2nd International Workshop on Validation of Computational Mechanics Models

Uncertainty Quantification and Robust Design Optimisation

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Uncertainties of Real Systems

Scatter of geometry

- Wall thickness
- Tolerances in shape or measure

Scatter of material properties

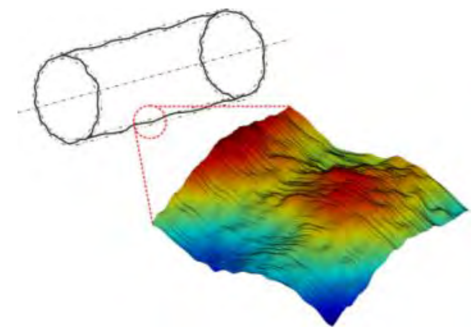
- Density
- Young‘s modulus
- Fibre orientation for composite materials

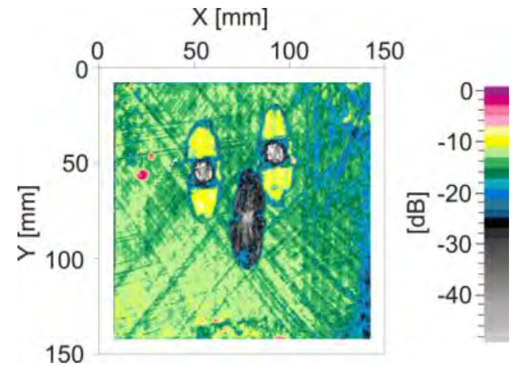
Scatter of loads

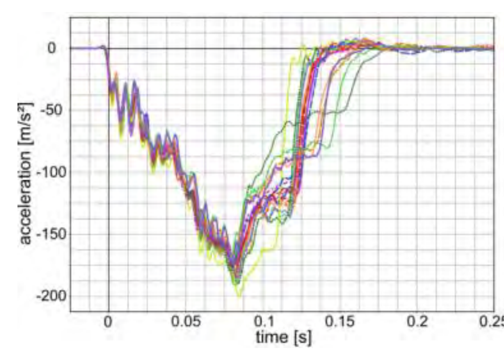
- Acceleration impulse

Scatter of initial and boundary conditions

- Initial velocity
- Spring and damper characteristics



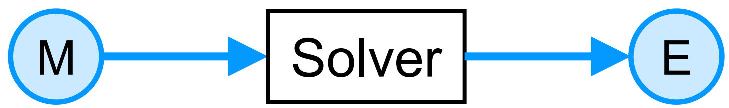




Deterministic Simulation

Problem definition as idealized Model with fixed system properties

Exact numerical result of the simulation



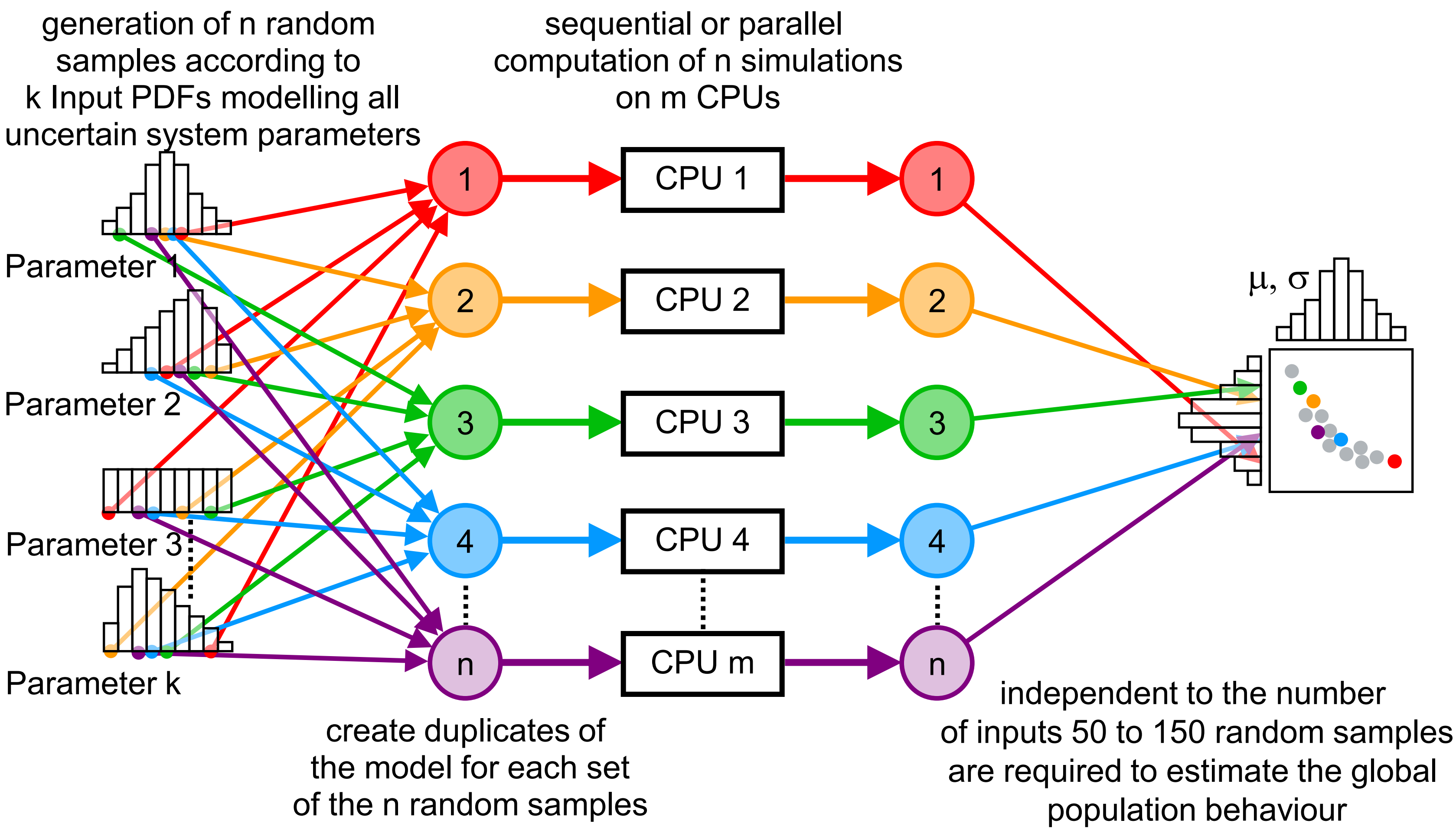
Calculation (Analysis)

Fixed link between Model and numerical analysis result

Disadvantages:

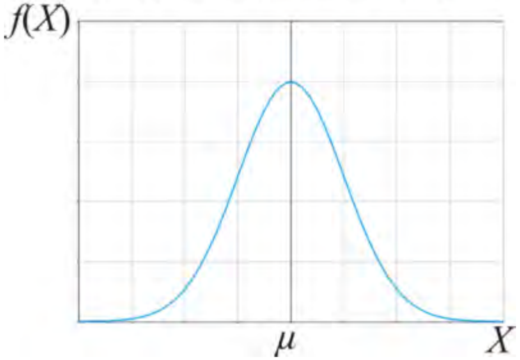
- Cause-effect relationships of the system may remain concealed
- Influence of scatter due to production and usage tolerances not quantifiable
- No information about system robustness

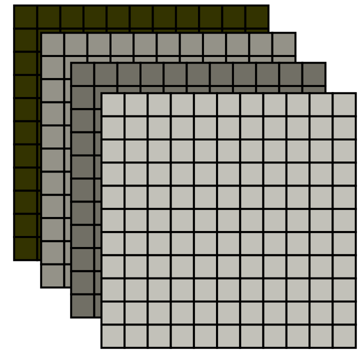
Stochastic Simulation (Monte Carlo Method)



