Industrial applications of Uncertainty and parameter space analysis

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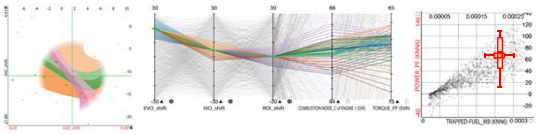
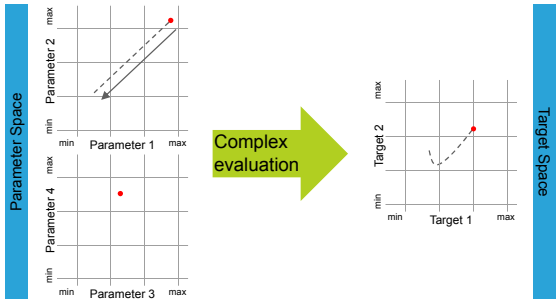
Application area 1: Car engine design



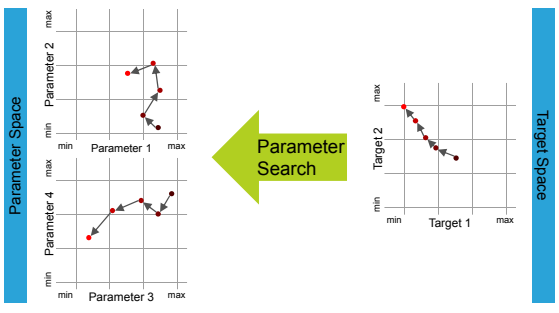
Motivation

- 1D-CFD multi-run simulations
- Parameter Space
  - e.g., fuel injection timing, engine speed
- Target Space (Simulation)
  - e.g., torque, fuel consumption
- Goals
  - Study the complex interactions in car engines
  - Optimize design choices

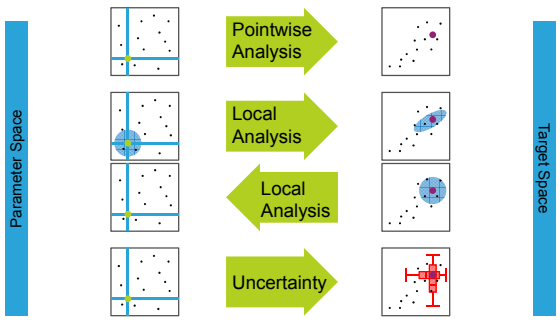
Motivation



Motivation



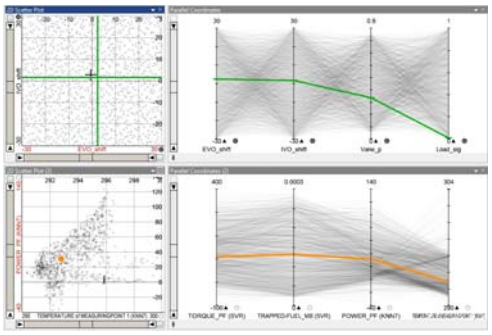
Contribution



Pointwise Navigation and Prediction

- User-defined focal point
  - Specifies values for all parameters
  - Coordinates multiple views
- Real-time prediction of associated targets
  - Uses surrogates for the more complex real functions, (e.g. regression models, K-nearest neighbor estimators)

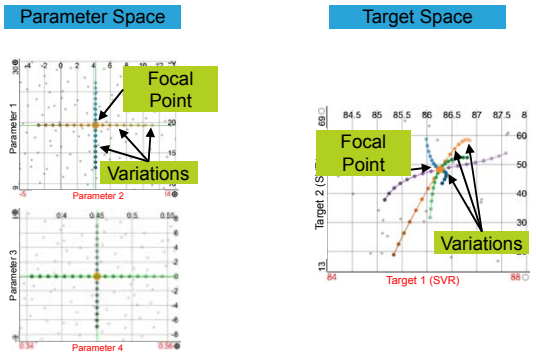
Pointwise Navigation and Prediction



Local Analysis: Parameter ➔ Target space

- Varies the parameters defined by current focal point
- Indicates target ranges within reach
- Enables quick navigation to interesting points

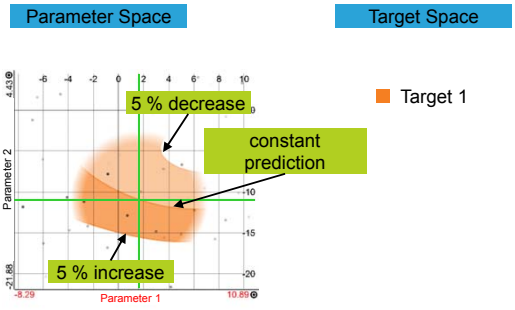
Local Analysis: Parameter ➔ Target space



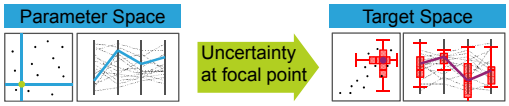
Local Analysis: Parameter ➔ Target space

- Visualizes neighborhoods around the prediction at the focal point
- Indicates gradients of the targets around predictions at the focal point
- Conveys the sensitivity of multiple targets

