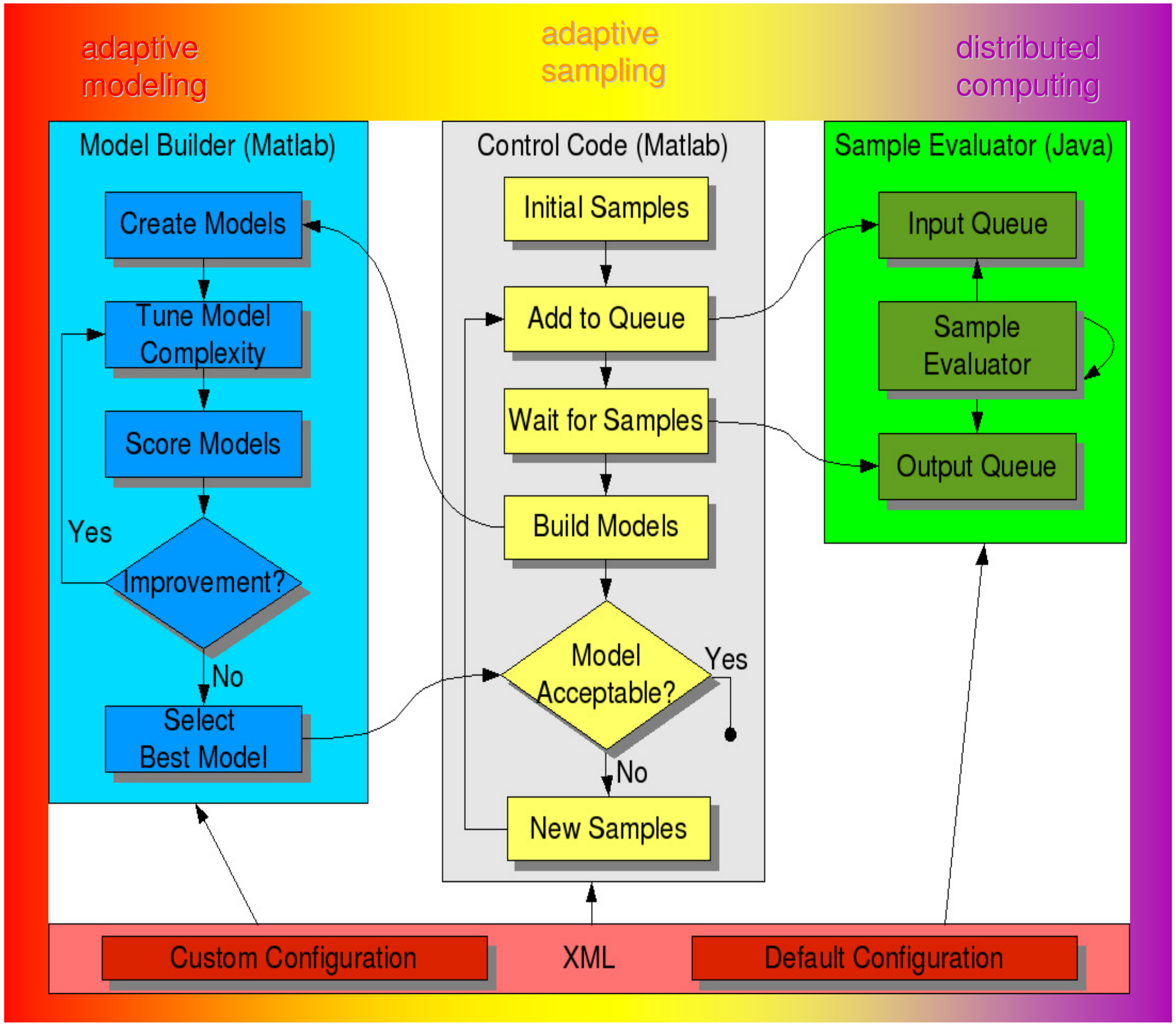
- flow chart



Outline

- Who are we ?
- Introduction
- Surrogate modeling
- SUMO Toolbox
  - control flow & design
  - automatic model type selection
  - integrating gridcomputing
- Examples
- Conclusions

SUMO toolbox – *control flow*



levels of pluggability

adaptive modeling

- supports multiple model types
  - Polynomial/Rational functions
  - Artificial Neural Networks
  - RBF models
  - Support Vector Machines
  - (Blind) Kriging models
  - Splines
- modeling algorithm (NSGA-II, pattern search, GA, PSO, ...)
- model selection (crossvalidation, hold-out, R^2, AIC, ...)

adaptive sampling

- initial experimental design (factorial, LHS, custom, ...)
- sequential design (error-based, density-based, hybrid, ...)

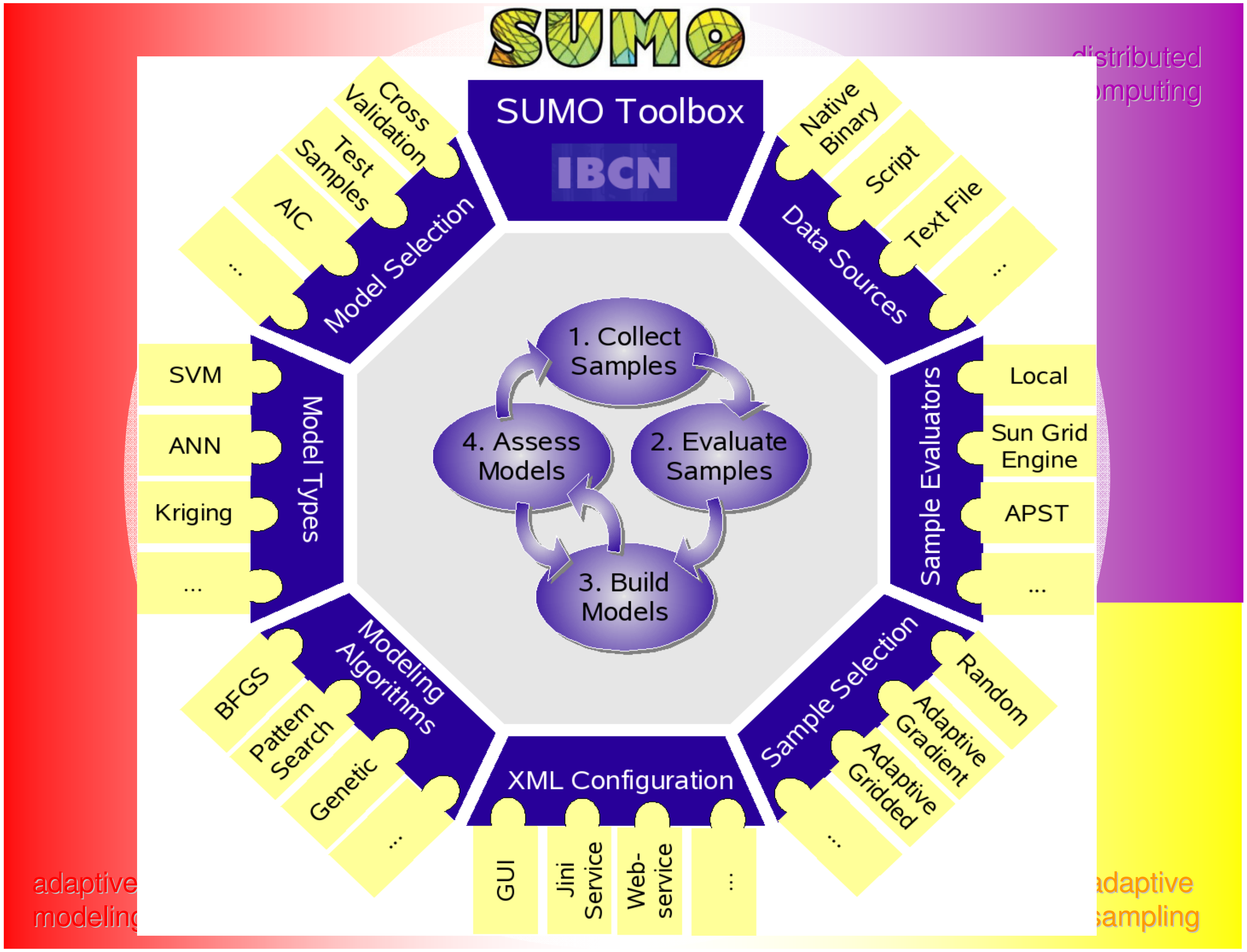
distributed computing

- sample evaluation (local, distributed)

optimization

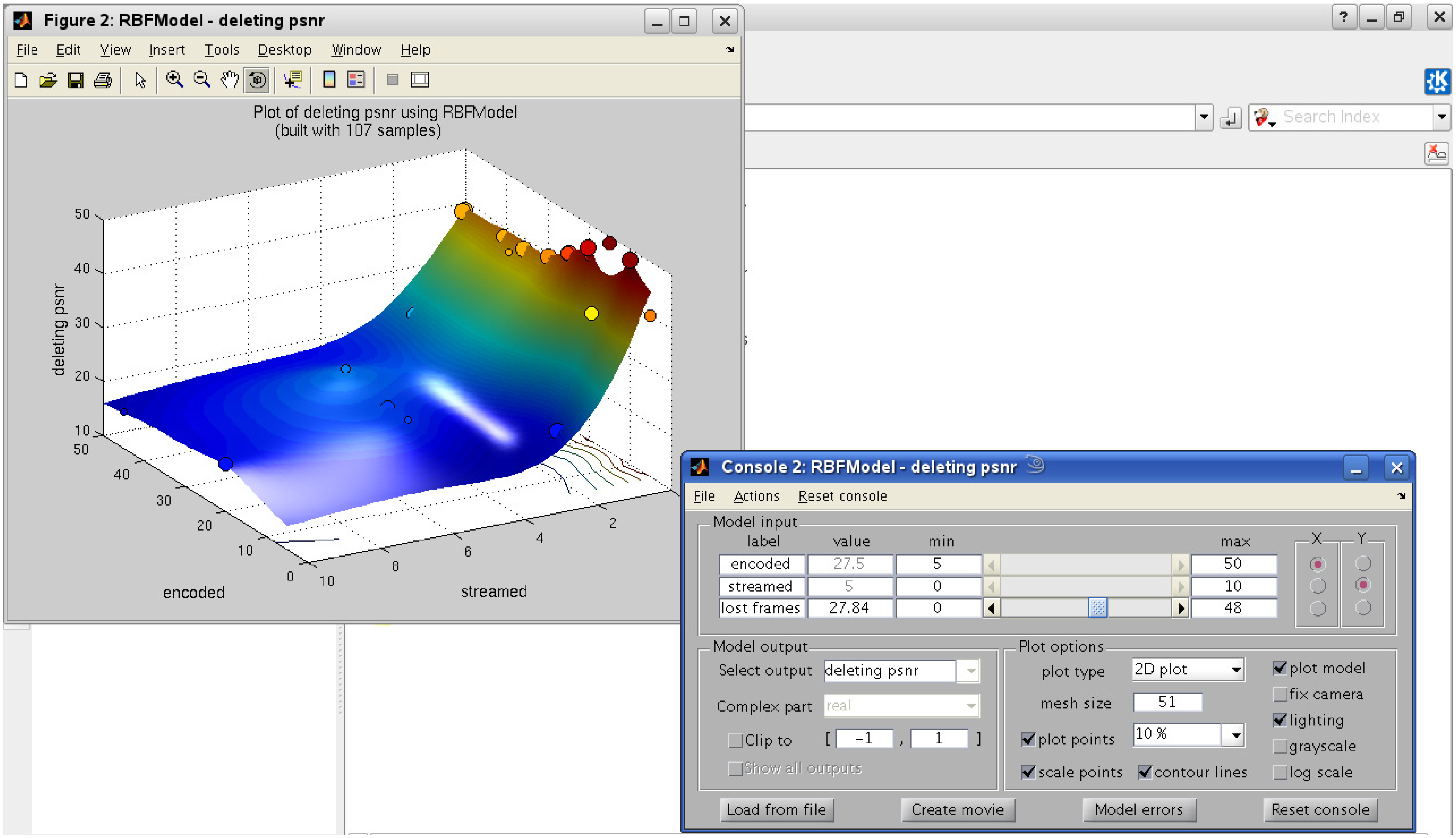
- multiple EGO criteria (GEI, EI, custom, ...)

SUMO toolbox – *pluggability*



- **SUMO Toolbox**
  - modular design to allow 3rd party extensions
    - **problem specificity can be controlled**
  - powerful XML based configuration framework
    - **modeling primitives can be combined in many ways**
    - **sensible defaults but many 'expert' options available**
      - user remains in control
  - extensive logging and profiling framework
    - **intermediate models (and plots) stored for further reference**
    - **understand behavior**
  - GUI Tool for easy visualization and data exploration

SUMO Toolbox – *GUI*



Model type selection

- **however, which plugins to use?**
  - most important within adaptive modeling
- **many surrogate model types available:**
  - Rational functions, RBF models, Kriging, MLP, RBFNN, SVM, LS-SVM, regresison trees, splines, ...
- **which type to use?**
  - problem & data dependent
  - little theory available
    - **e.g., rational functions and EM data**
  - usually pragmatic
  - impossible to solve in general

Model type selection

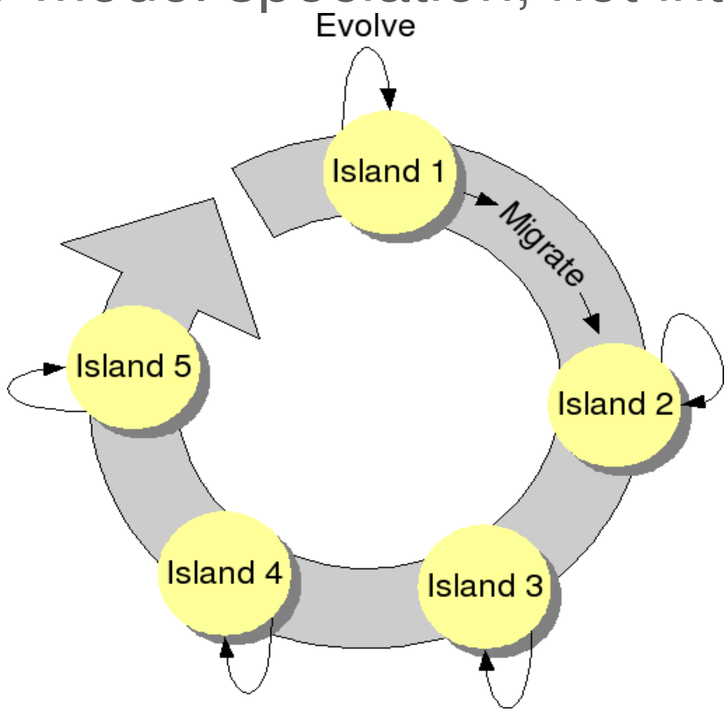
- **each model is characterized by parameter set θ**
- **how to select θ_i?**
  - by hand?
  - rule of thumb?
  - optimization algorithm?
    - **BFGS, GA, pattern search, simulated annealing, PSO, ...**
- **optimization landscape is dynamic!**
  - cfr. adaptive sampling

Model type selection

- **SUMO Toolbox makes it trivial to run and compare different methods**
- **however, an idea...**
  - Tackle the model type selection and model parameter optimization problem in one speciated evolutionary algorithm
- **let evolution decide**
  - survival of the fittest
  - multiple final solutions possible
  - hybrid solutions possible (cfr. ensembles)
- **interesting population dynamics?**

