Fraunhofer Institute for Algorithms and Scientific Computing SCAI

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Analysing Data From Many Car Crash Simulations

Machine Learning (ML) in (Virtual) Product Development

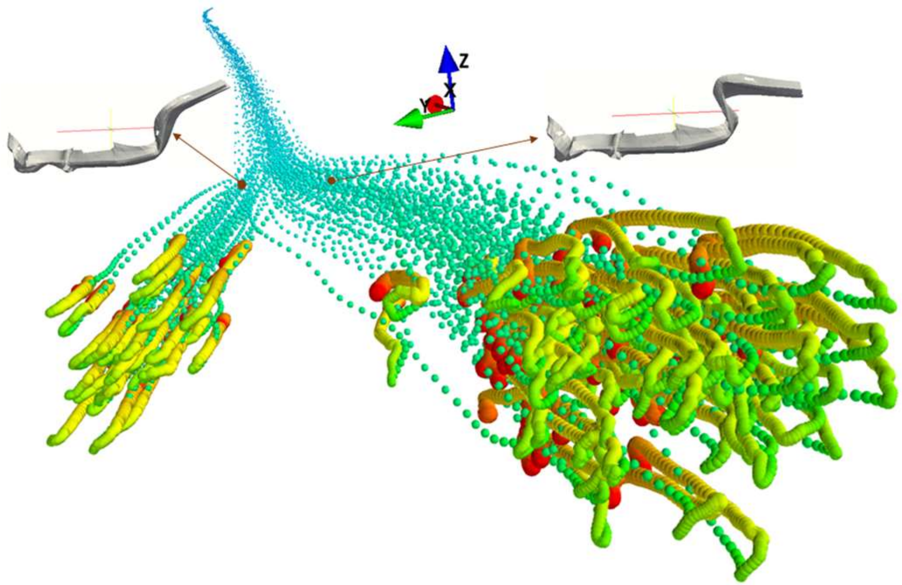
ML combined with domain expertise

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

assist engineer in simulation data analysis workflow

- ML allows analysis of complex data arising from detailed numerical simulations during (virtual) product development
- use ML to
  - simplify data analysis in R&D process
  - assist development engineer
- for physical data observe domain knowledge during analysis
- Fraunhofer SCAI develops tools for comparative and explorative analysis of data from numerical simulations, e.g.
  - automotive crashworthiness with FEM
  - forming, e.g. cup drawing
  - fluid flows
  - wind turbines under (turbulent) load



visualization of two deformations behavior modes over time

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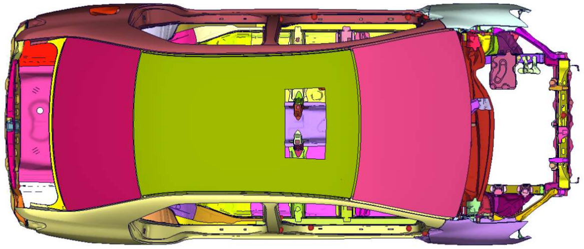
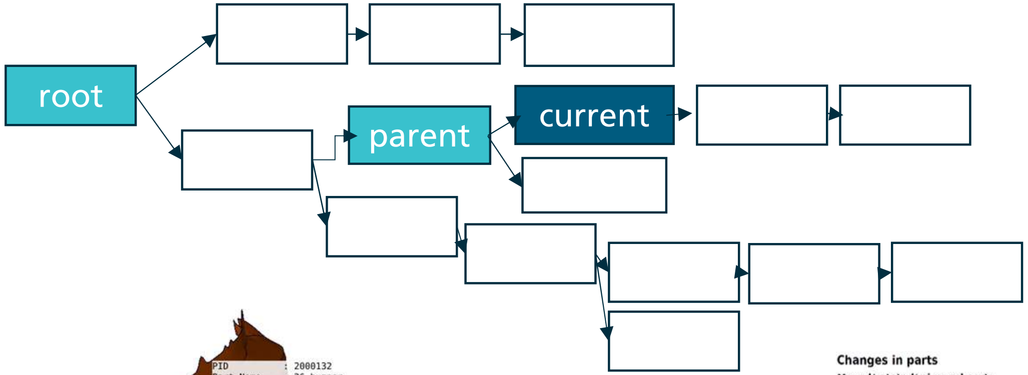
Components of Simulation Data Analysis Workflow