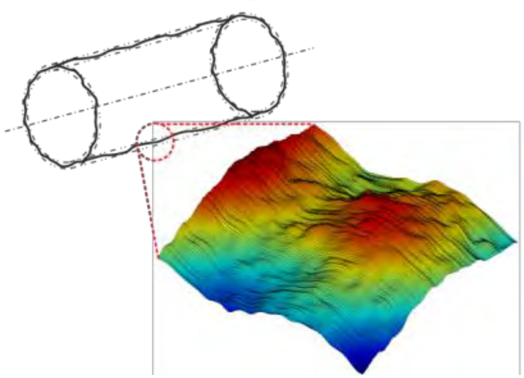
Mathematical Models of Uncertainties

random variable

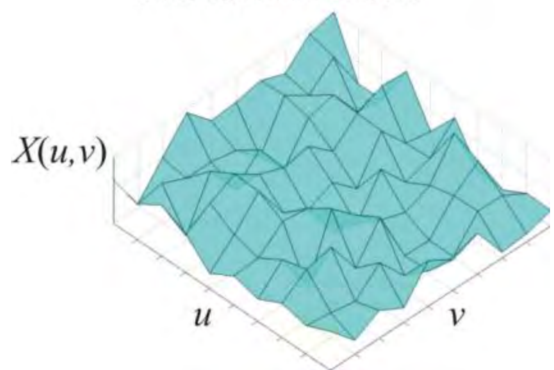




real property distribution

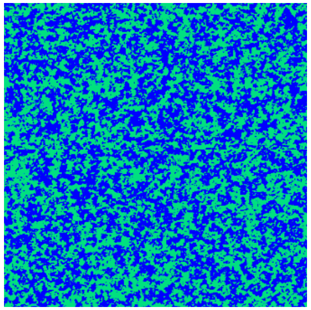


random field



Some Random Field Properties

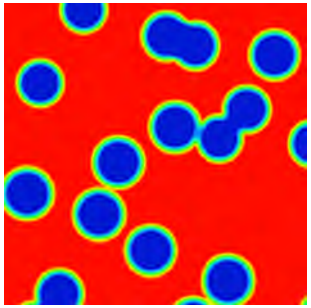
Description by a finite set of parameters is needed



Gaussian random field: mean and covariance function

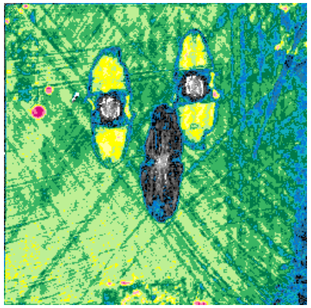
Structural features like shape or connectivity:

- Short-range correlation model
- 2nd-order statistics: lowly-structured morphologies
- 3rd-order statistics: medium-structured morphologies



Random fields may have highly complex structure

- Composites with various fibre orientations, cavities,…
- Efficient modelling method is required (e.g. MCS)

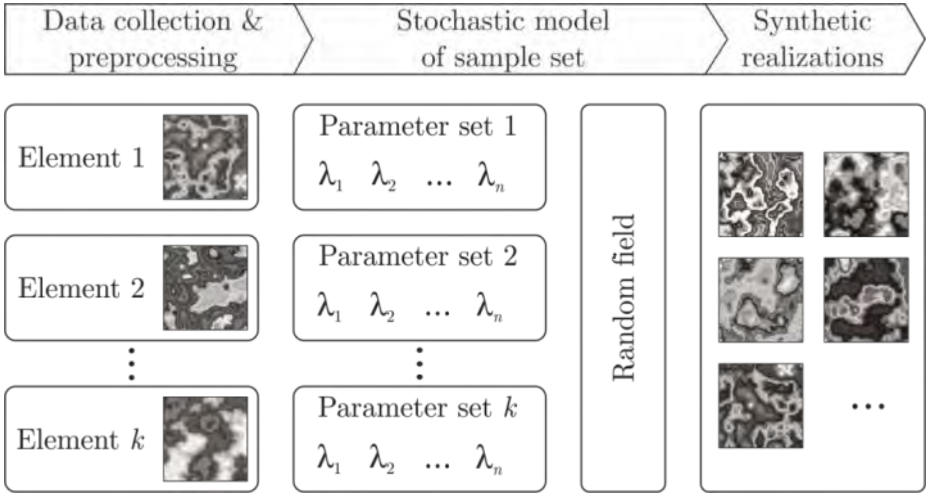


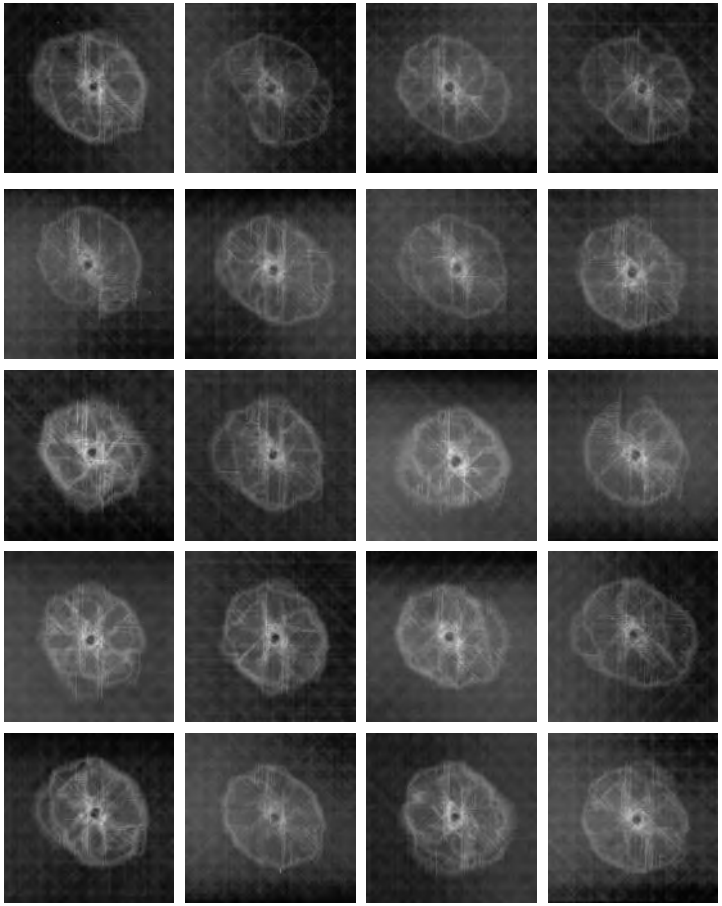
Pattern Recognition Based Parameterisation

Random field: n-dimensional image

Approach: Methods derived from image processing

Objective: Pattern recognition based parameterisation method capable to represent highly structured morphology