Local Analysis: Parameter ➔ Target space

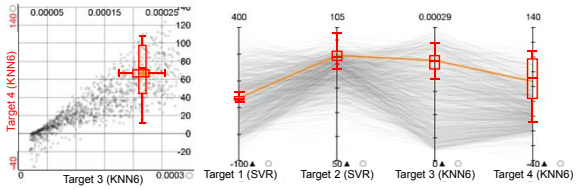


Uncertainty of Predictions



- Regression models
  - Potentially insufficient complexity
- Nearest-neighbor predictors
  - Depend on the local sampling density

Uncertainty of Predictions

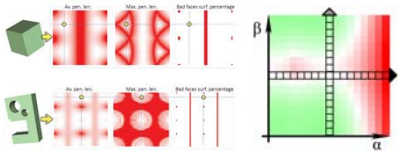


Optimization of a car engine

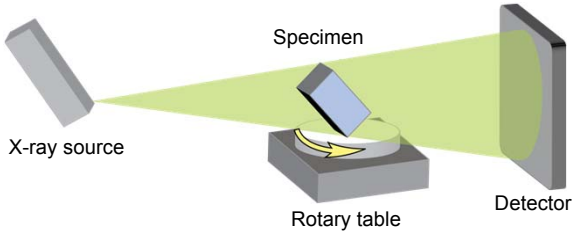
Application Example:

Optimize the design of a real-world turbo-charged car engine

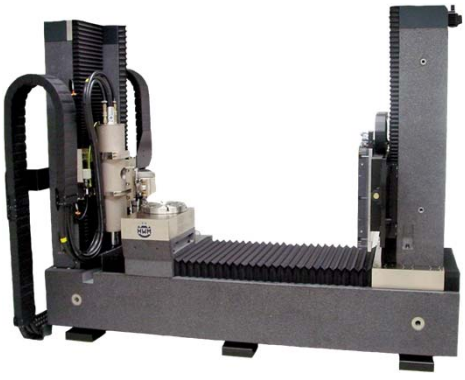
Application area 2: Industrial 3D X-ray Computed tomography



Specimen placement in Industrial 3DXCT



Specimen placement in Industrial 3DXCT



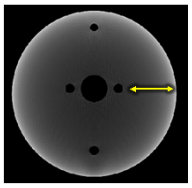
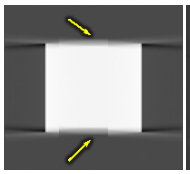
Motivation

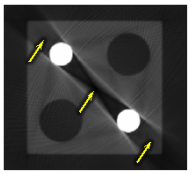
- Placement is crucial for
  - Non destructive testing
  - metrology
- Requires knowledge
- Good placement is hard to find
  - Shortest penetration lengths
  - Smallest bad planar faces area
  - Stable within a certain range



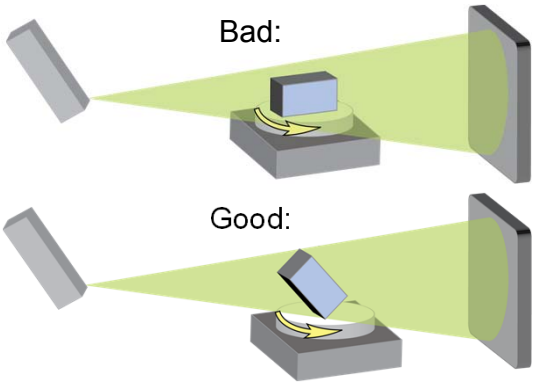
Placement

- Beam-hardening artifacts
  - Cupping artifacts
  - Streaks
- Bad planar faces artifacts
  - Blurring

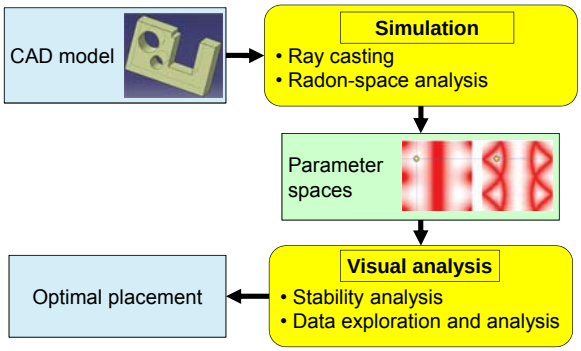





Good/Bad Placement Example

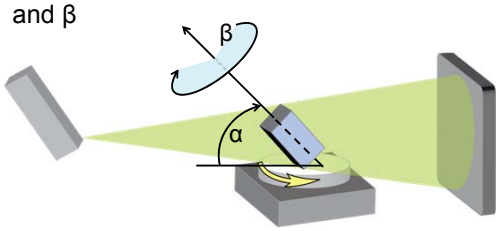


Workflow



Parameter Space Analysis

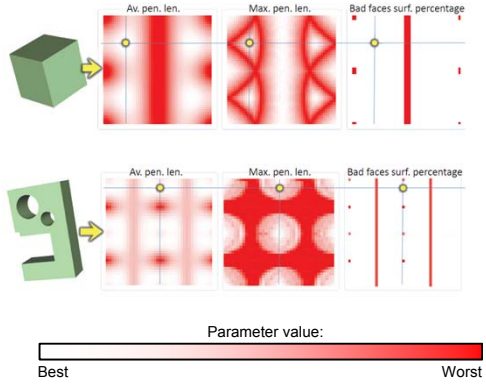
- Simulation
  - Set of candidate placements
  - Placement is defined by the orientation
  - Orientation is defined by two Euler angles α and β