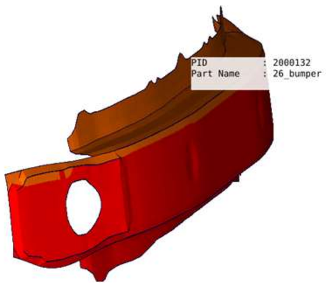
analysing pairwise simulations



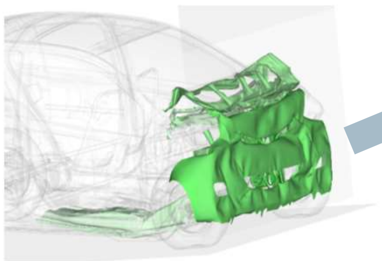
development tree



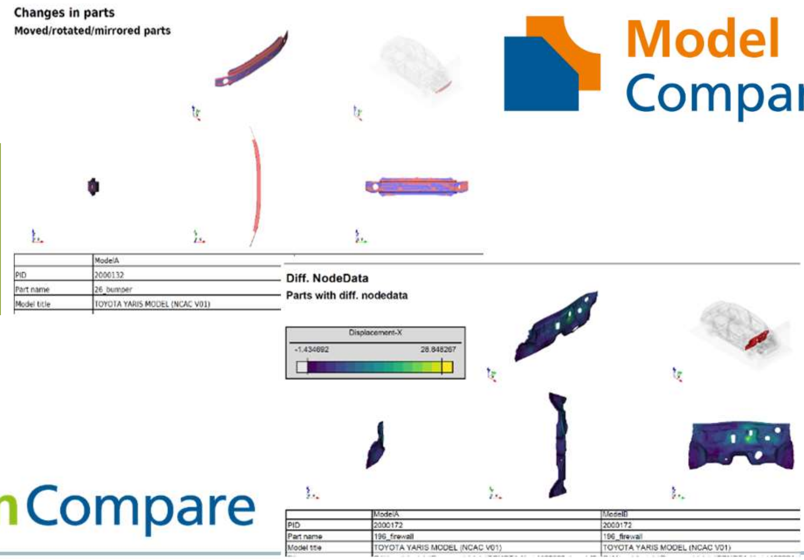
design measures



behavioral events



PDF report and JSON export



Model Compare

SimCompare

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Comparative Analysis of Many Simulations