Application example: 20 X-ray scans of damaged CFRP-plates

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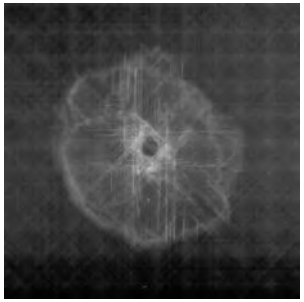
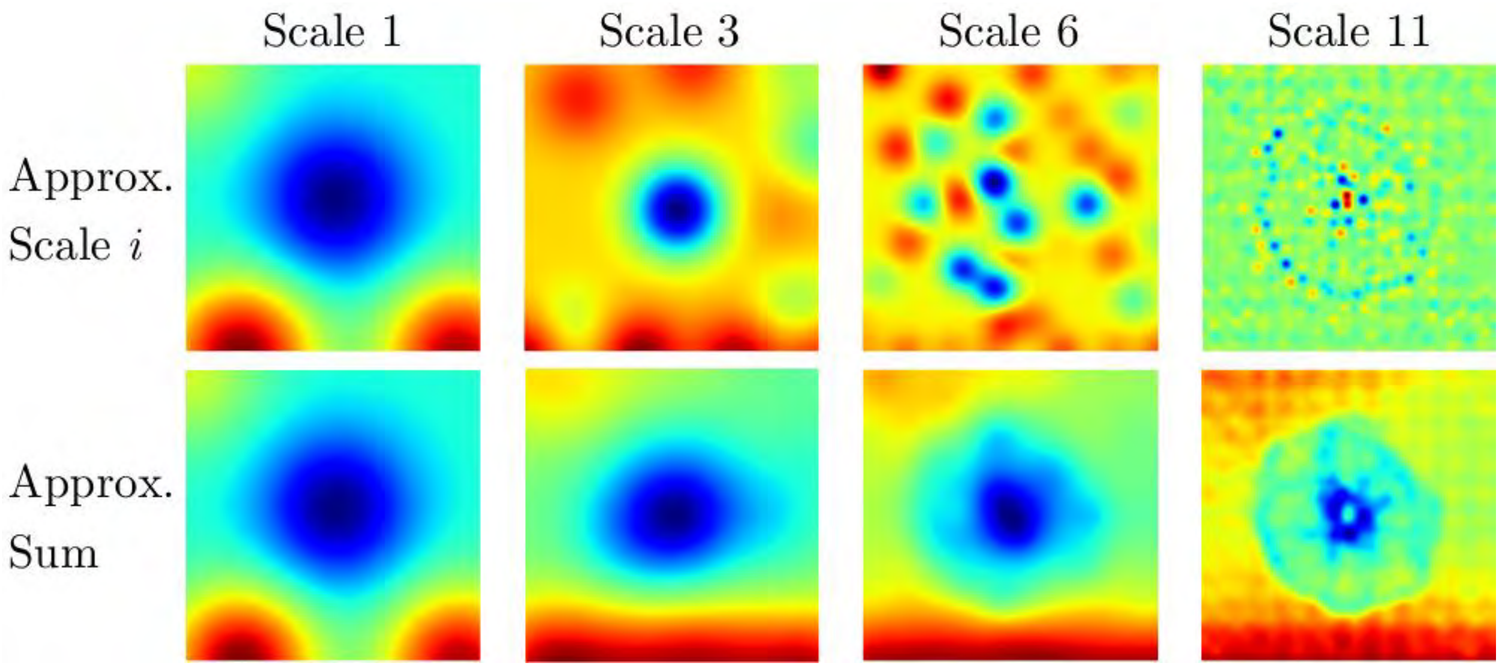
Feature Extraction and Multiscalar Approximation

Basic idea: split discrete signal x into limited frequency bands

- Local extreme is called Blob
- Each Blob is approximated by one Gaussian kernel
- Gaussian kernels positioned at extremes of Diff.





Probabilistic Model for Synthetic Realizations

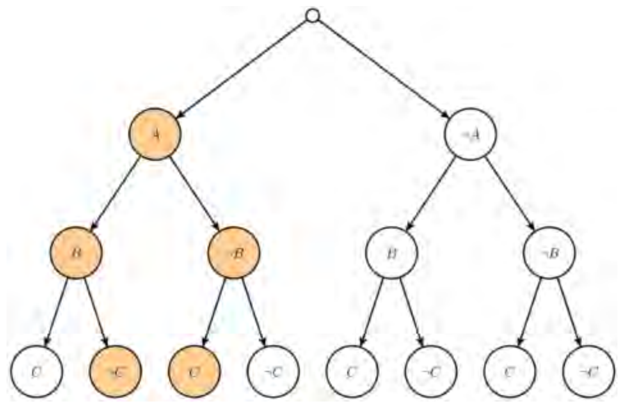
Probabilistic Model by means of kernel density estimation

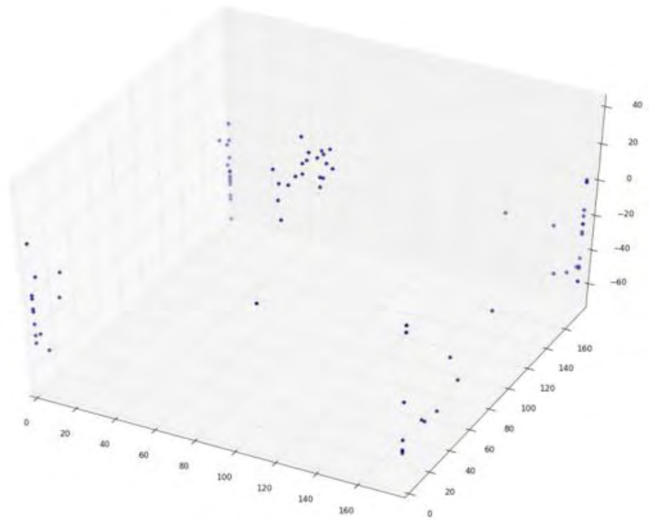
Conditional probabilities between the scales

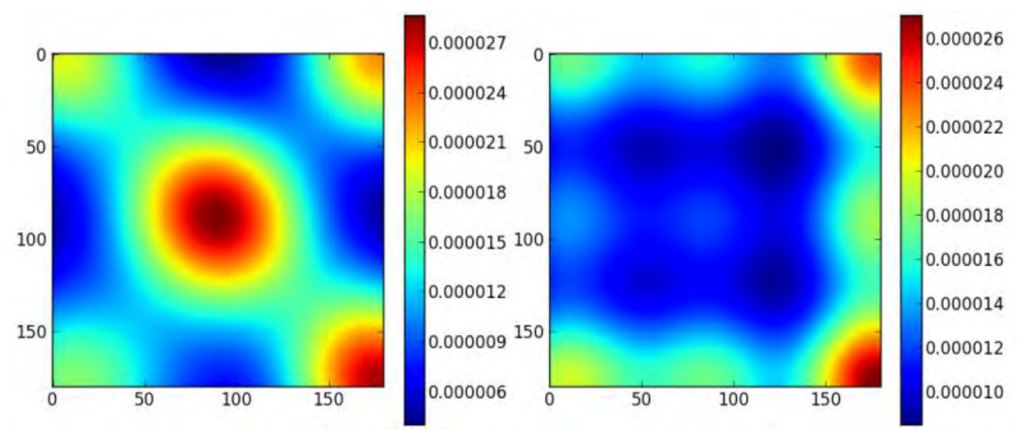
Properties of new Blobs and Children Blobs

- Number of Blobs
- Positions of Blobs
- Intensities of Blobs

Importance of Multidimensional probability law







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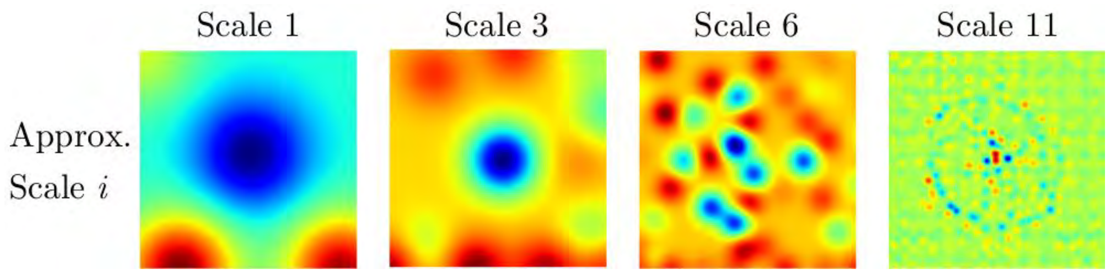
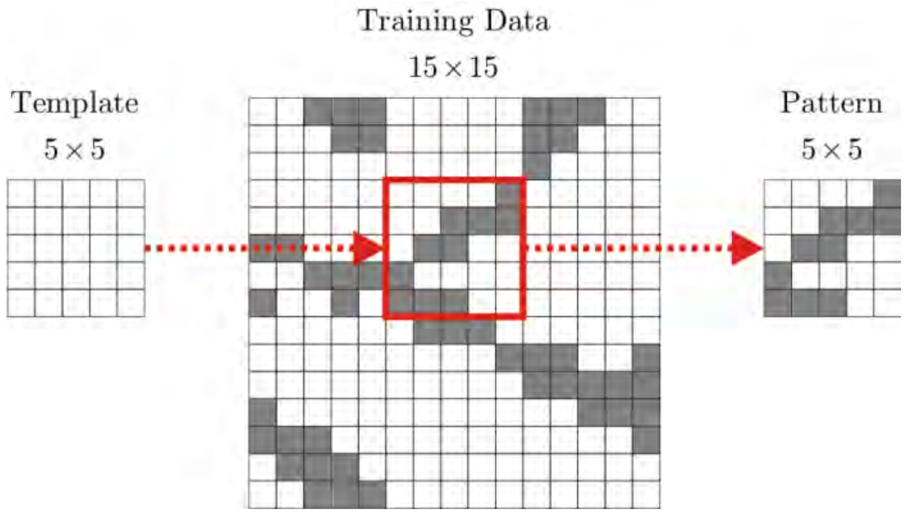
Simulation of Local Structures