Model type selection

- **island model (migration model)**
  - most natural
  - ring topology with different migration directions
  - NB: inter-model speciation, not intra-model

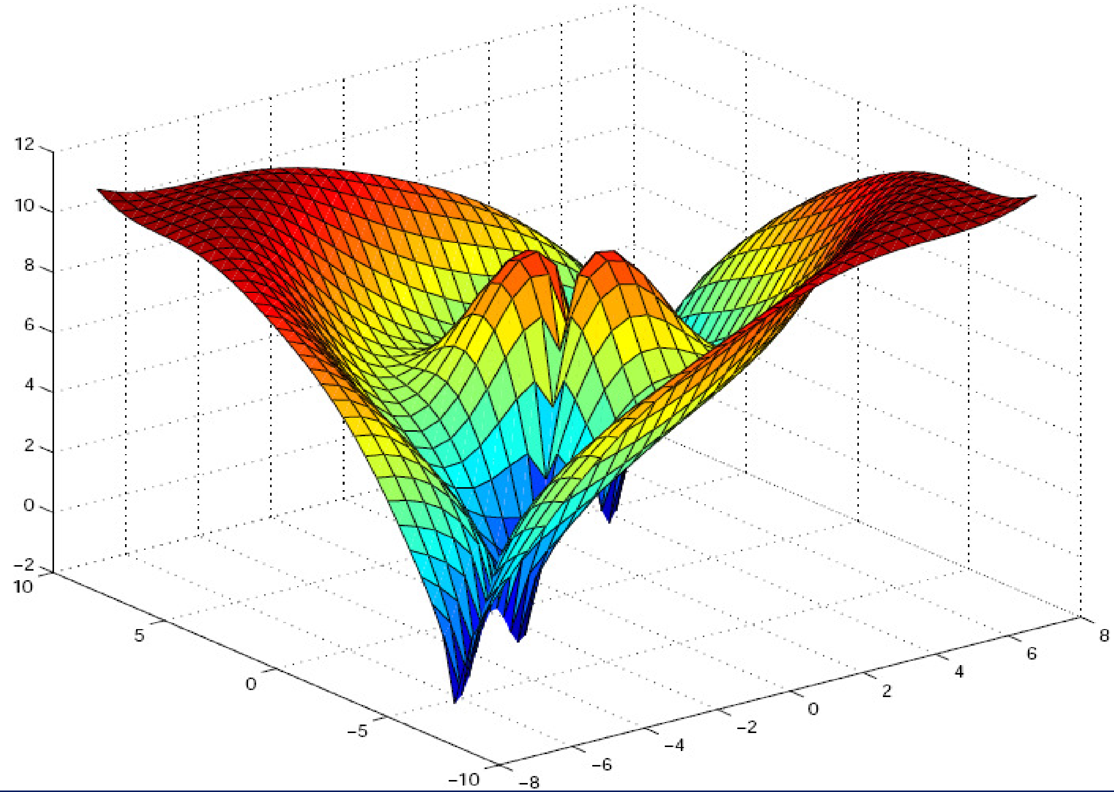


Model type selection

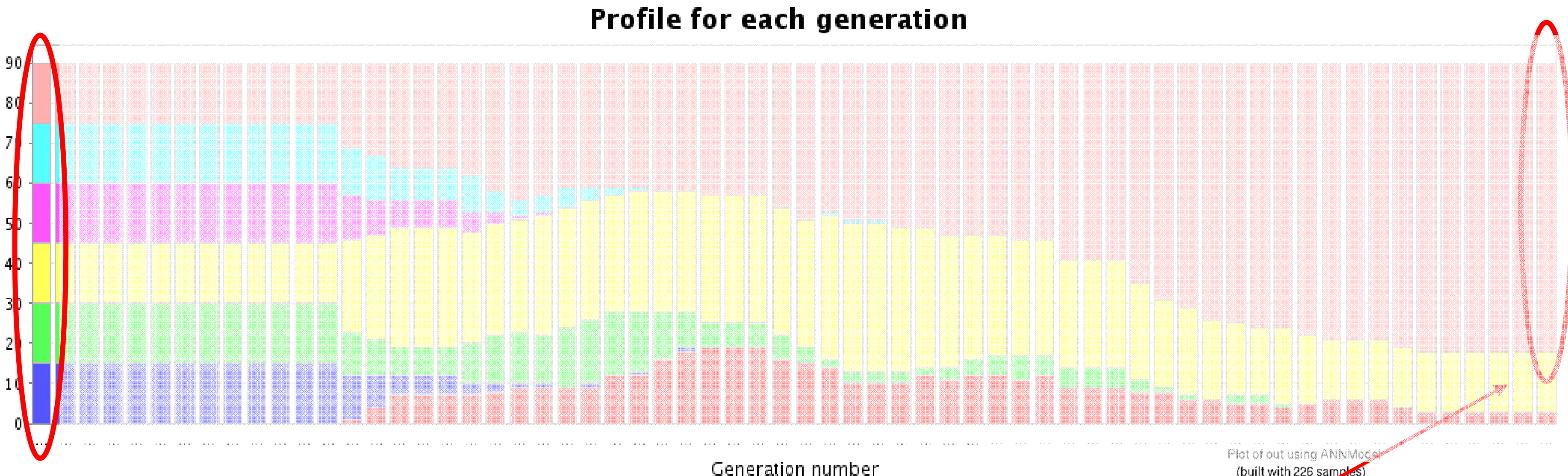
- **heterogeneous recombination**
  - Rational model x SVM = ???
- **use ensembles**
  - phenotypic (behavioral) recombination
  - avoid when possible
  - many ensemble methods
    - **use simple average**
    - **others can easily be used instead**

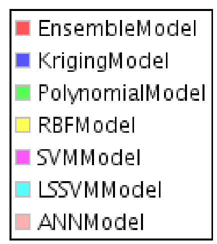
- **3D example** *(z=0)*

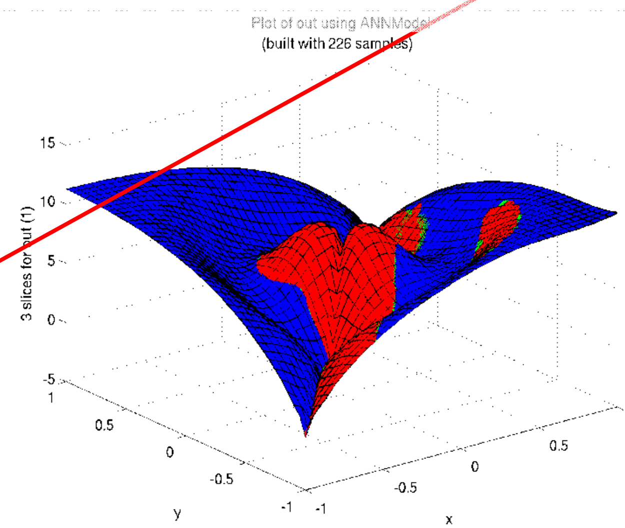
$$f(x,y,z) = 7\,\frac{\sin(\sqrt{x^2+y^2})+\epsilon}{\sqrt{x^2+y^2}} + 3|x-y|^{1/2} + 0.01z$$



Model type selection

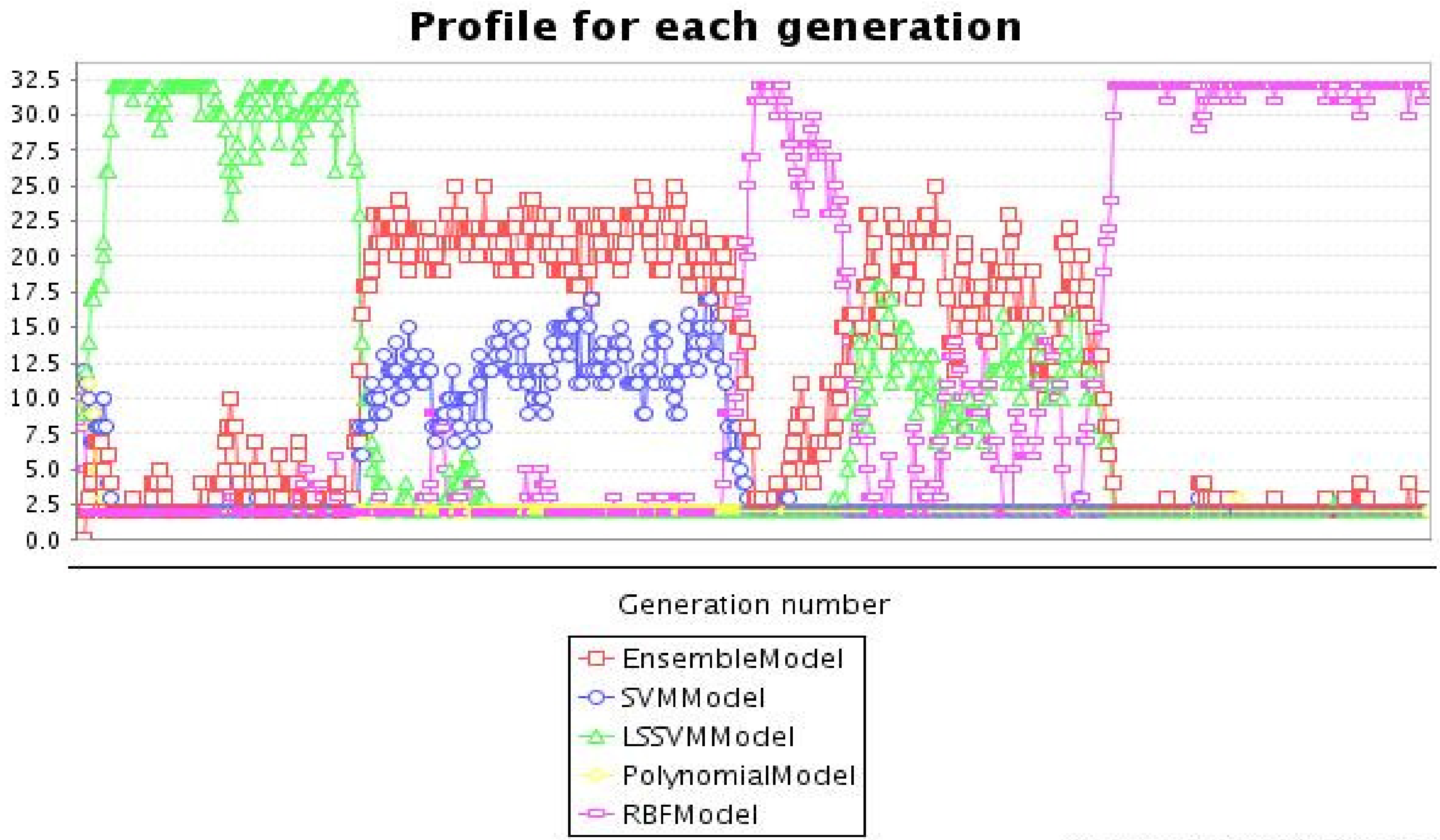






- Model type selection
  - start with 6 model types
  - after multiple "generations", favourable model(s) automatically selected

Model type selection



Generated using the M3-toolbox

Model type selection

- **promising results**
- **computation time ≤ pure sequential**
- **delivers more insight**
- **however**
  - model type selection is not solved absolutely
    - **theoretically impossible without assumptions**
    - **GA meta parameters expected to be more robust**
  - sensitivity to migration/selection parameters?
  - constraints on reproducibility?

Model Assesment

- **Ok, we have generated a model**
  - Why should you trust it?
- **Available assessment metrics depend on**
  - the model type
  - the problem requirements
- **In general if only data is available**
  - => data or response based generalization estimaters (more than just accuracy!)
- **Some model types support more**
  - e.g., pole-zero rational models vs SVM
- **Golden standard : the domain expert**

Model Assesment

- **The SUMO-Toolbox can support**
  - Whatever the model type supports
  - Any metric that can be expressed as a function
    - *metric*(model) → $\mathbf{R}^n$
- **A metric can be..**
  - Checked manually at the end
  - Enforced during the model generation process
    - **As a constraint**
    - **As a penalty or score**
- **Note the ‘n’ in $\mathbf{R}^n$**
  - Multiple metrics can be combined
    - **Weighted sum**
    - **Multi-objectively**

Multi-objective modeling

- **stop once a good model is found**
- **problem: What is a good model?**
  - traditionally: one target accuracy/measure
  - e.g., average relative crossvalidation error of 5%
  - specified upfront

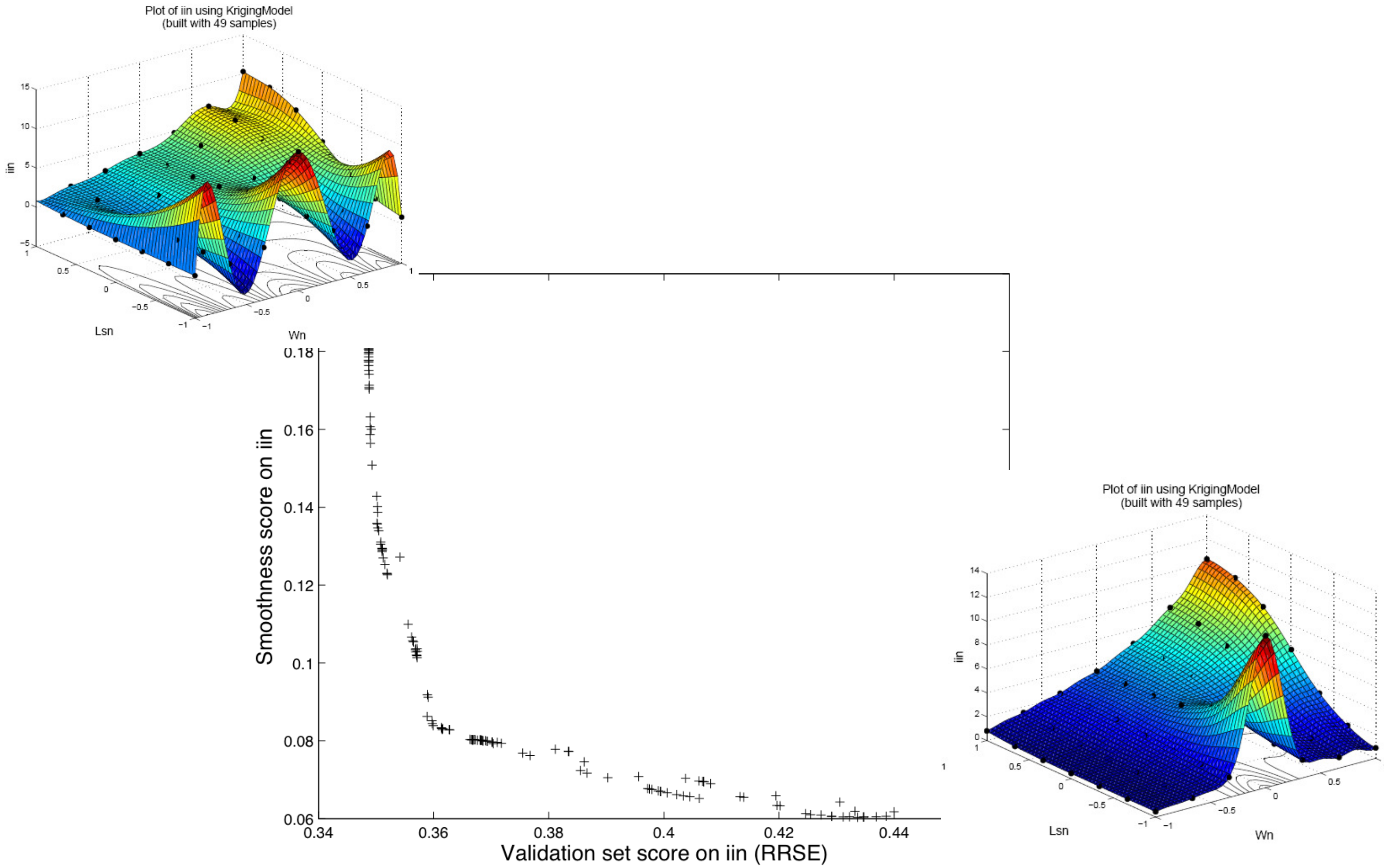
simplistic and impractical!