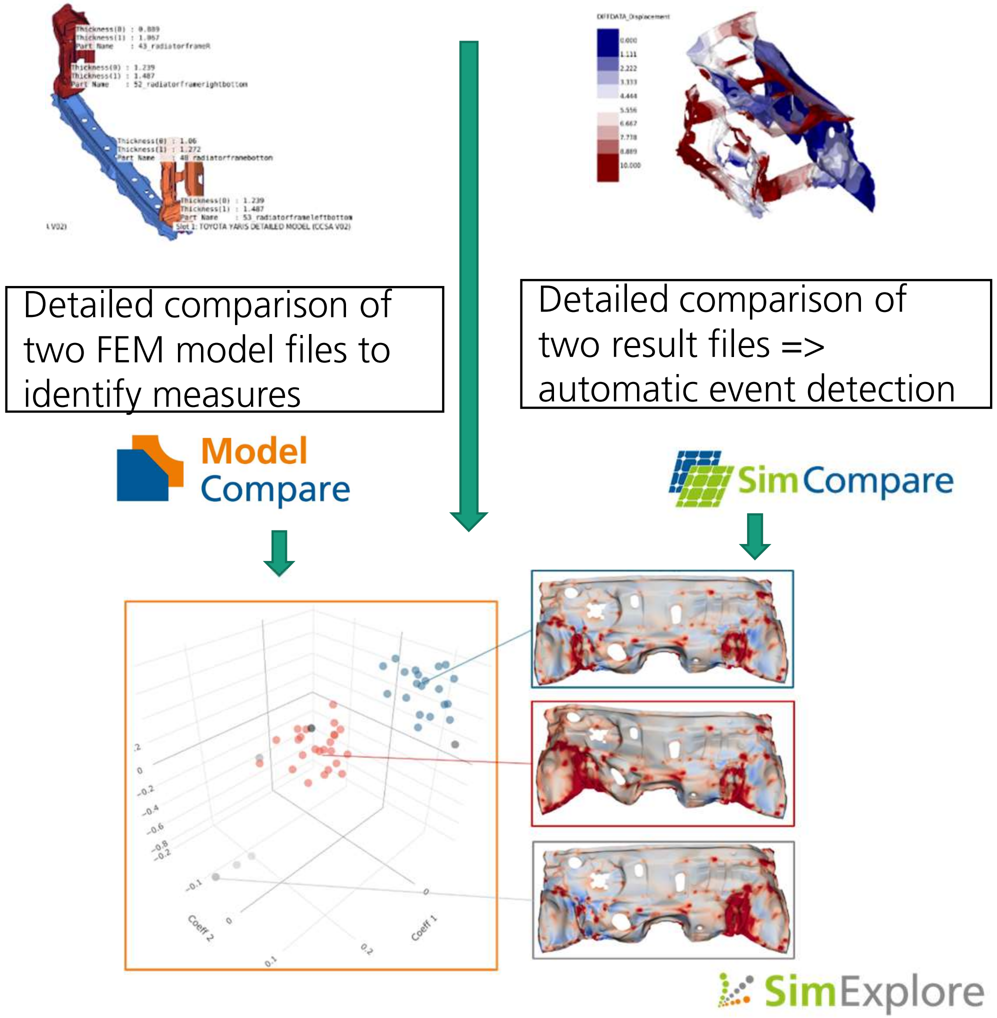
Measure and Event Detection

Current data analytics capabilities of SCAI tools

- Compare all models in a project phase to detect, categorize and save changes (measures) automatically
- Comparatively assert the effect of the detected measures on many simulations (events)
- Automated similarity and outlier analysis

Challenges to extract the most interesting measures

- characteristics of CAE data, especially geometrical changes, as features for ML algorithms
- bringing the applied model changes into relation with the detected events, correlation analysis
- learn from these relationships for future development projects



open FE- model of Toyota Yaris http://www.ncac.gwu.edu/vml/models.html

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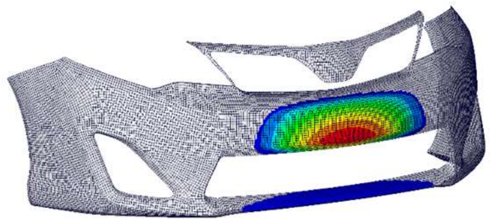
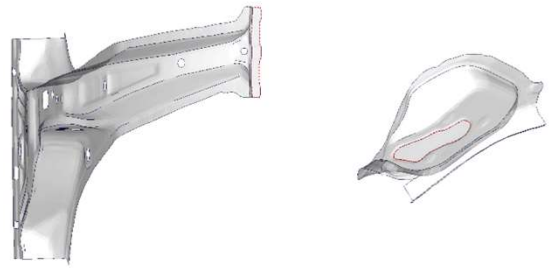
Design Measures – (Geometric) Diff for Inputdecks