Strong increase of number of Blobs for finer structures on higher scales



Assumption: Fine structures have a “local” character

Approach: Analysis and classification of local patterns within moving “template”



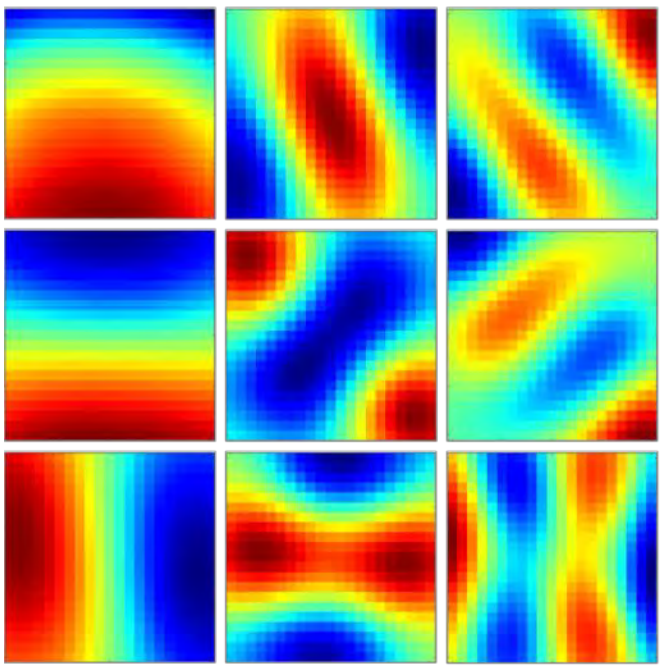
Analysis and Classification of Local Patterns

Relevant local structures have to fit into the template

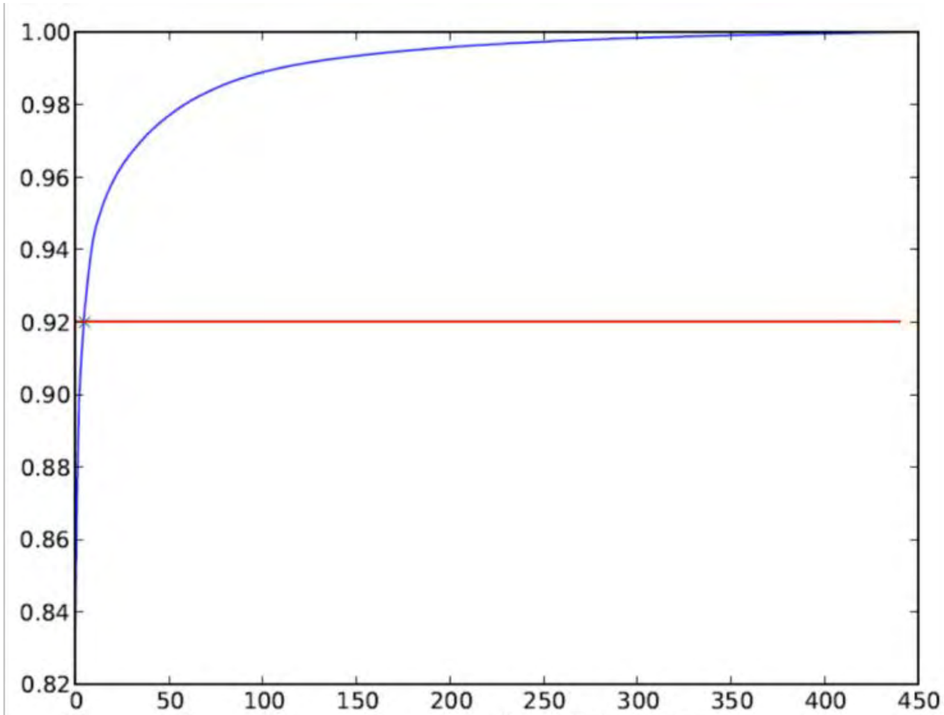
- Suitable template size leads to high dimensionality

Treatment in reduced "score space" by means of Principal Component Analysis

- 14 dimensions instead of 441



Filter 1 … Filter 9

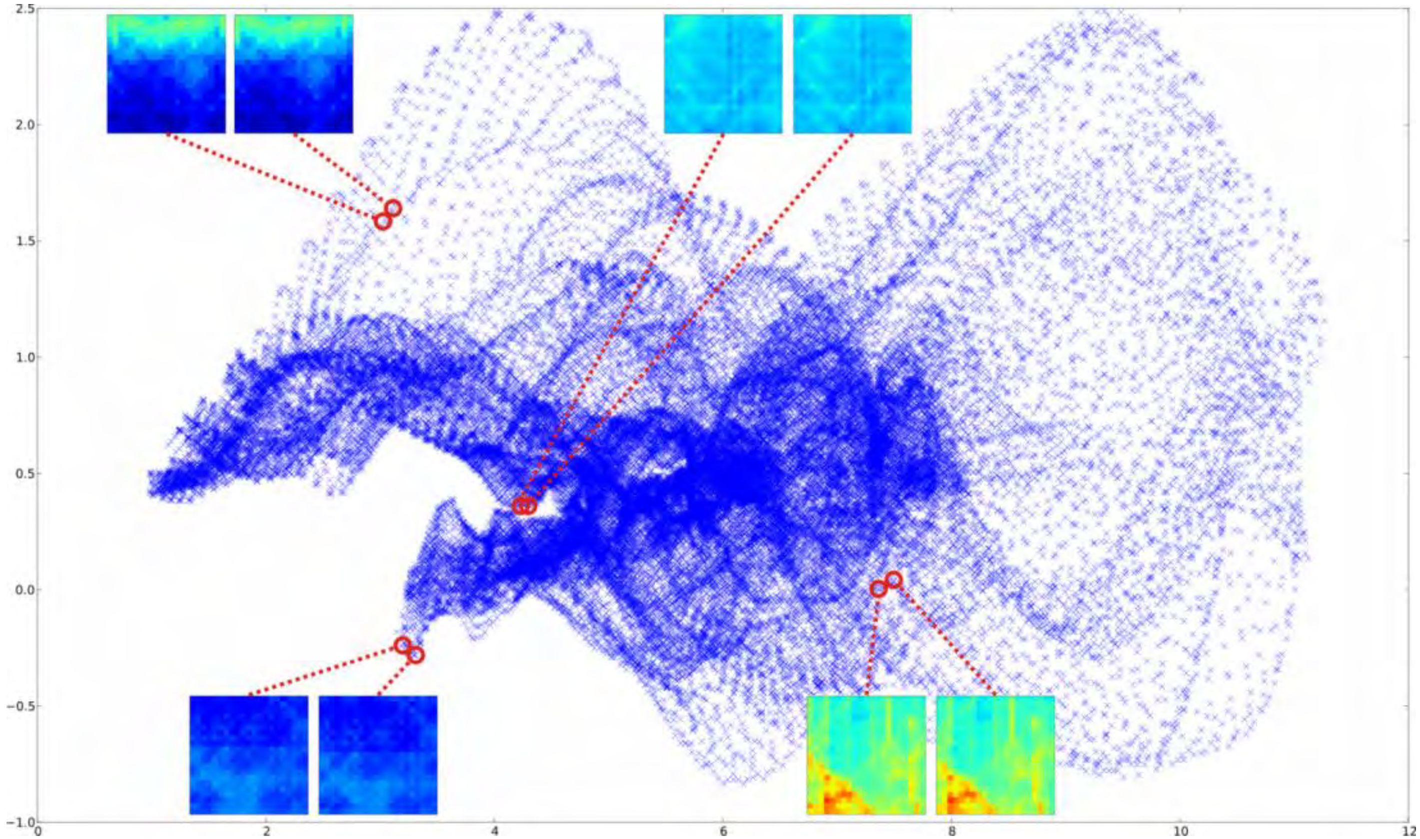


Cumulated variance for 21×21 template

Local Patterns in the Score Space

Scatter plot of principal component 1 and 2 in the score space

- Pattern shows significant amount of structure
- Distance measure in just 2 dimensions yields excellent results