  - many desirable model properties
    - **smoothness, accuracy, generalization, complexity, ...**
    - **may conflict**
  - one metric cannot capture all requirements
  - upfront specification is hard (interpretability)
- **5% Problem**

Multi-objective modeling

- **model selection = inherently multi-objective**
- **different solutions**
  - scalarization, multi-level approach, multi-objective, hybrid, ...
  - each has different merits
- **multi-objective (MO) approach**
  - use standard MO algorithms for hyperparameter optimization (NSGA-II, AMALGAM, ...)
  - multi-output modeling
    - **enables automatic model type selection per output**
- **extension: dynamic number of objectives**

Multi-objective modeling



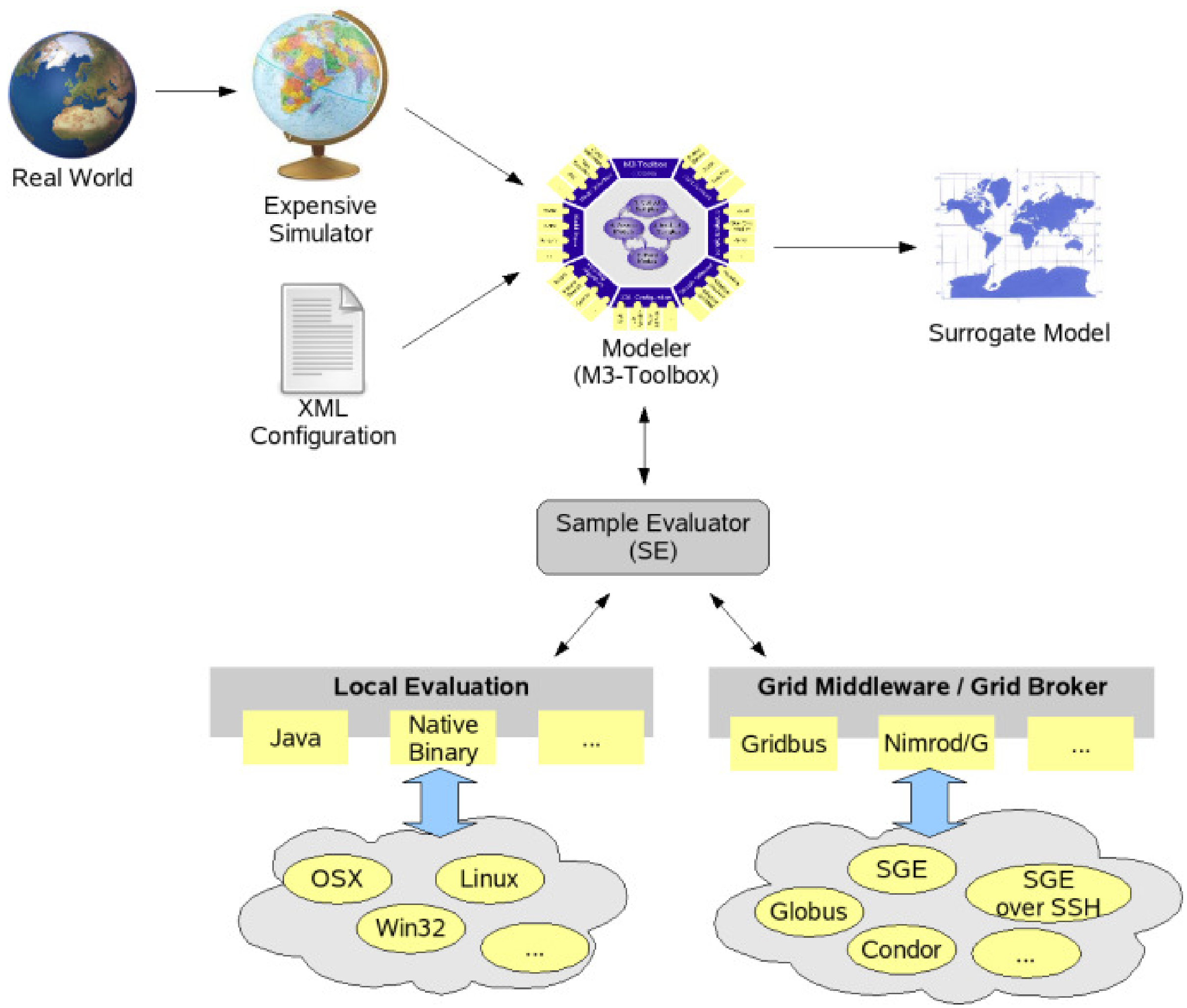
Integrating gridcomputing

- **Simulations are expensive**
  - Adaptive sampling
  - 1-time up front investment
  - Provide interface to the grid
- **Goal**
  - Transparent integration
  - Avoid middleware lock-in
  - Hide grid details
- **Integration on 3 levels**
  - Resource level
  - Scheduling level
  - Service level

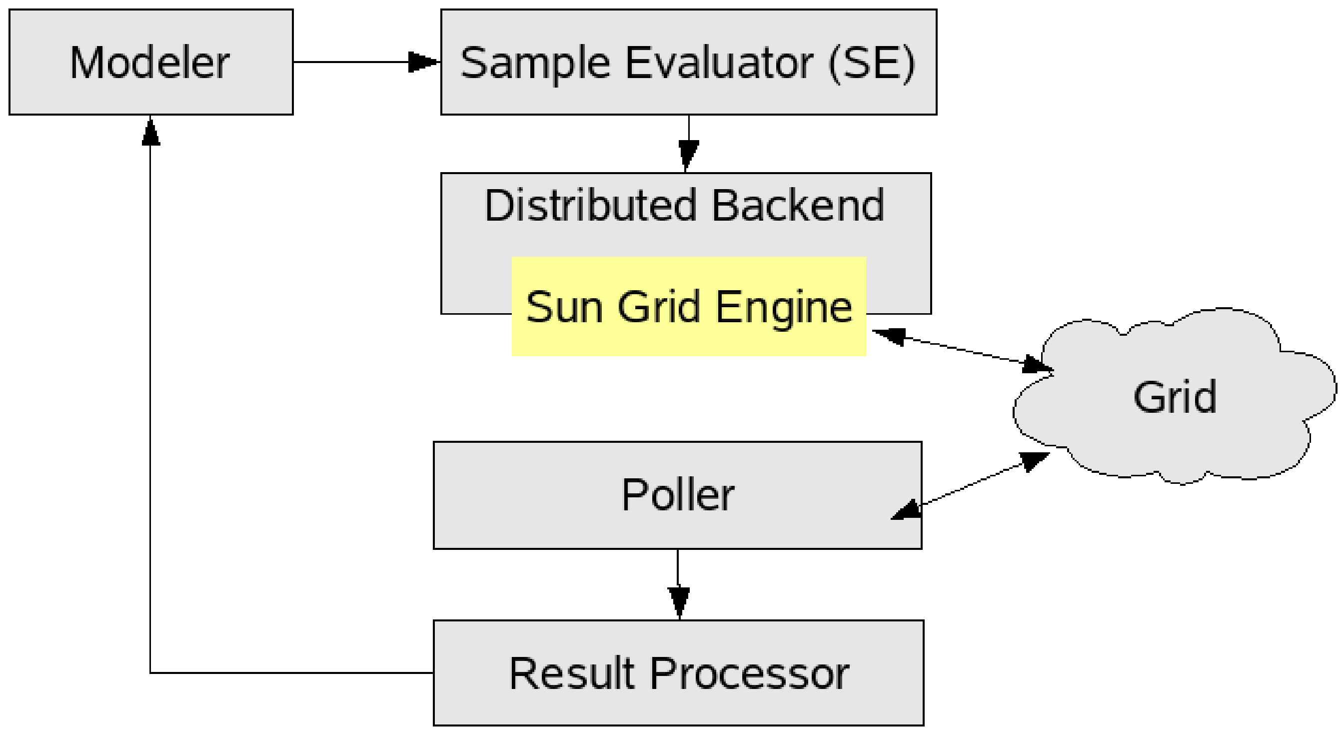
Integrating gridcomputing

- **resource level**
  - raw distribution
  - un simulations in parallel
- **SampleEvaluator abstraction**
  - cfr. flow chart
  - clean object oriented interface
  - translates modeler requests into middleware specific jobs
  - support multiple backends
    - **Sun Grid Engine**
    - **LCG middleware**
    - **APST**
    - **...**

Integrating gridcomputing



Integrating gridcomputing



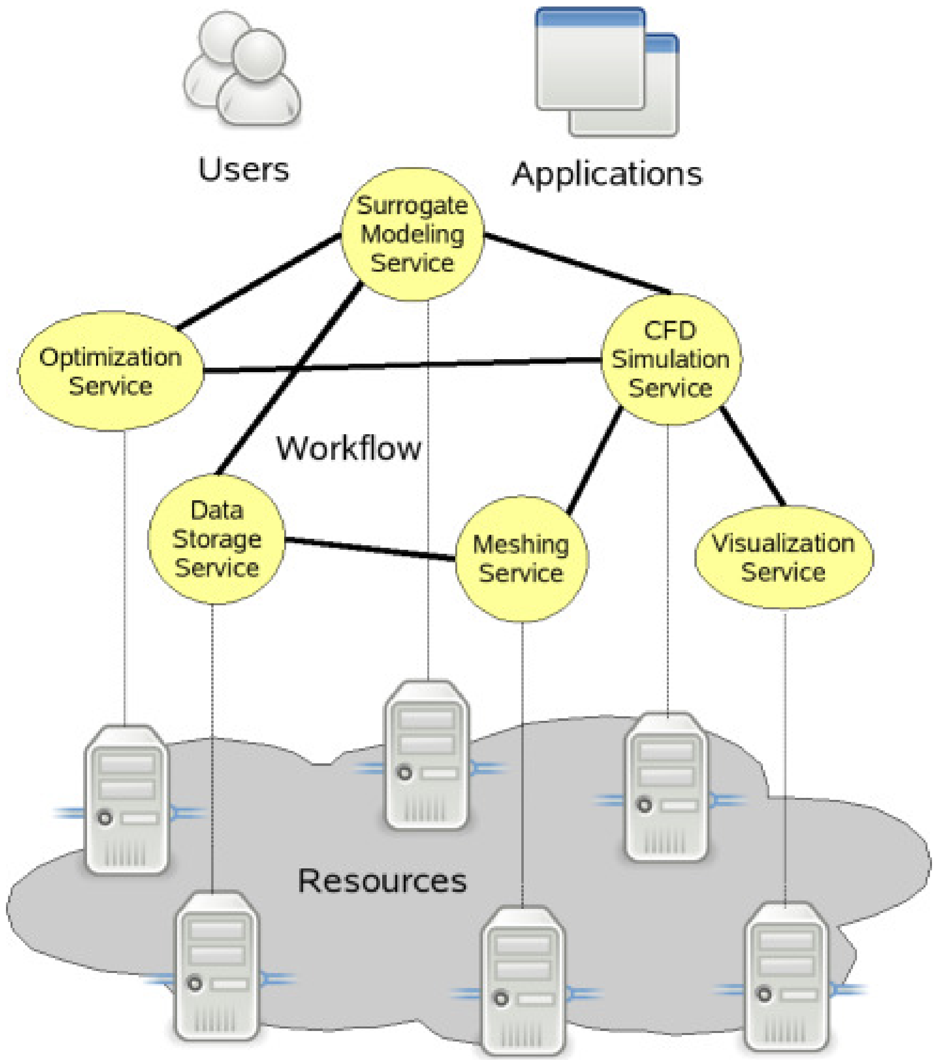
Integrating gridcomputing

- **scheduling level**
  - data points have different priorities
    - **e.g., domain borders, optima, sparse regions, ...**
  - compute resources are heterogeneous
  - resources are shared (dynamic!)
  - integrate grid resource information and modeling information into scheduling decisions

→ Application and resource aware scheduling

- **service level**
  - integration as part of a larger service oriented architecture (SOA)
  - easy access and integration into the design process
    - **web browser, Jini, SOAP, ...**
  - complicated workflows possible

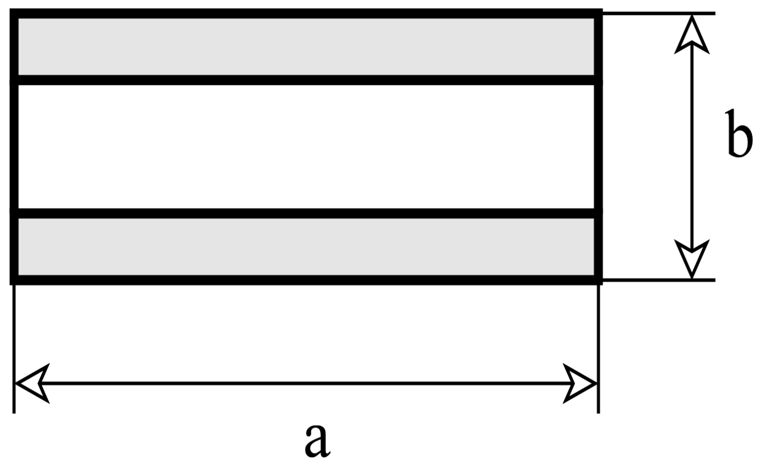
Integrating gridcomputing

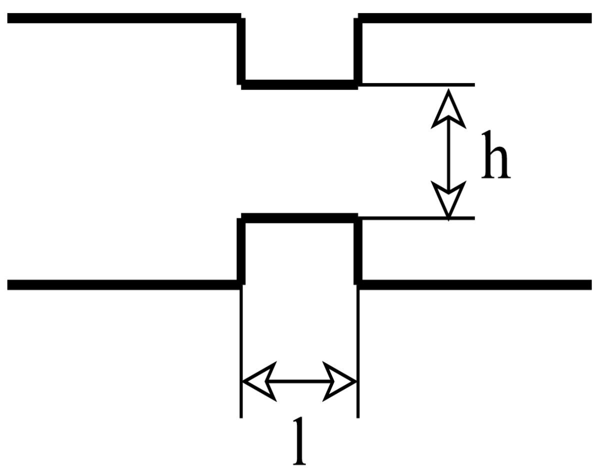


Outline

- Who are we ?
- Introduction
- Surrogate modeling
- SUMO Toolbox
- Examples
- Conclusions