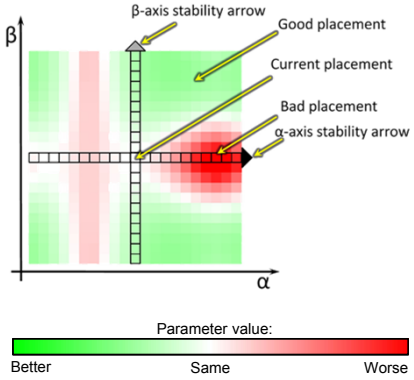
Simulation

- Raycasting
  - Maximum penetration length
  - Average penetration length
- Radon-Space Analysis
  - Bad faces area percentage

Parameters Representation

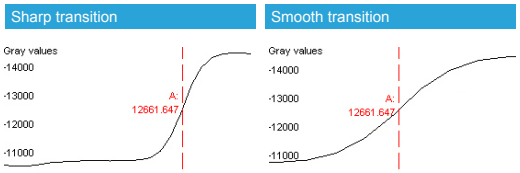


Stability Widget



Statistical Analysis in 3DXCT

- Lack of uncertainty information
  - Surface models for metrology
  - Transition quality



Statistical Analysis in 3DXCT

- Specific pipeline
  - Complementary DECT scans
  - Uncertainty by probability vectors $\mathbf{p} = \begin{pmatrix} p_1 \\ \vdots \\ p_n \end{pmatrix}$

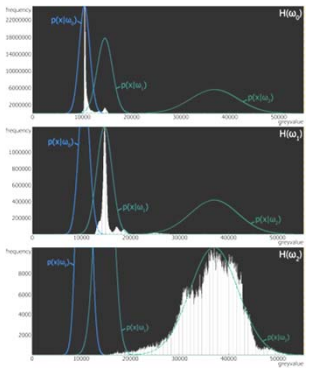
Statistical Analysis

- Bayesian decision theorem
  - Define classes
  - Greyvalues as feature
  - Definition of suitable classifier
- Assumptions for 3DCT:
  - Homogeneous materials
    - Nearly constant greyvalues
    - Modifications of irregularities
    - Continuous greyvalue distribution
- Gaussians as probability density functions

Statistical Analysis

- Local histogram decomposition
- Partial range histograms (Lundström)
- Recombination
  - Weighted multidimensional k-means
- Estimation of PDF
  - Gaussian fitting
  - Calculation

Statistical Analysis



Class conditional PDFs p(x|ω_j): Air Plastics Metal

Statistical Analysis

- Bayesian decision theorem
  - Estimated class conditional PDFs
  - Equal priors
  - Posteriors

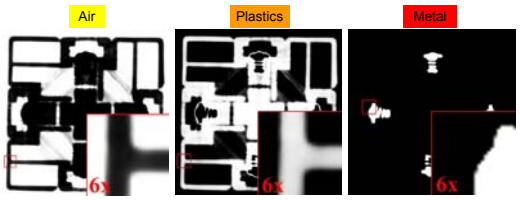
Class conditional PDF — Prior

$$p(\omega_j|\mathbf{x}) = \frac{p(\mathbf{x}|\omega_j)P(\omega_j)}{p(\mathbf{x})}$$

Posterior — Evidence

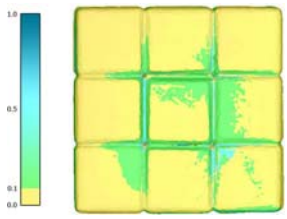
Statistical Analysis

- Posterior probability volume
- Implicit fuzzy segmentation



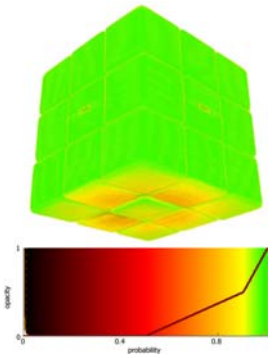
Uncertainty visualization

- Uncertainty mapping:
  - Spatial uncertainty color-coded on the surface



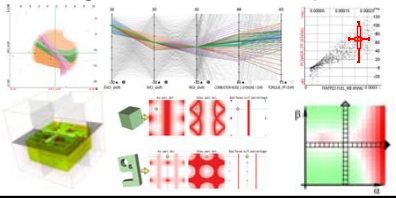
Uncertainty visualization

- Direct volume rendering:
  - Color and opacity transfer function



Summary

- 2 Industrial areas addressed:
  - Uncertainty vis + parameter space analysis already in daily industrial use
  - Generated awareness of uncertainty in data
  - Essential for the acceptance and applicability of future algorithms and techniques



Acknowledgments / Papers

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