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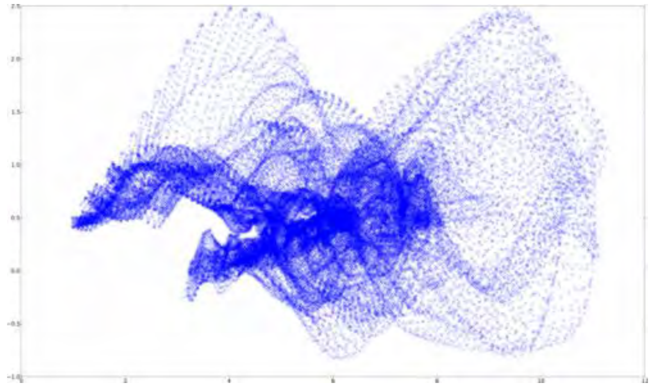
Clustering of Patterns in Score Space

Transformation to score space enables for effective separation of features

- Heterogeneous pattern density in score space: HAC does not yield good results
- Large number of patterns ($>10^6$) demands a simple approach

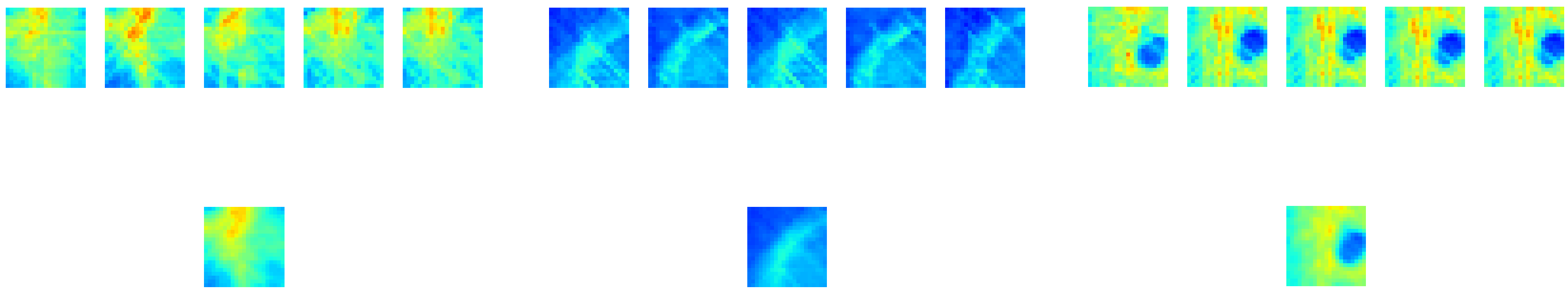


Approach: Binary tree clustering

- Minimum size of cluster
- Minimum “representativeness”

$$R = 1 - \frac{\sum_i \sigma_i}{n_{\text{class}} \sigma_{\text{class}}}$$

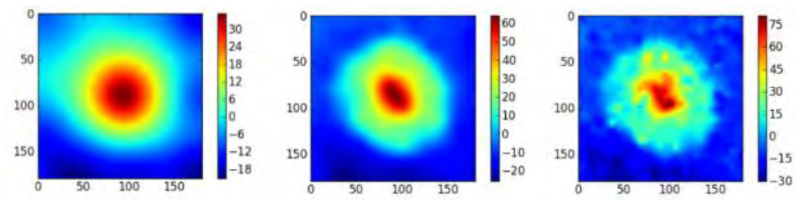
Class consists of patterns and mean “prototype”



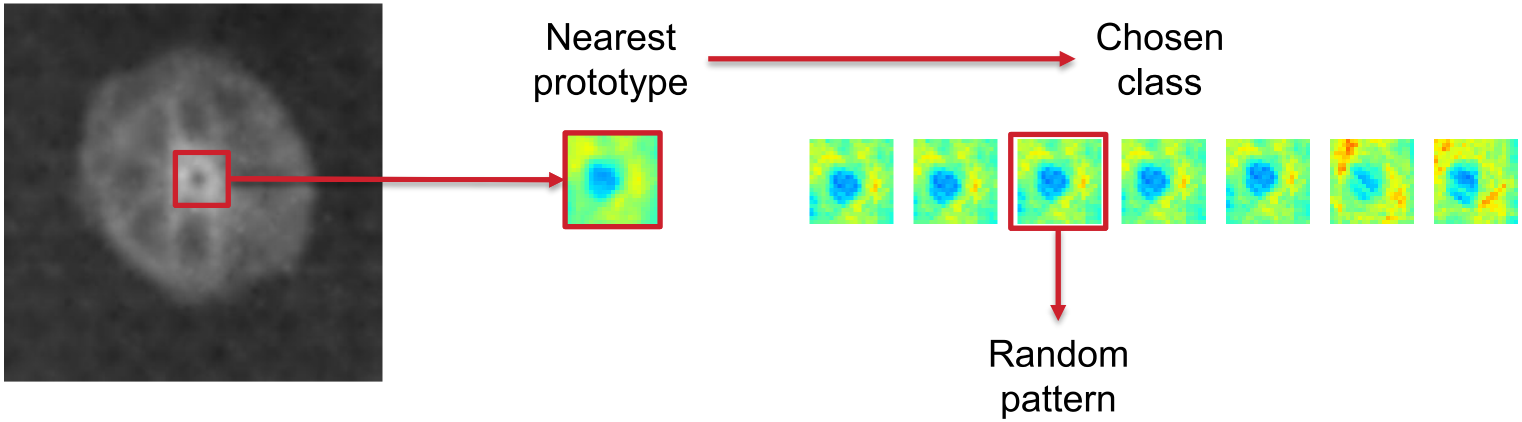
Simulation of Synthetic Realization

Simulation of Synthetic realizations in a two step approach:

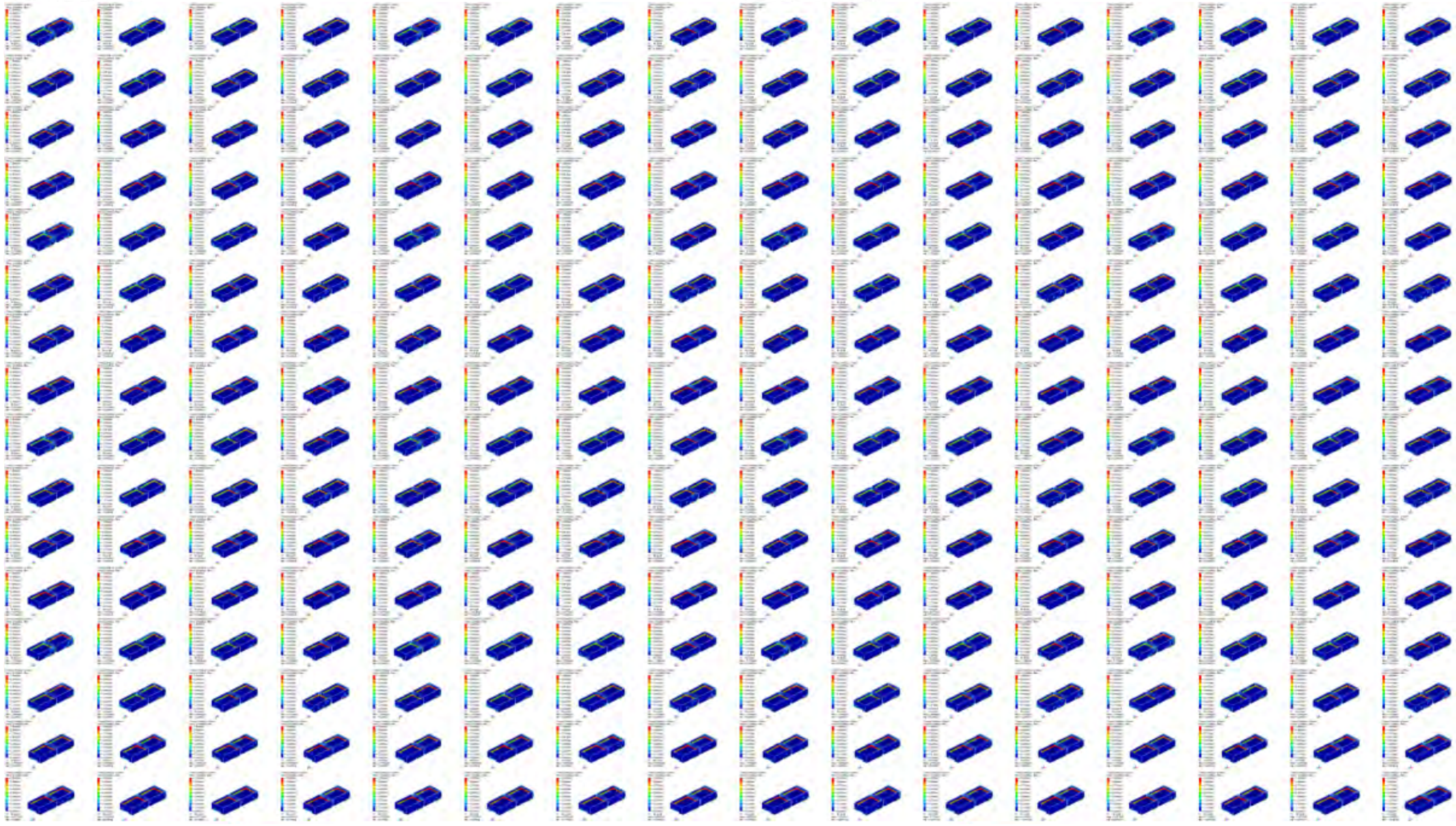
1. Simulation of global features and coarse local features by means of multiscalar approach based on conditional probabilities of Blobs between scales



2. Synthetic realization of Blobs is used as a seed for the completion based on local pattern matching



Simulation Post Processing (Scientific Visualisation)

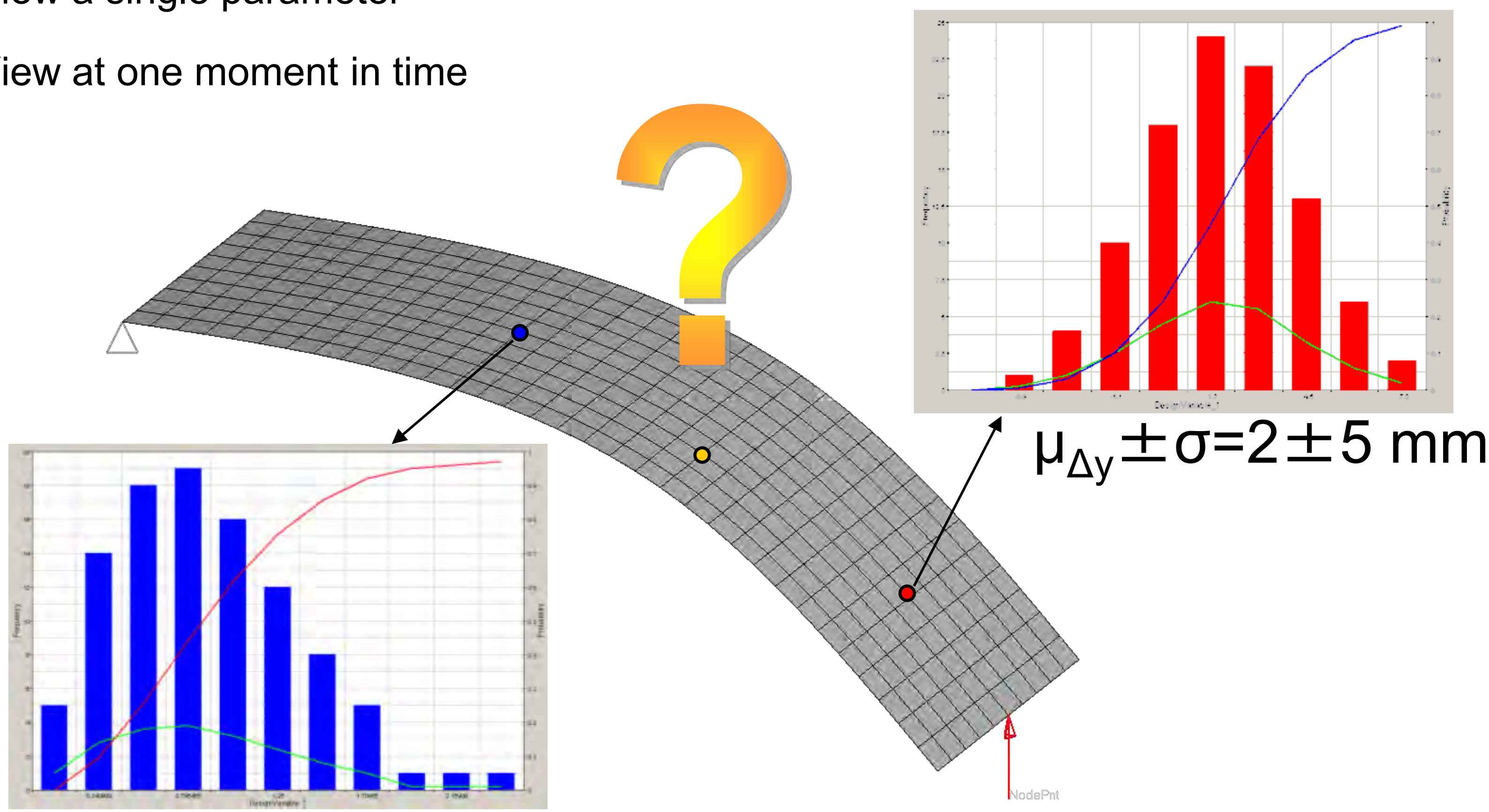


Limitations of Today‘s Statistic Visualisation in CAE

View a single point in space

View a single parameter

View at one moment in time



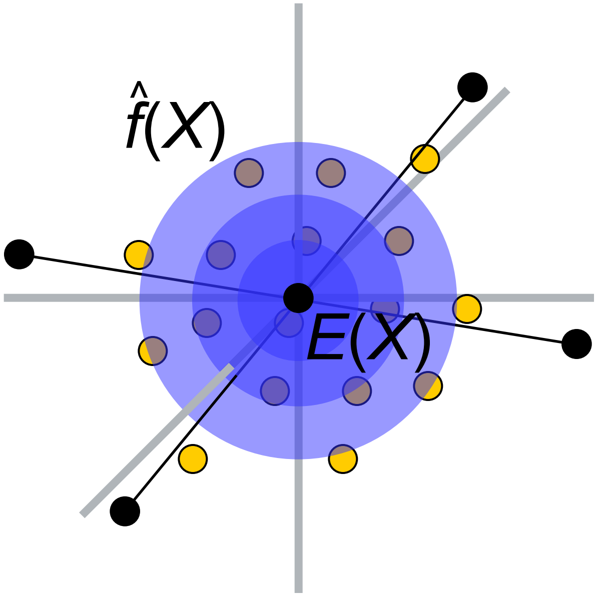
New Method to Visualise Geometric Scatter