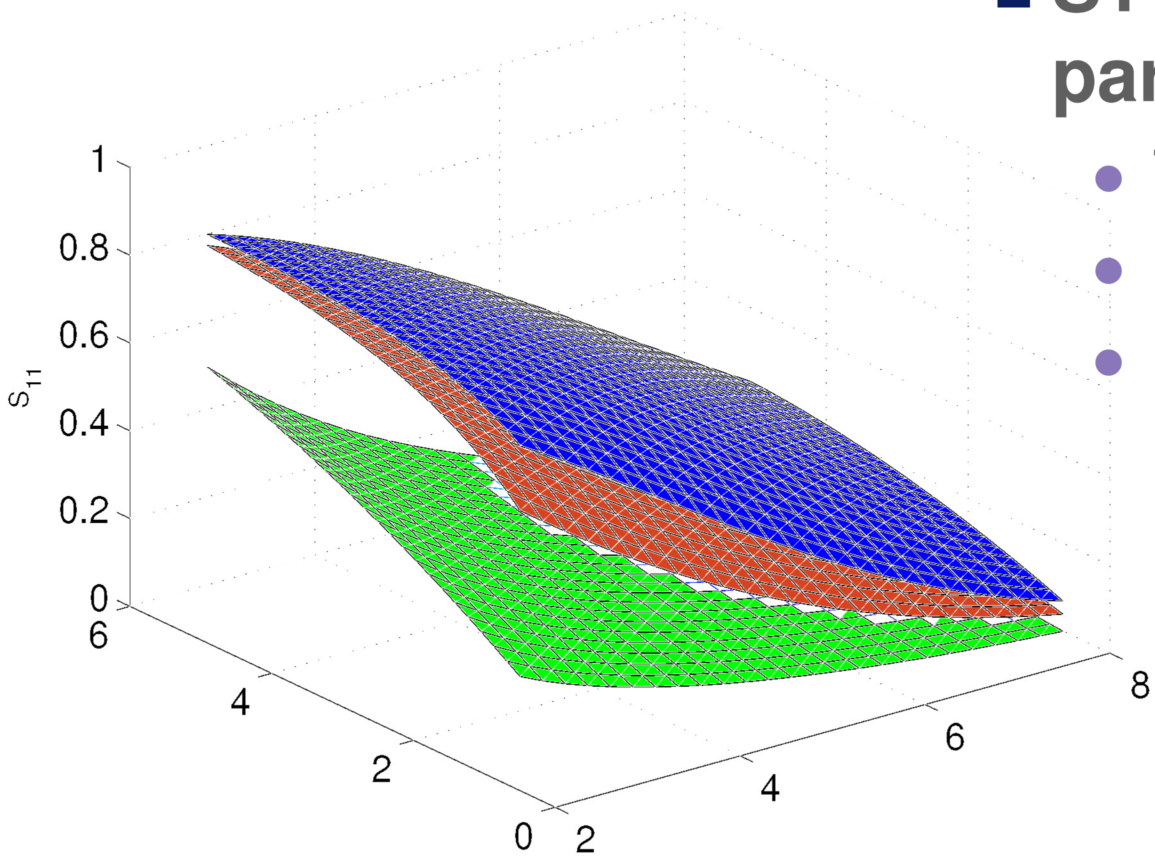
Example - Step Discontinuity (SD)





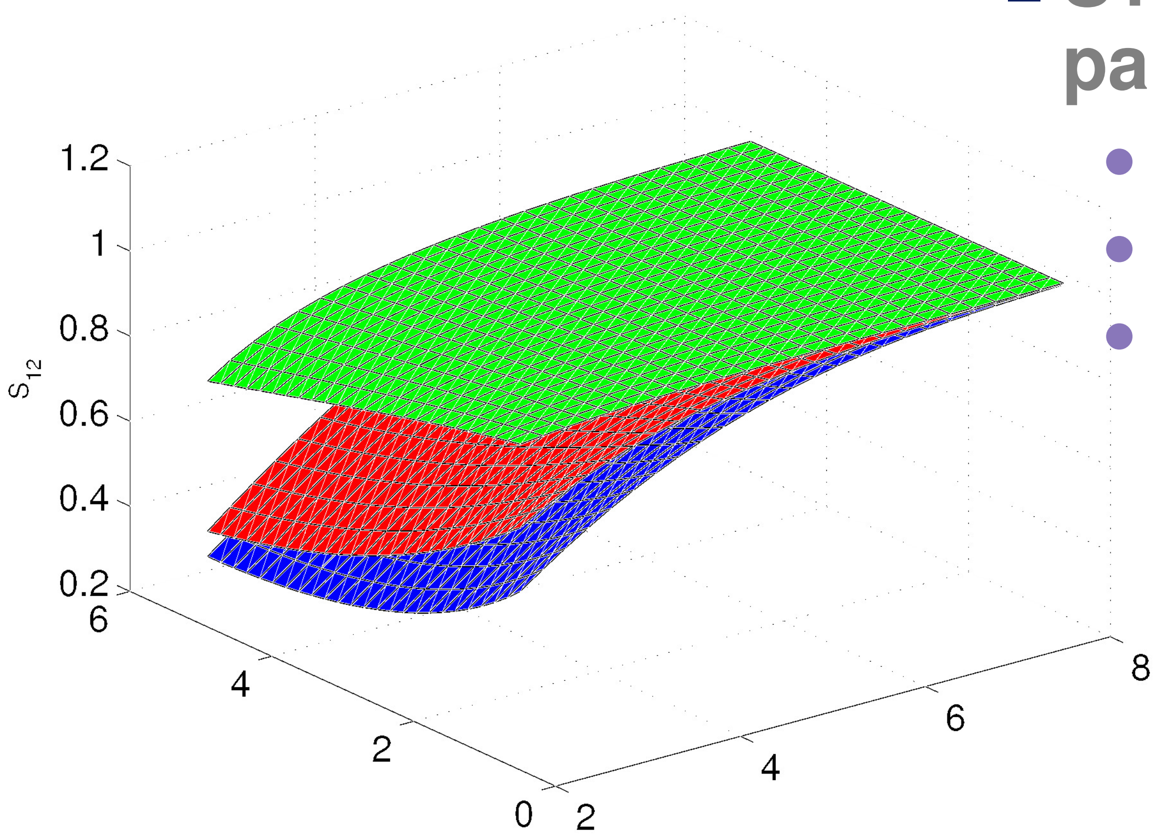
- **Step discontinuity in a rectangular waveguide**
  - Frequency : 7-13 GHz
  - Step length [l] : 2-8 mm
  - Gap height [h] : 0.5-5 mm
  - Waveguide width [a] : 22.86 mm
  - Waveguide height [b] : 10.16 mm
- **Distributed backend:**
  - Remote 256 node SGE cluster

SD : First output



- **S11 scattering parameter**
  - 7GHz (green)
  - 10GHz (red)
  - 13GHz (blue)

SD : Second output



- **S12 scattering parameter**
  - 7GHz (green)
  - 10GHz (red)
  - 13GHz (blue)

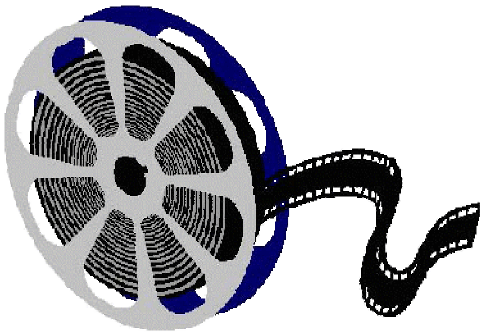
Simulator configuration

```xml
<Simulator>
    <Name>Step Discontinuity</Name>
    <InputParameters>
        <Parameter name="frequency" type="real" minimum="7" maximum="13"/>
        <Parameter name="gapHeight" type="real"/>
        <Parameter name="stepLength" type="real"/>
    </InputParameters>

    <OutputParameters>
        <Parameter name="S11" type="complex"/>
        <Parameter name="S12" type="complex"/>
    </OutputParameters>

    <Implementation>
        <Executable platform="unix" arch="amd64">StepDiscontinuity</Executable>
        <DataFiles>...</DataFiles>
    </Implementation>
</Simulator>
```

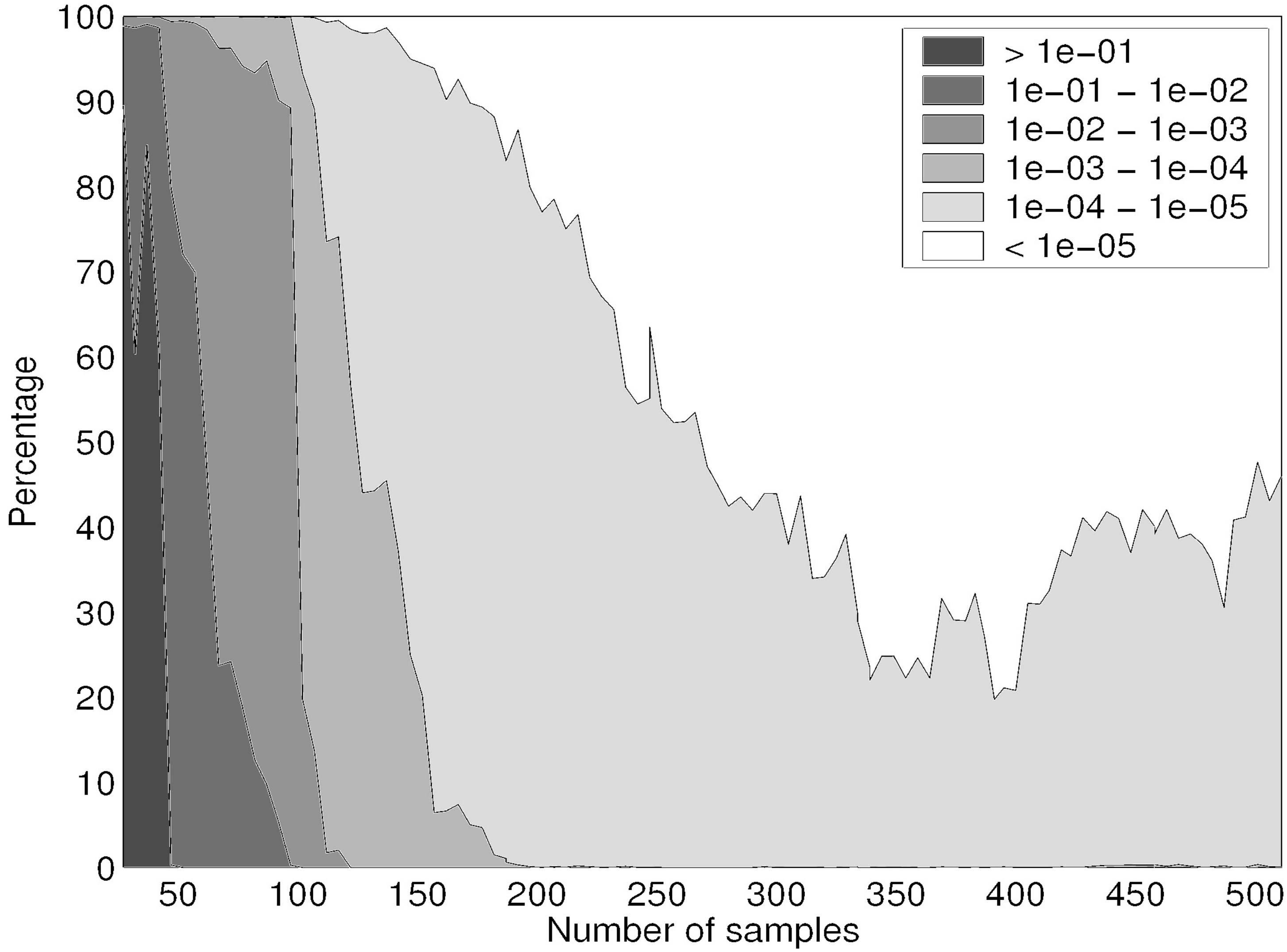
Toolbox configuration

```xml
<ToolboxConfiguration version="6.1">
    <Plan>
        ...
        <SampleSelector>gradient</SampleSelector>
        <Measure type="CrossValidation" target=".0001" errorFcn=”absoluteRMS” use="on" />
        ...
        <Run>
            <Simulator>StepDiscontinuity.xml</Simulator>
            <SampleEvaluator>sge</SampleEvaluator>

          <Outputs>
            <Output name="S11" complexHandling=”complex”>
              <AdaptiveModelBuilder>poly</AdaptiveModelBuilder>
            </Output>
            <Output name="S12" complexHandling=”split”>
              <AdaptiveModelBuilder>kriging</AdaptiveModelBuilder>
            </Output>
            <Output name="S11,S12" complexHandling=”modulus”>
              <AdaptiveModelBuilder>anngenetic</AdaptiveModelBuilder>
            </Output>
          </Outputs>
        ...
```