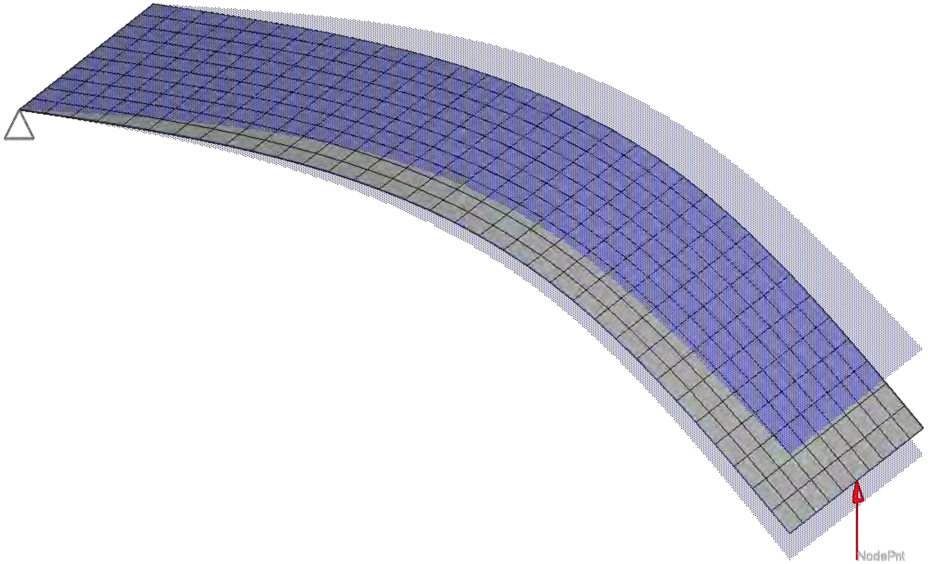
Density estimation of three-dimensional density function from the samples

Calculation of the expected value per each node of the mesh

Assembly of the expected value geometry by connection of these nodes

Derivation of convex hulls with regard to user defined *α*-levels of maximum probability density





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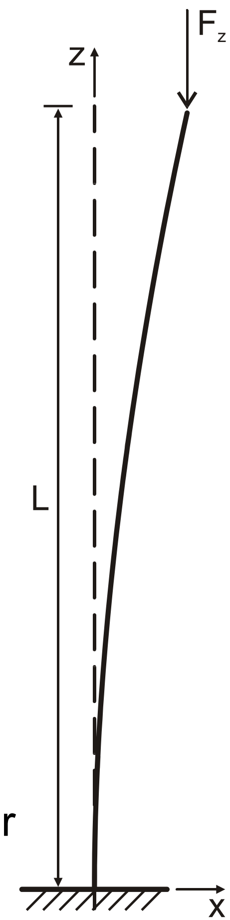
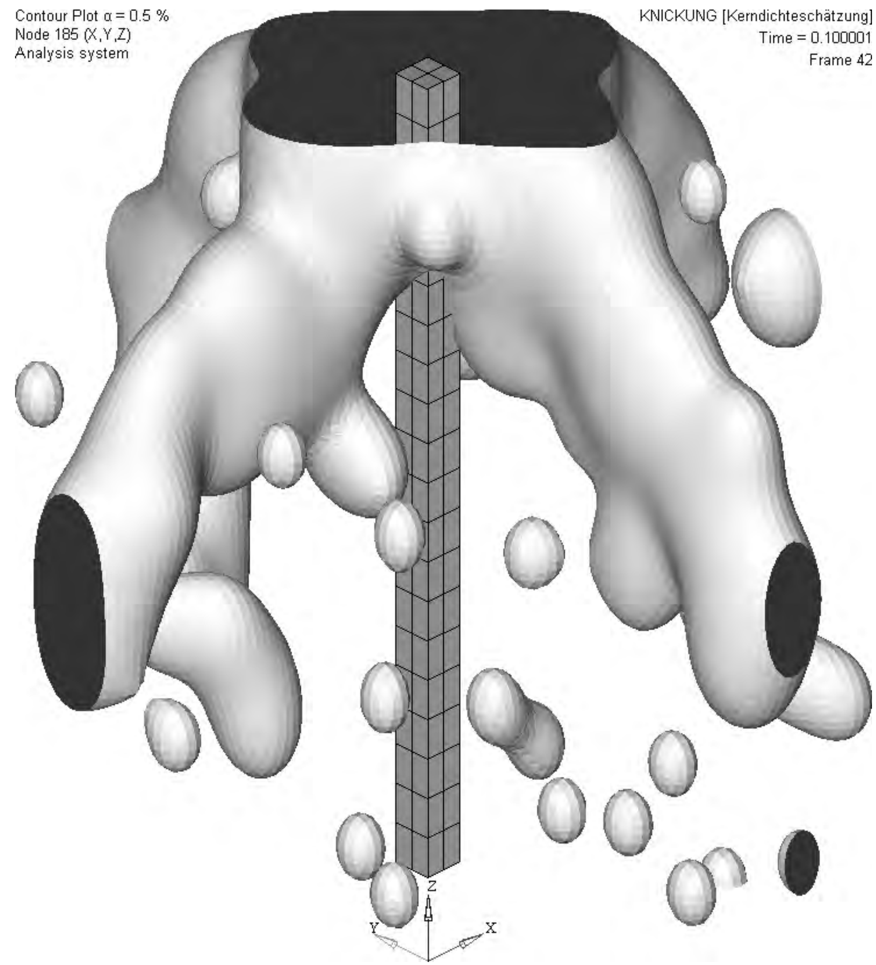
Stochastic Simulation of 1st Euler Buckling Mode

Stochastic parameters:

- Length
- Edge lengths
- Force
- Young's modulus





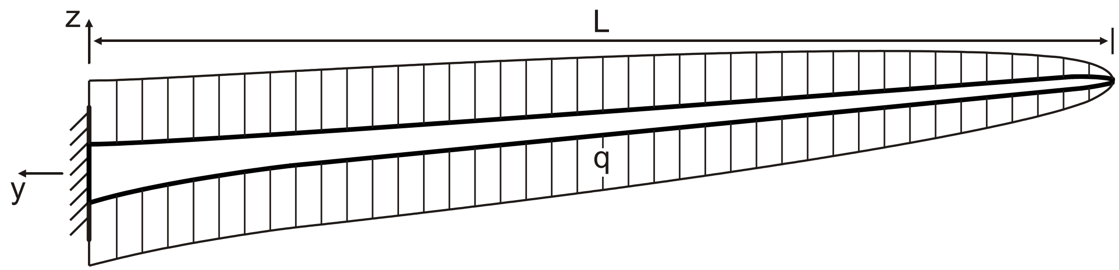
Isoprobability surface of column tip:

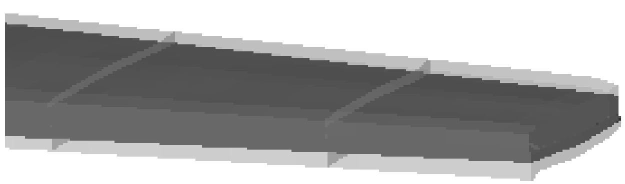
- User defined *α*-level of max PDF
- Marching cube algorithm for convex hull

Aircraft Wing Under Varying Load Conditions

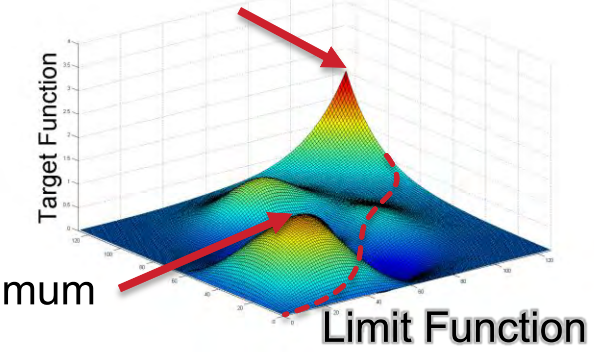
Variation of air loads caused by:

- Turbulence
- Altitude
- Flight conditions





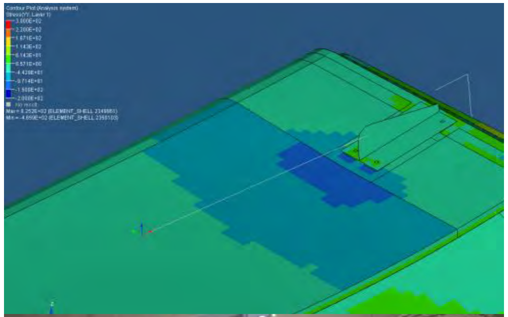
Application Examples

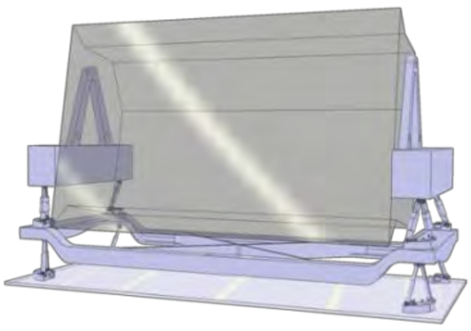


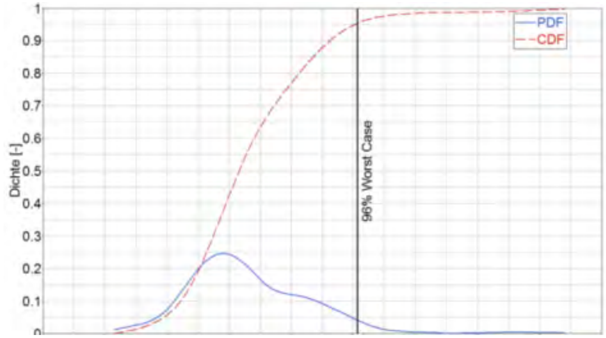
Optimizing models with uncertain system properties or boundary conditions using probabilistic modelling.

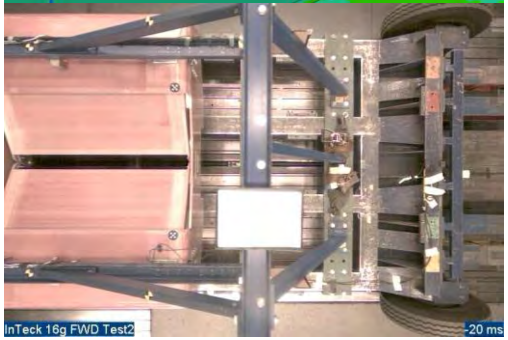
Optimise performance with respect to robustness and reliability

- TRS-3D Shock-Frame with tuned mass-damper
- Energy-Absorber (load limiter) for cabin components









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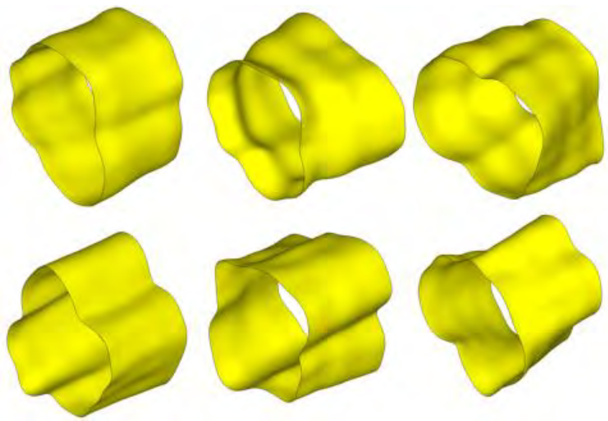
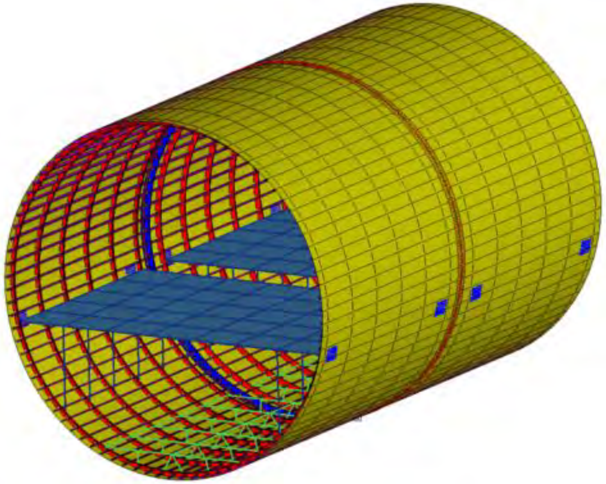
Application Examples

Fuselage assembly process

- Random fields for geometrical uncertainties
- Simulate residual stresses for different riveting sequences

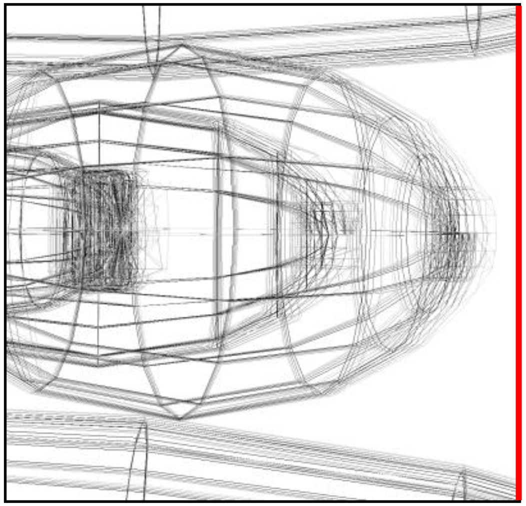


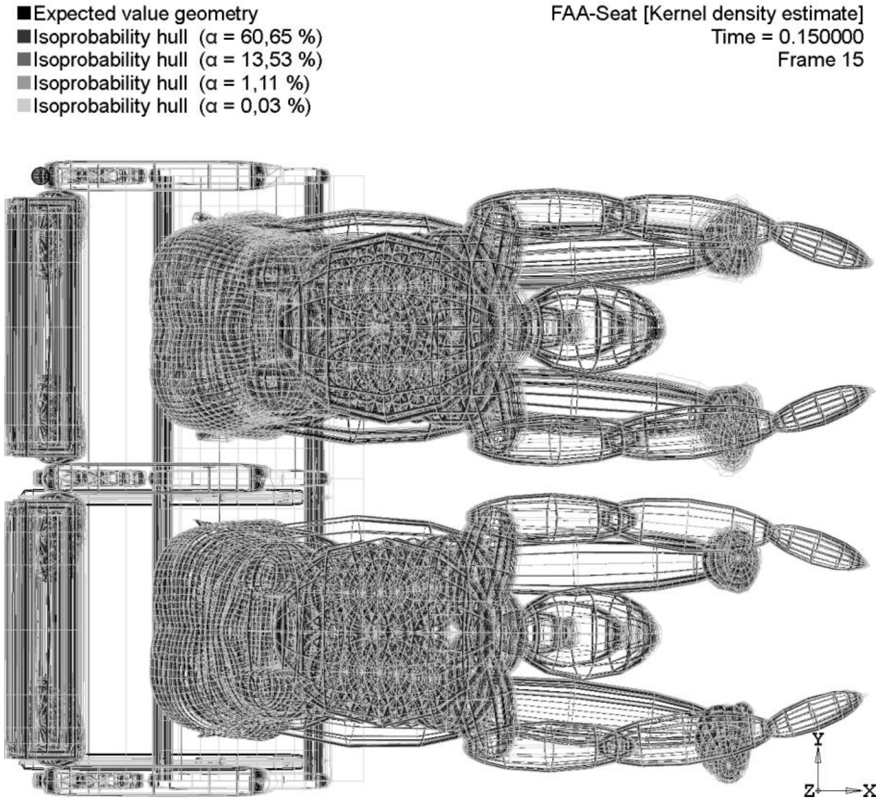


Application Examples

Nonlinear dynamic simulation of seat

- Optimise seat leg stiffness
- Constraint: HIC
- Decrease head displacement





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Thank you for your attention.

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