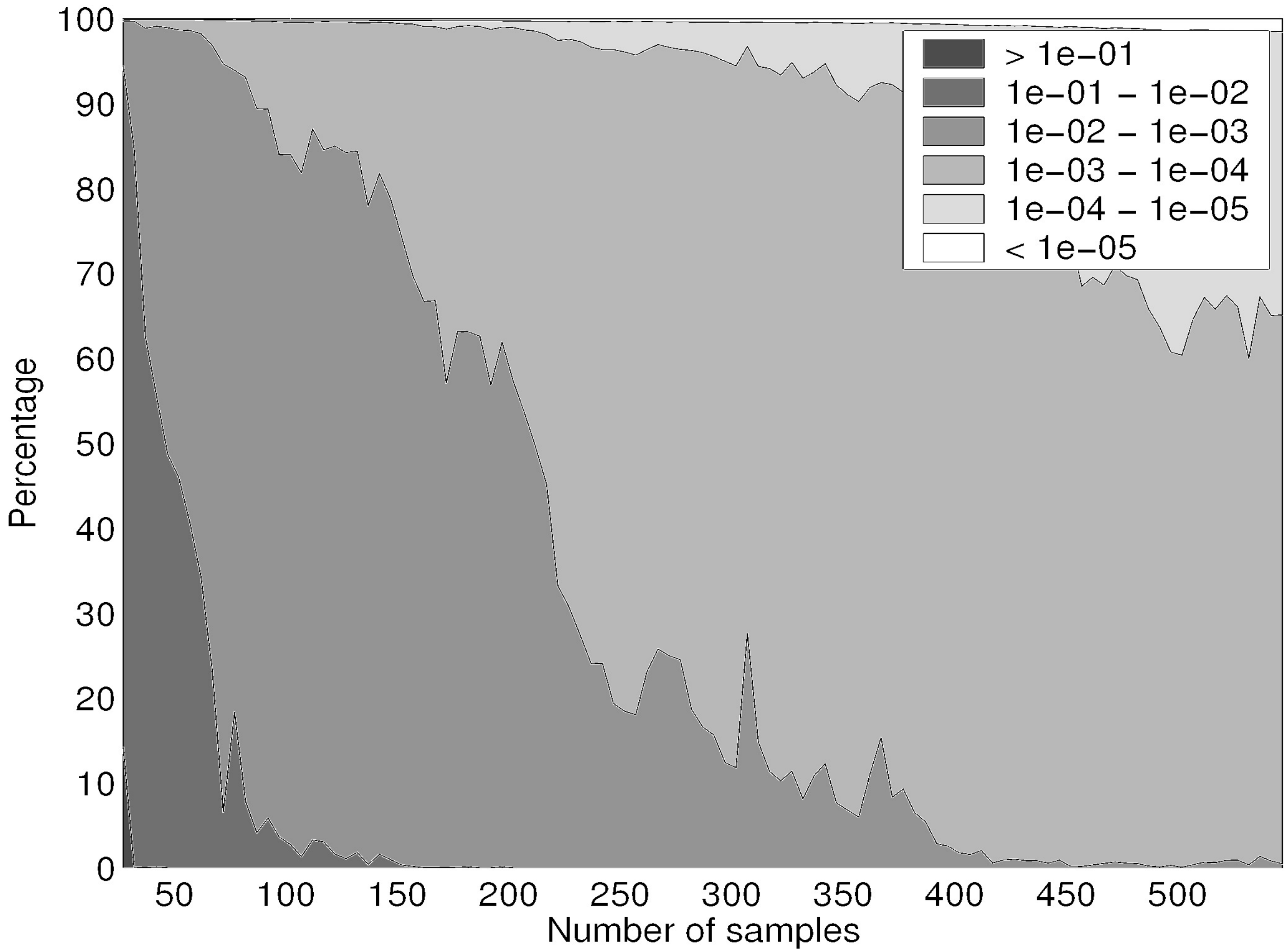
Modeling progres - Movie



Results – Rational models

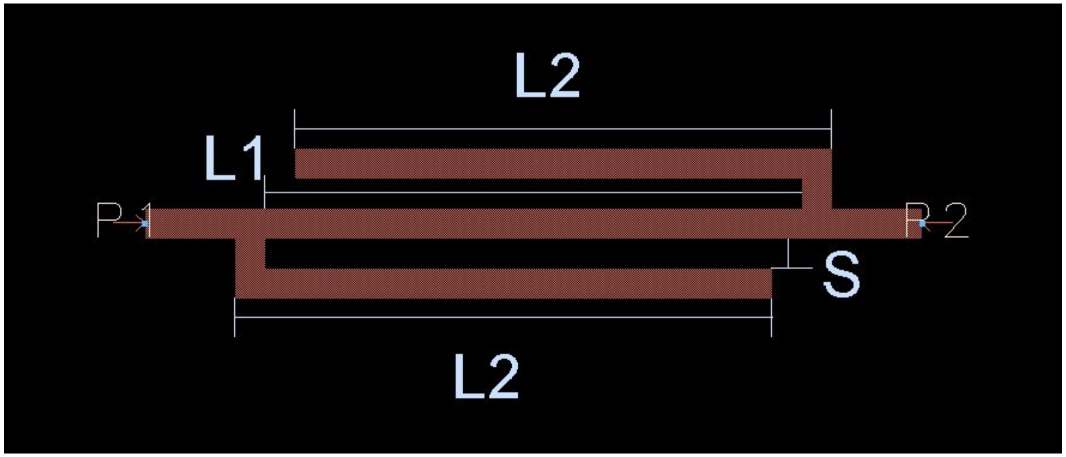


Results – RBF models



EM example : Filter

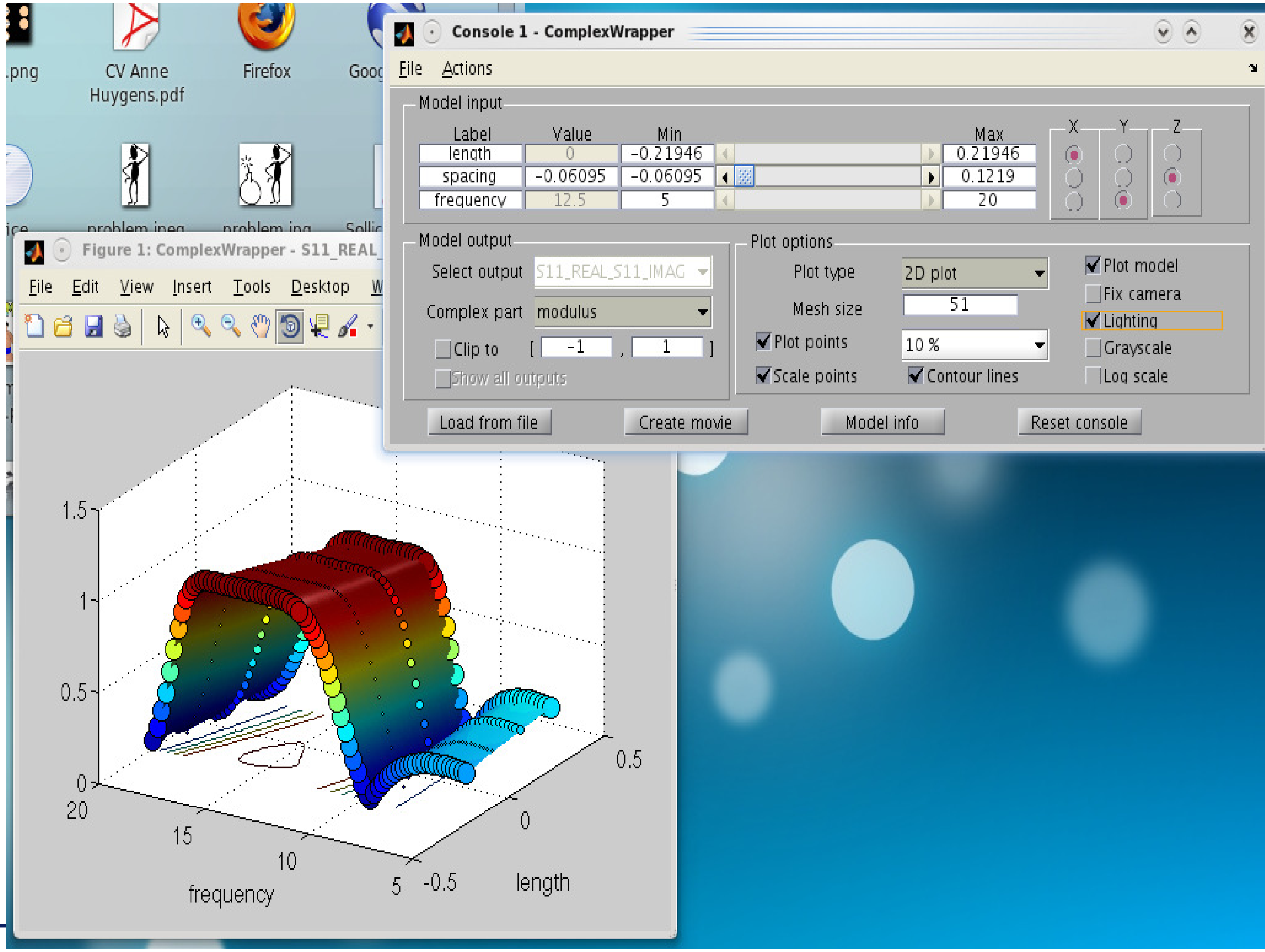
- **Double-folded microstrip stub bandstop filter** (see Bandler 1994)
  - Model scattering parameters
  - Simulated with ADS Momentum
    - **Input: L1, L2, frequency**
    - **Output: S11, S12**



EM example : Filter

- **Experimental setup**
  - Model with ANN
    - **topology selected automatically using a GA**
    - **Minimize (LRM + in-sample error)**
  - Select samples using a combination of
    - **Error based sampling and gradient based sampling**
      - Select samples where the model is uncertain and the response is non-linear
- **Important**
  - Momentum = a frequency domain solver
    - **Frequency is sampled automatically**
  - => only sample in L1-L2 space

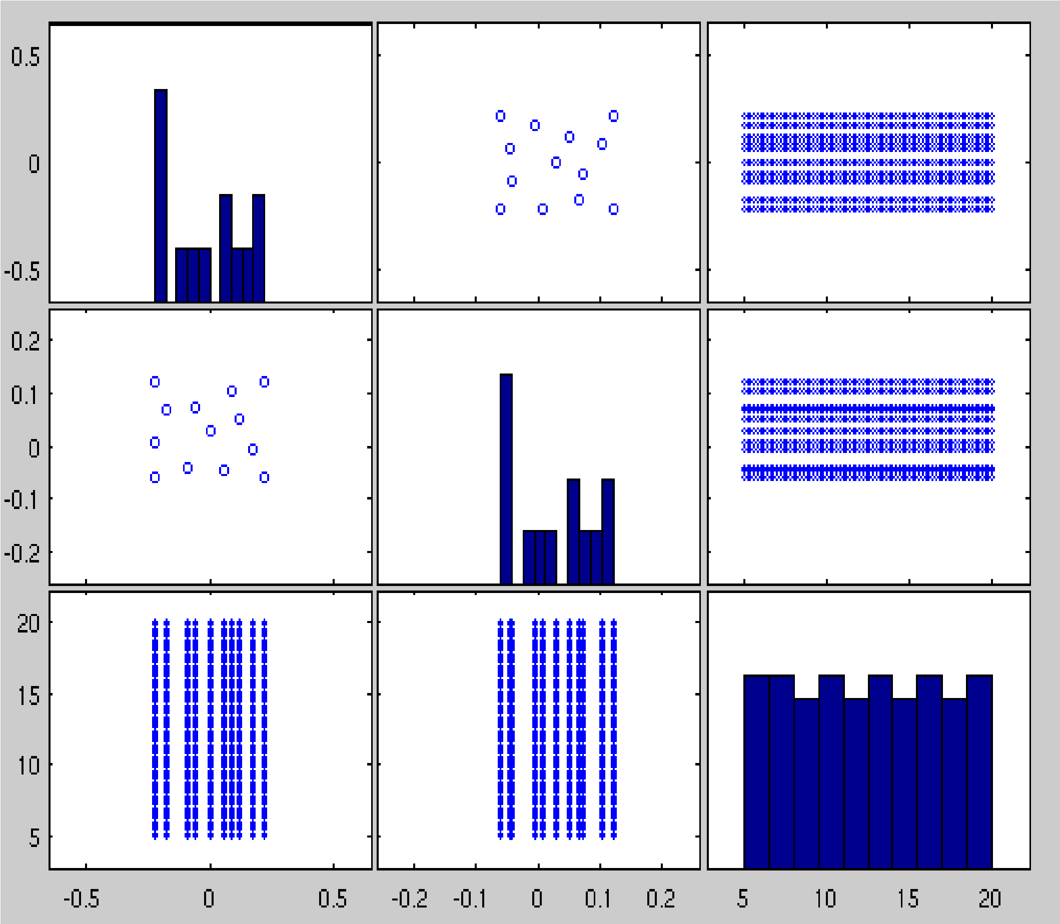
EM example : Filter



IBBT

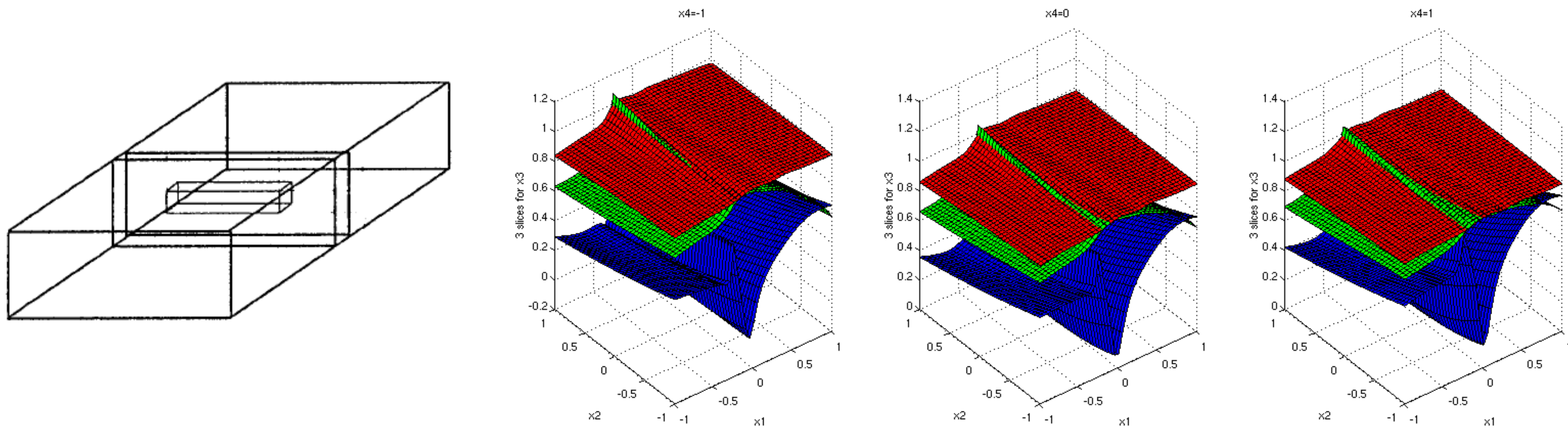
EM example : Filter

- **Sample distribution**

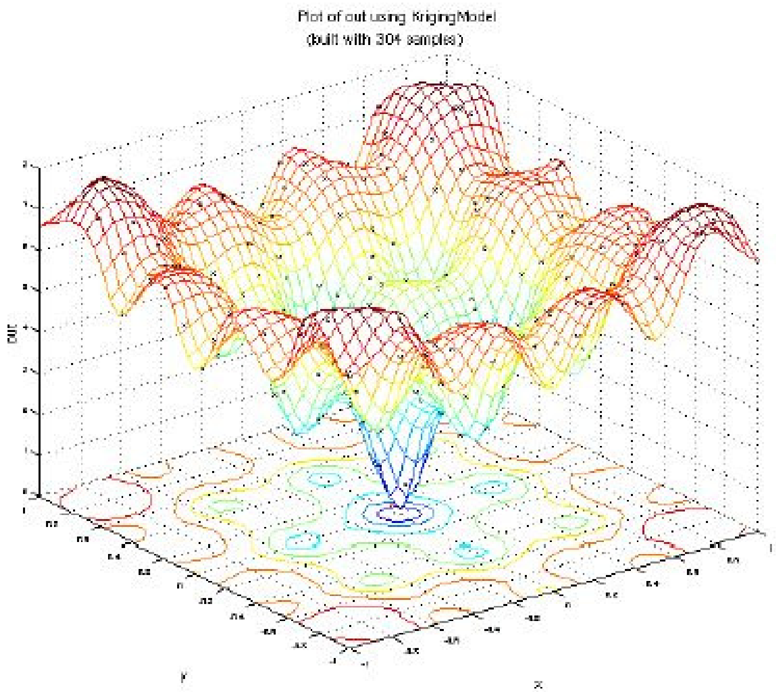


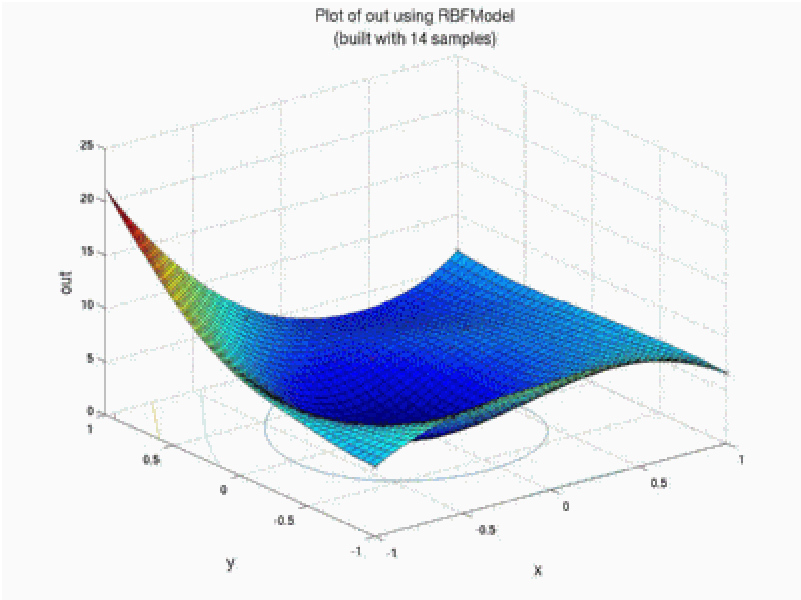
EM example: 3D Iris

- iris in rectangular waveguide (From Lamecki 2005)
  - Simulation of scattering parameters
    - Input : frequency, iris height, length, width,
    - Output : S11, S12

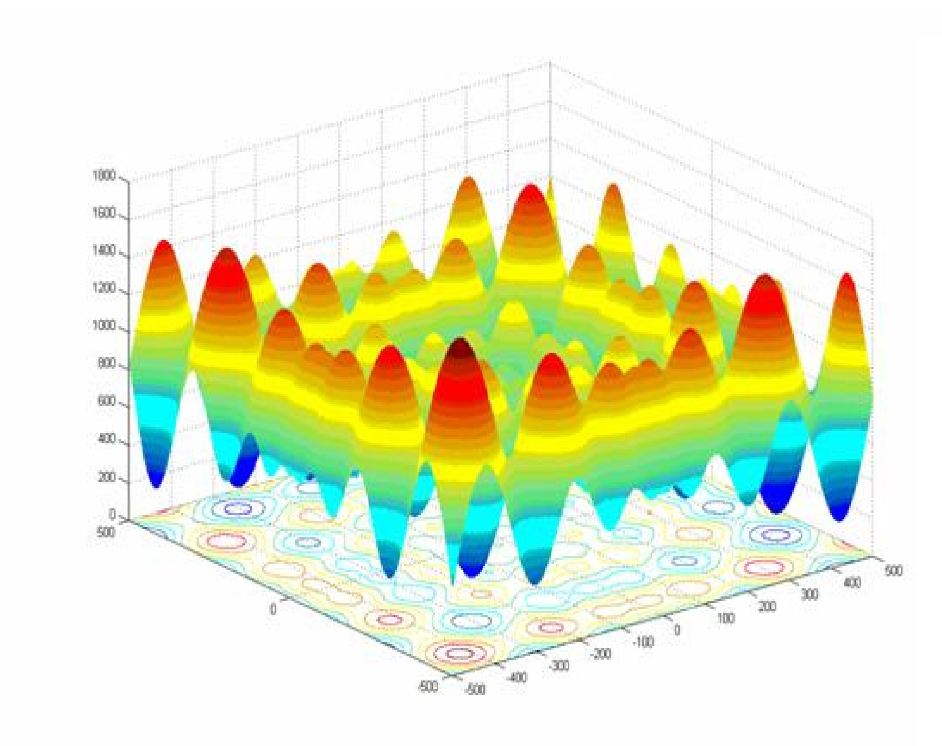


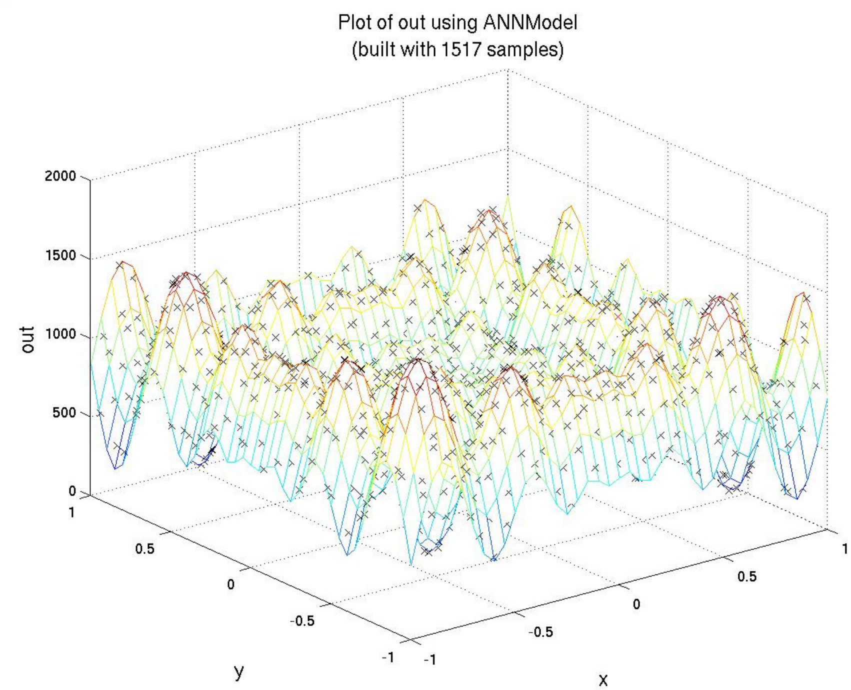
- Ackley function
  - Classic 2D test function from optimization





- Schwefel Function
  - Classic 2D test function from optimization





Chemistry example

- methane – air combustion (From Ihme 2007)
  - Simulation of temperature
    - Input : mixture fraction variable z, reaction progress variable c
    - Output : temperature

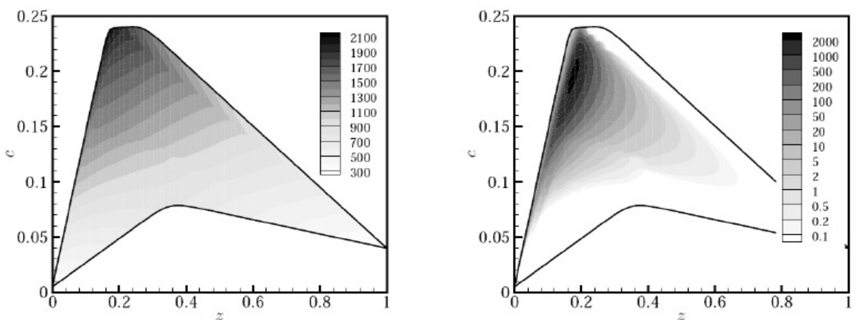
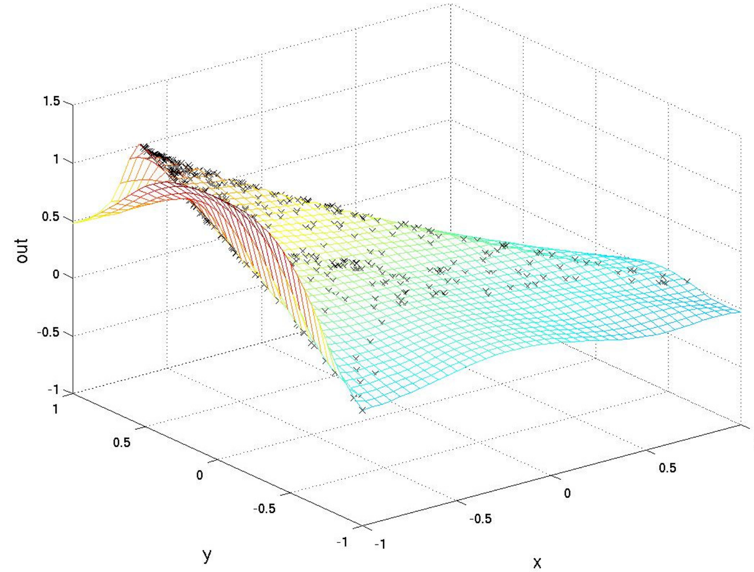


Figure 5.3: Solution of the steady laminar flamelet equations as a function of mixture fraction z and progress variable c; (a) temperature (K) and (b) chemical source term ($kg/(m^3s)$) (Source: [77])

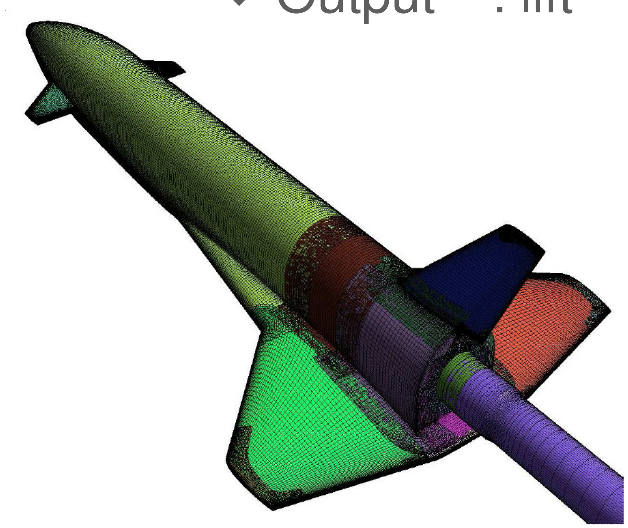


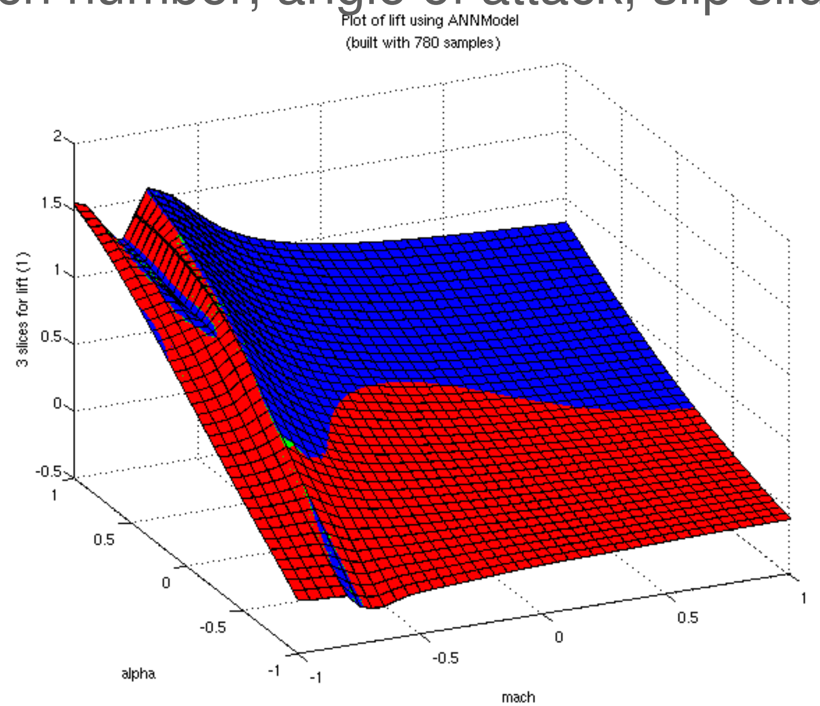
Aerodynamics example

- re-usable Langly Glide Back Booster (LGBB)

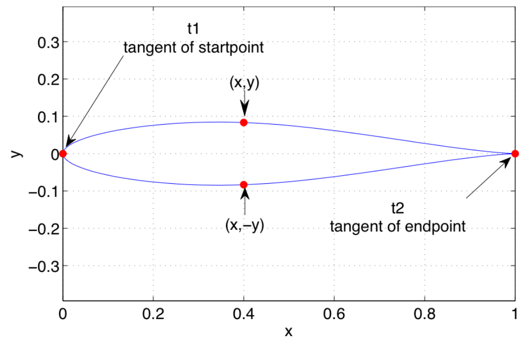
  (From Gramancy 2004 / NASA)

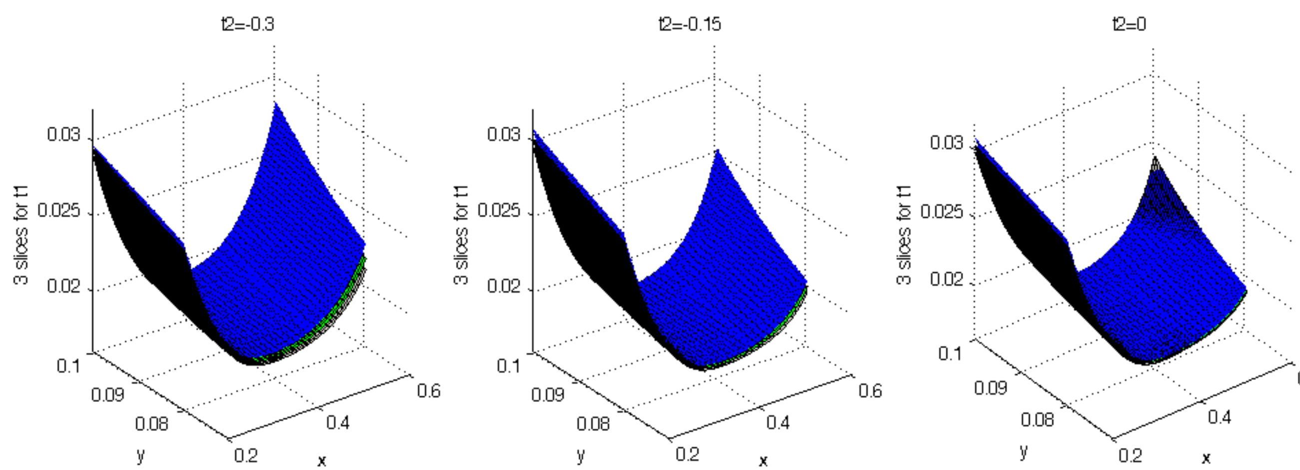
  - Simulation of lift
    - Input : mach number, angle of attack, slip slide angle
    - Output : lift





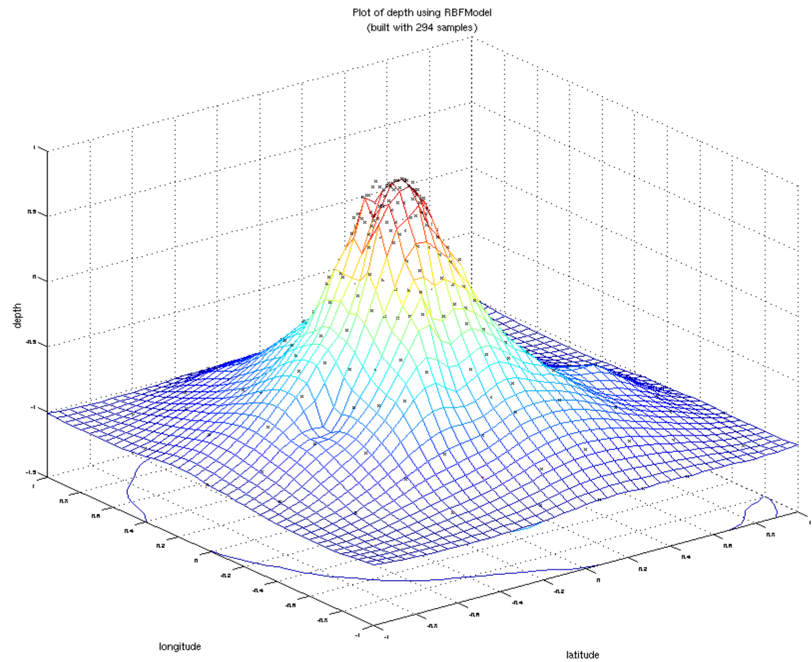
- **Xfoil – subsonic airfoil development (Xfoil)**
  - Model drag on Wheel-Fairing airfoil





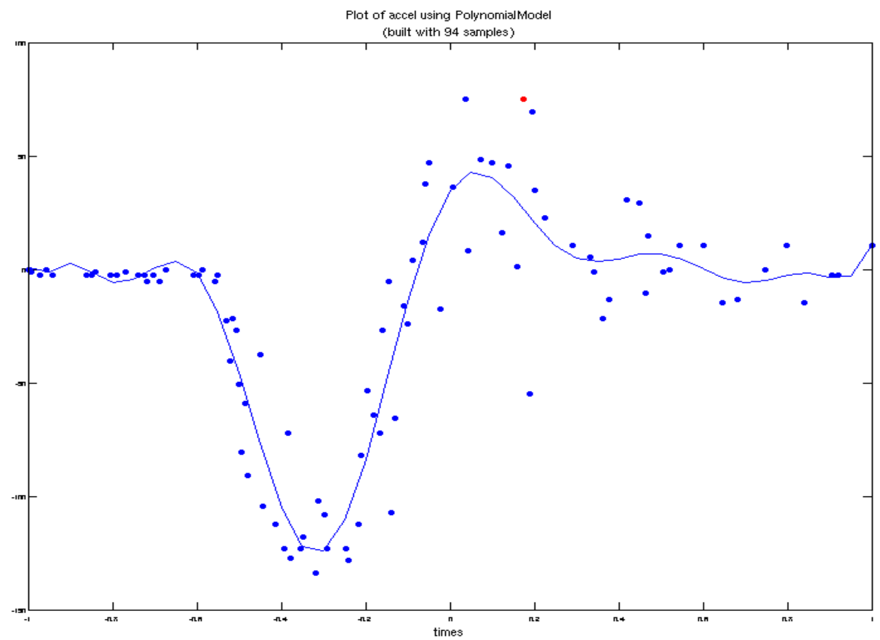
Geology example

- **seamount** (From Parker 1987)
  - Elevation data from a submerged mountain
    - Input : latitude, longitude
    - Output : depth



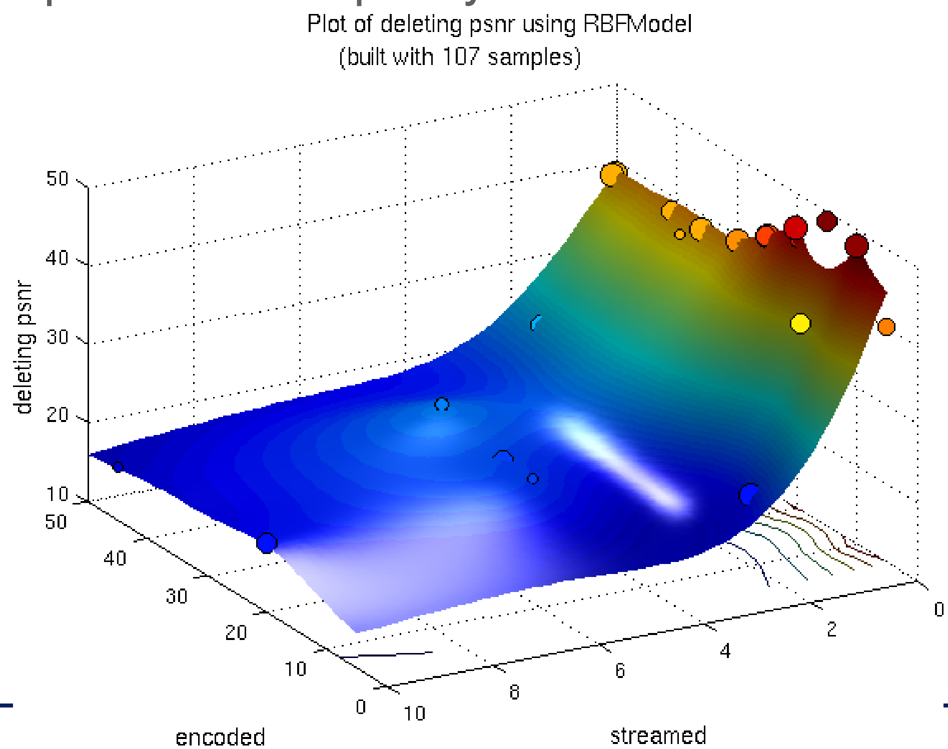
Automotive example

- motorcycle accident (From Silverman 1987)
  - Simulate a motorcycle crash against a wall
    - Input : time in milliseconds since impact.
    - Output : the recorded head acceleration (in g)

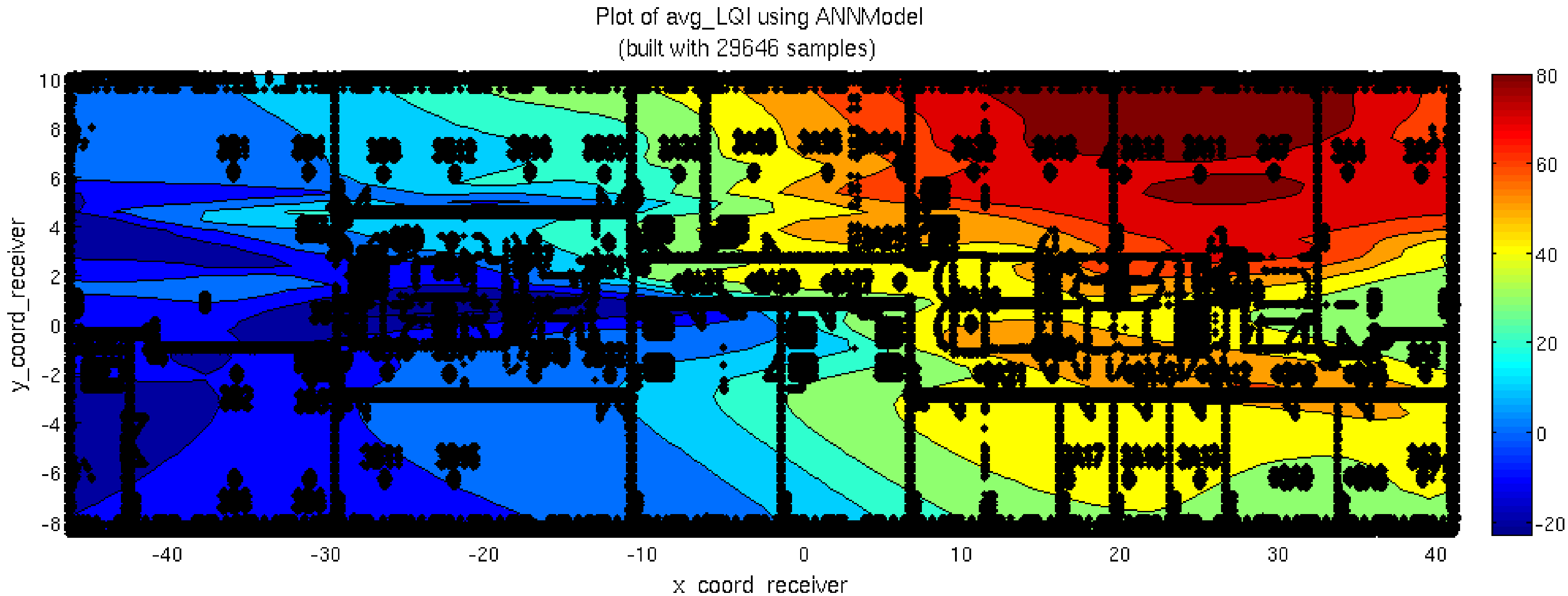


Multimedia example

- Video quality data (From Nick Vercammen, IBBT)
  - How does streaming/encoding affect quality
    - Input : encoding, transmission parameters
    - Output : quality metric

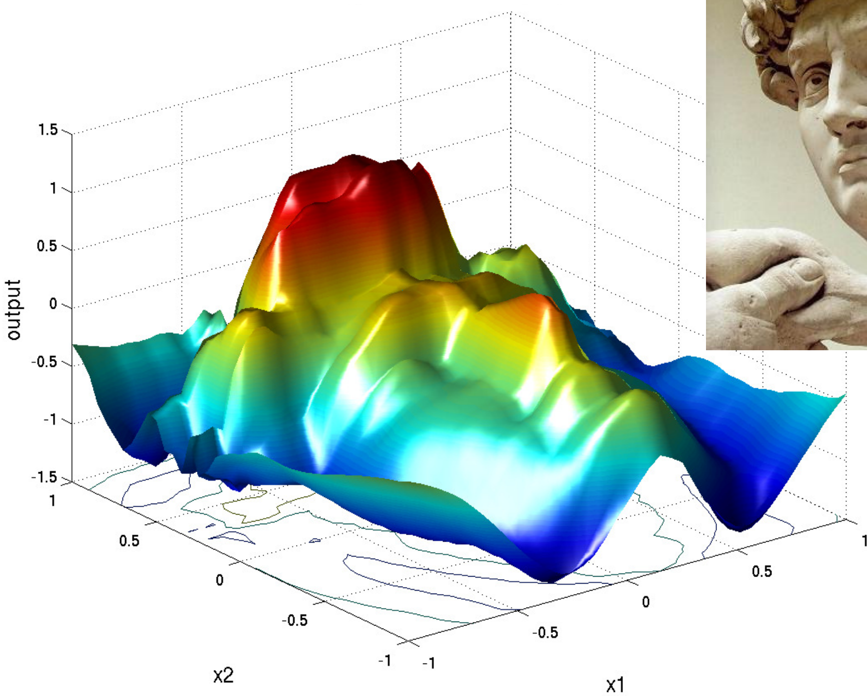


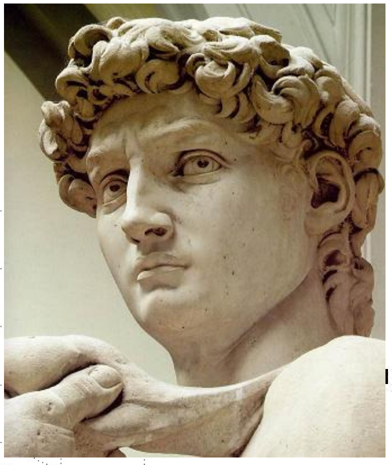
- **Wireless sensor data** (From Sensor Lab, IBBT)
  - Model reception quality
    - Input : sender/receiver coordinates
    - Output : reception quality metric

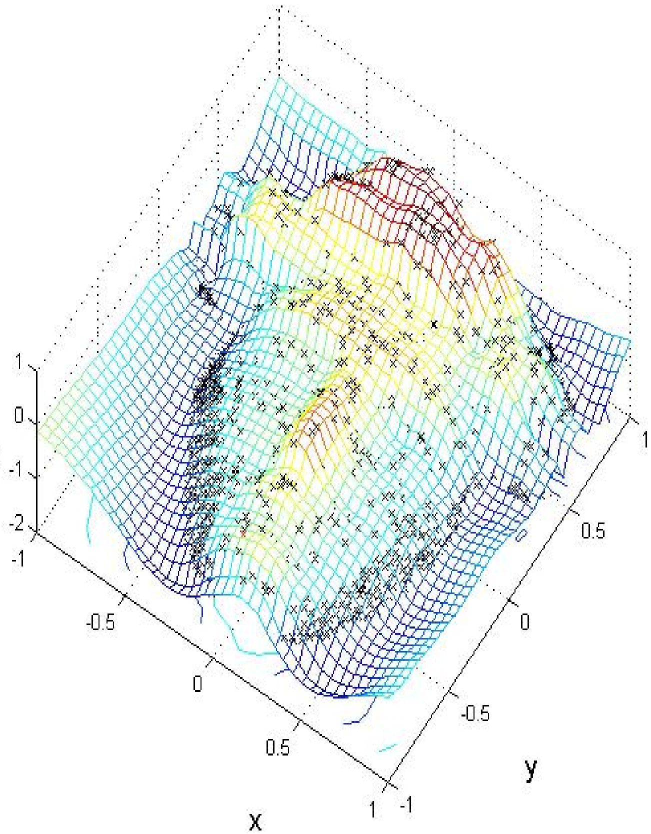


■ David data

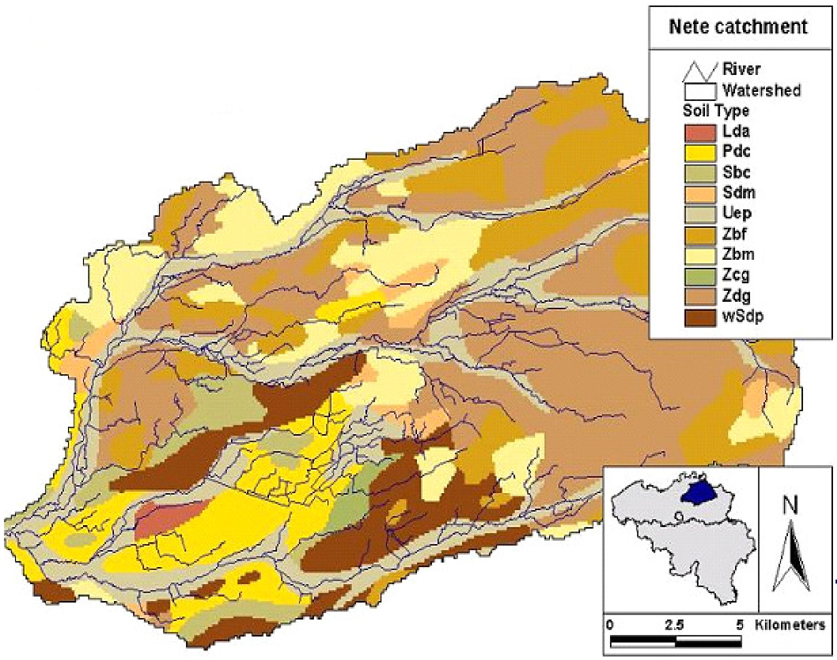
- (From the Digital Michalangelo project, Stanford University)

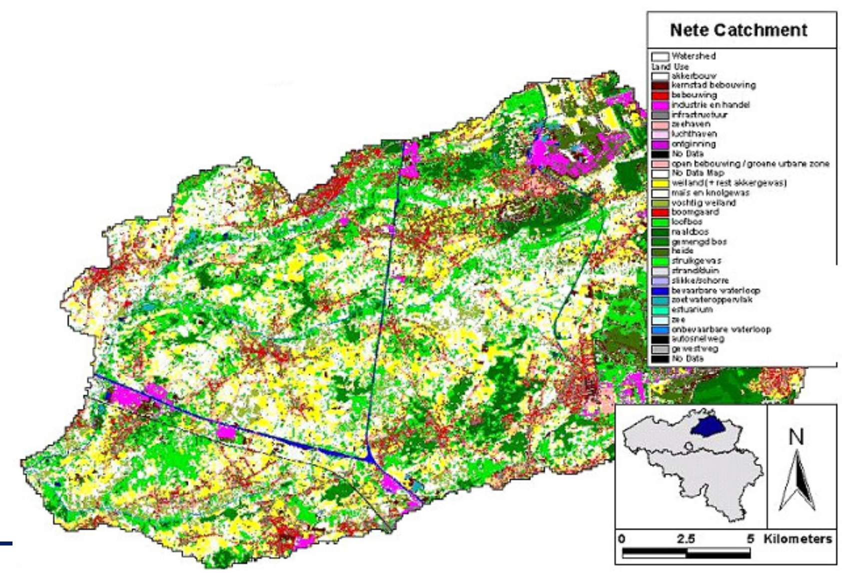






- **Soil and Water Assesement Tool**
  - river basin model (Grote Nete, Belgium)
    - **Quantify the impact of land management practices in large, complex watersheds**
  - Runtime for one simulation: 4 to 10 minutes
- **SWAT2005: http://www.brc.tamus.edu/swat/**

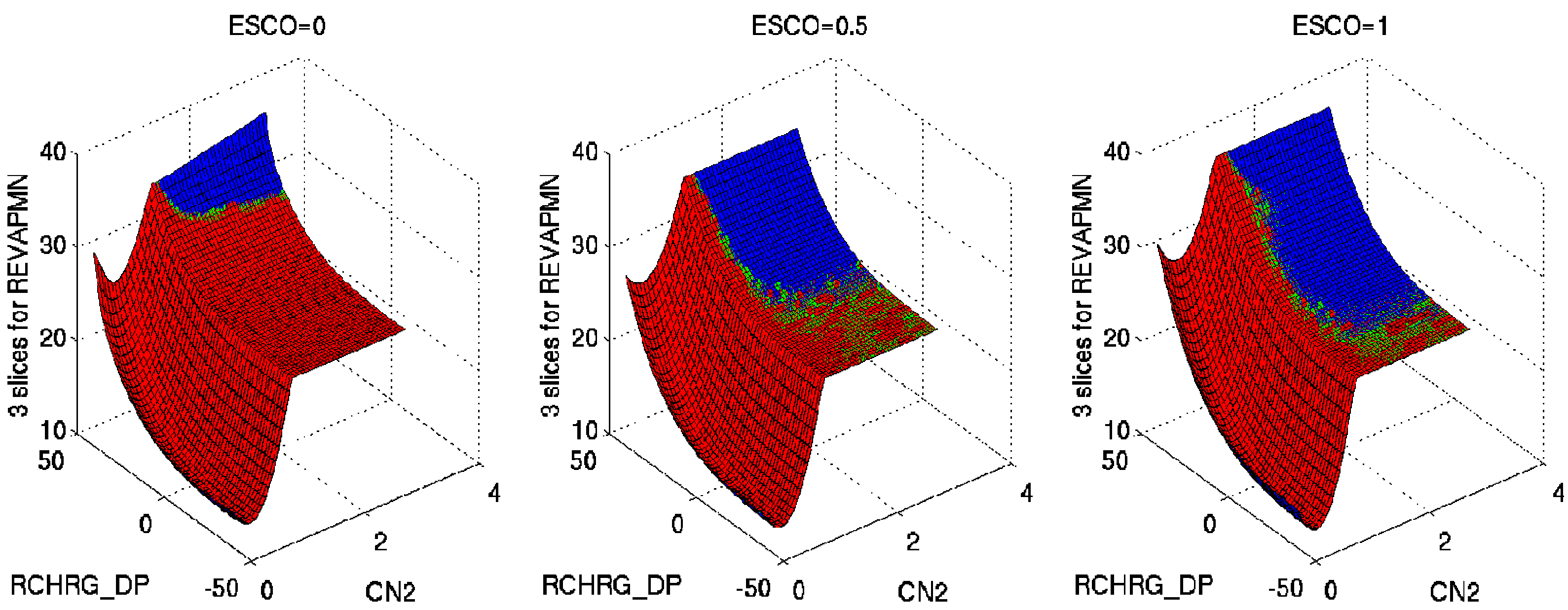




IBBT

SWAT (cont'd)

- **Approximating global behaviour**
  - Models error (MSE) between SWAT and observations
  - Constructed model with 1016 samples
    - **5.6 samples in each dimension (4 dimensions)**
    - **3.1 percent error (generating validation set on-the-fly)**

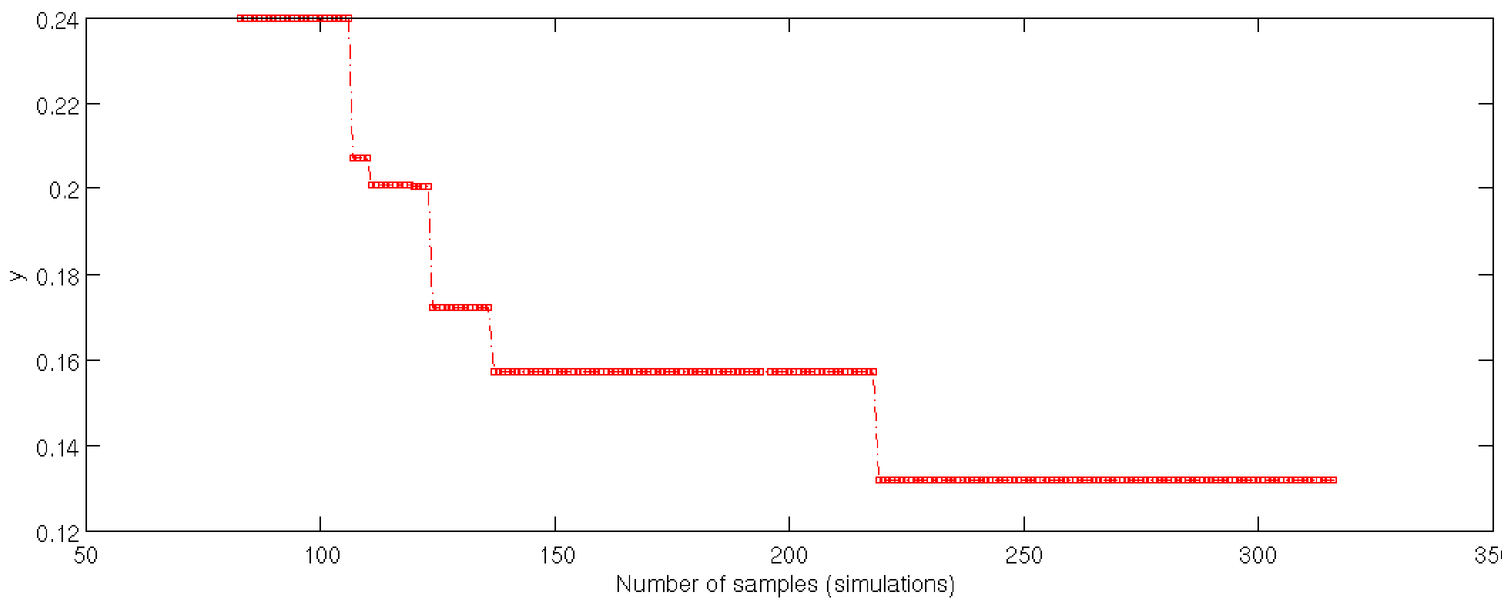


Microwave filter

- **Band-pass filter (2.32-2.56 Ghz)**
- **Software: MicroWave Studio (MWS)**
  - Computer Simulation Technology (CST)
- **Inputs: 5 dimensions**
  - Spacing: S1, S2
  - Offsets: Off1, Off2, Off3
- **Output**
  - Max(S-parameter) between 2.32 and 2.56 Ghz
- **Simulation time: 5 – 10 minutes**
- **Optimization algorithm: EGO + Kriging**

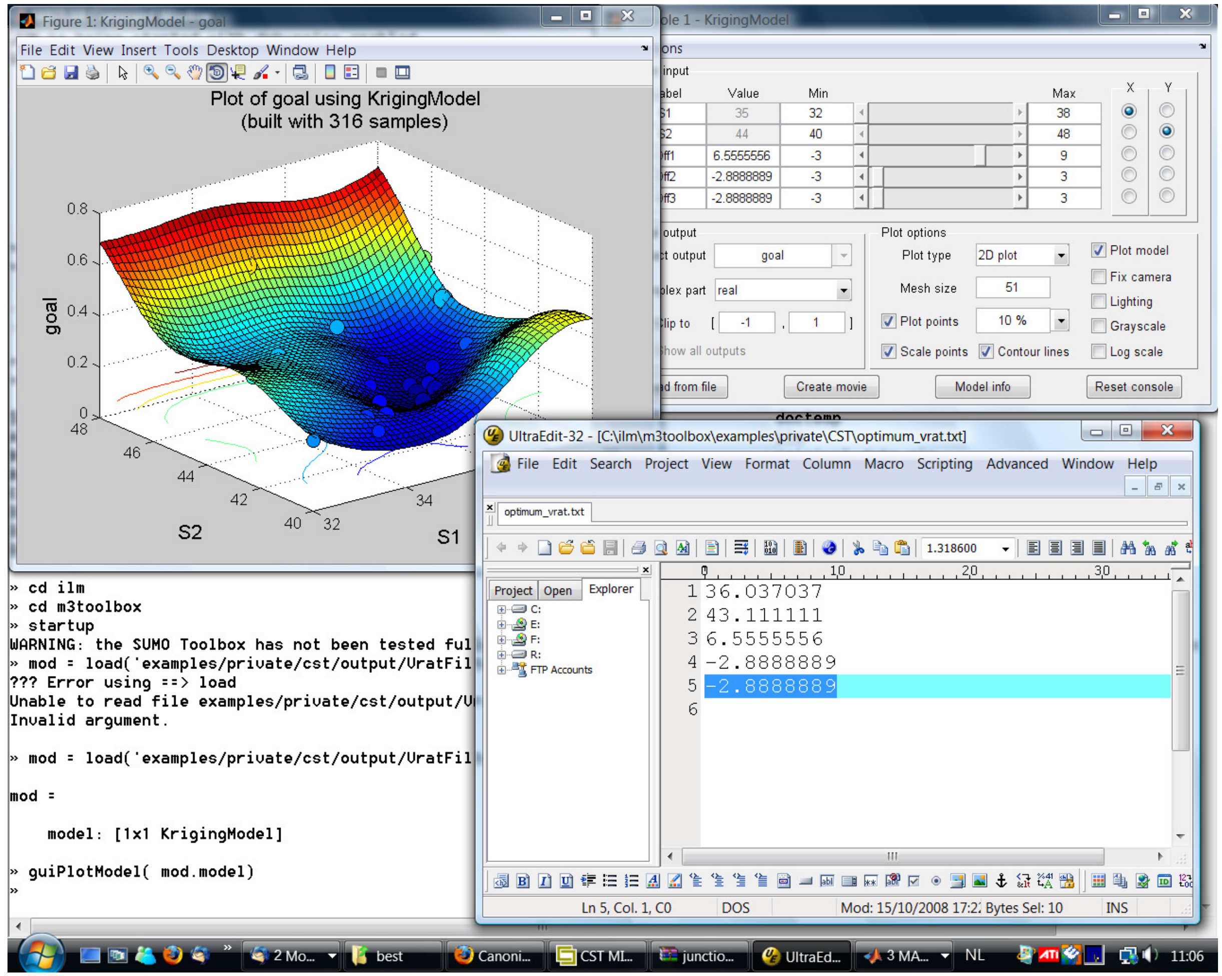
Microwave filter (cont'd)

- **Initial design of 83 samples**
- **Results**
  - 'Very good' minimum after ~150 samples
  - Add 100 simulations more 'to be sure'



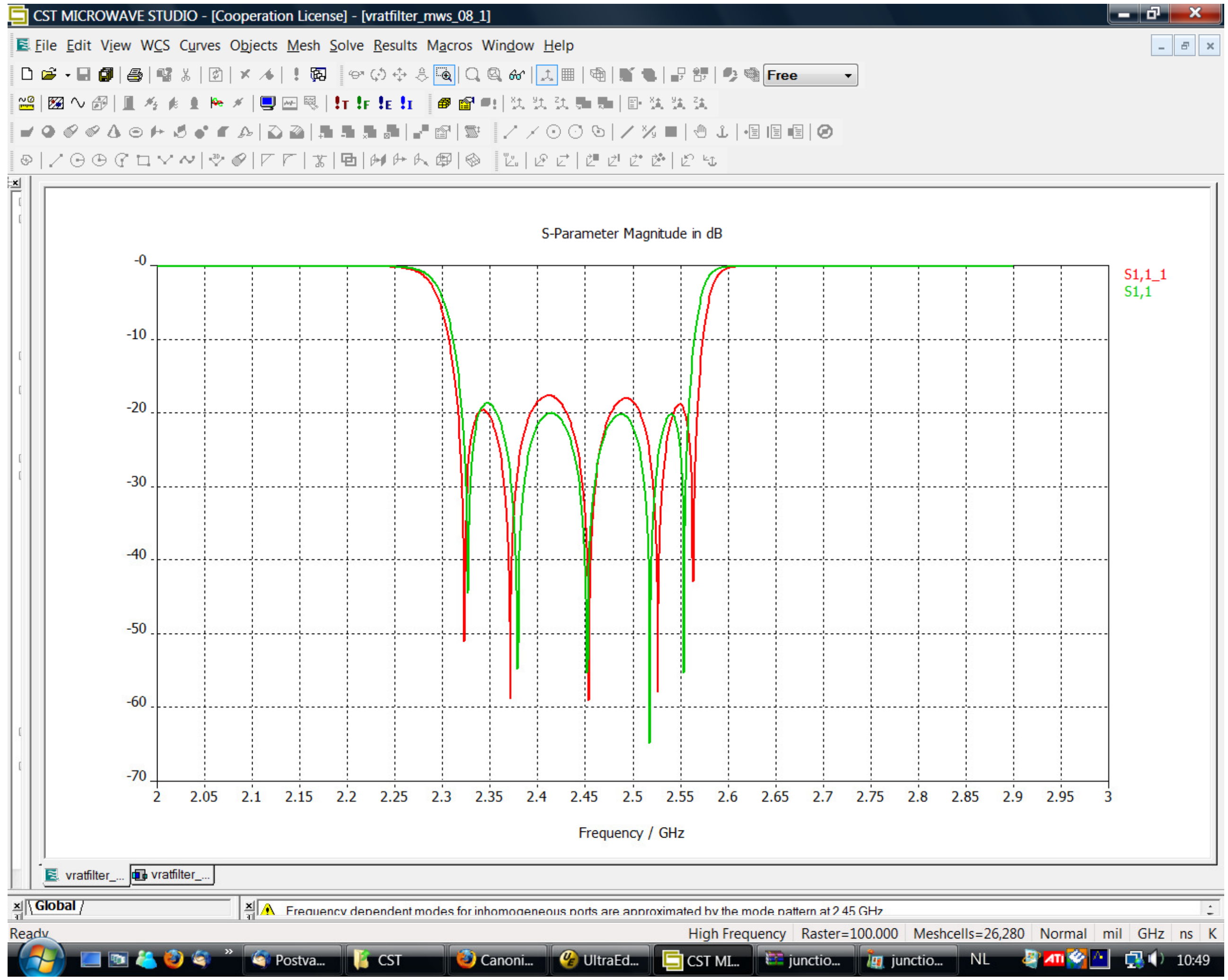
Microwave filter (cont'd)

- **Model browser**
  - Sensitivity
  - Robustness
  - …



Microwave filter (cont'd)

- **Green curve**
  - Reference
- **Red curve**
  - Optimum found

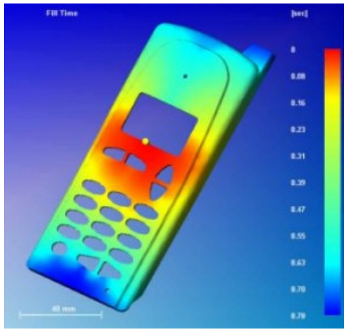


Outline

- Who are we ?
- Introduction
- Surrogate modeling
- SUMO Toolbox
- Examples
- Conclusions

Conclusions

- **Compact surrogate models**
  - Global, local
- **Fully automated**
  - Adaptive model selection
  - Adaptive sample selection
  - Distributed computing
  - (optimization)



- **Surrogate Modeling (SUMO) Toolbox**
  - Easy to setup and run different modeling experiments
  - Natural platform for benchmarking different techniques
  - Download from http://www.sumo.intec.ugent.be

Questions

- **Questions ?**