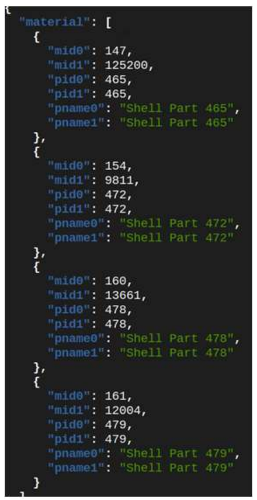
- identification and interactive exploration of the design changes between two FEM models
  - detection of thickness and material changes
  - duplicate parts (translated / rotated parts)
  - new / missing parts and elements
  - changes in HAZ, RBEs, welds
  - changes in contours, holes, adhesives
  - PID grouping in GUI
  - Animator plugin or standalone batch mode
- documentation of design changes (measures)
  - automatic PDF reporting
  - JSON export
- comparison FE-SurfaceMesh vs. CAD-HullMesh



identification of geometry and mesh changes



detection of an extended contour and a closed hole



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  },
  {
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    "mid1": 9811,
    "pid0": 472,
    "pid1": 472,
    "pname0": "Shell Part 472",
    "pname1": "Shell Part 472"
  },
  {
    "mid0": 160,
    "mid1": 13661,
    "pid0": 478,
    "pid1": 478,
    "pname0": "Shell Part 478",
    "pname1": "Shell Part 478"
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  {
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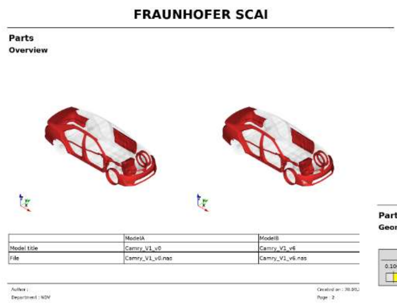
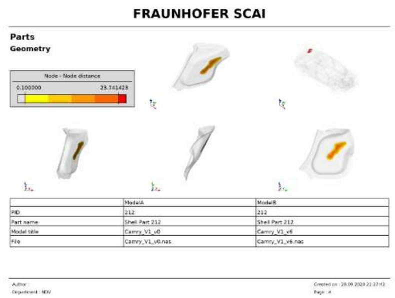
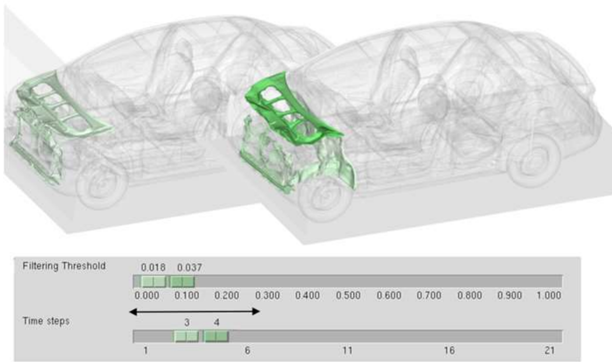
    "pname0": "Shell Part 479",
    "pname1": "Shell Part 479"
  }
```

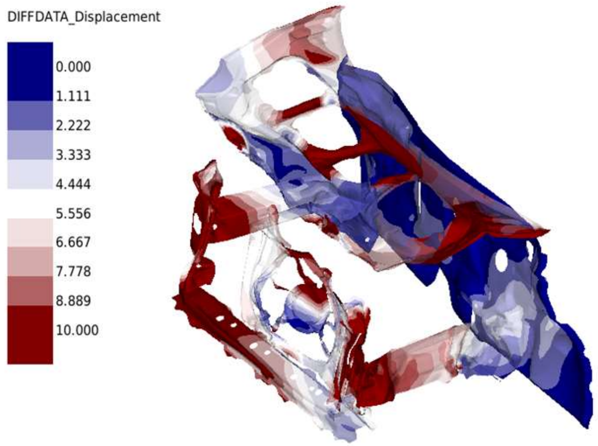


Detection of Events vs. Predecessor

- comparison of two FEM simulation results
  - based on any node or element function
  - semantic segmentation handles different geometry or PIDs
  - automatic PDF documentation
  - JSON export for further processing and usage, e.g. integration in SCALE.result
- interactive visualization in Animator
  - filtering of most influenced parts
  - visualize differences per part over time
  - highlighting of regional areas of interest



most influenced parts at 20ms, 30ms, after change of lower load path part thickness



structural parts in middle and upper load path are detected based on largest deviations

"metricvalue_L1Norm" :
[
0.487163424491882
0.487529695034027
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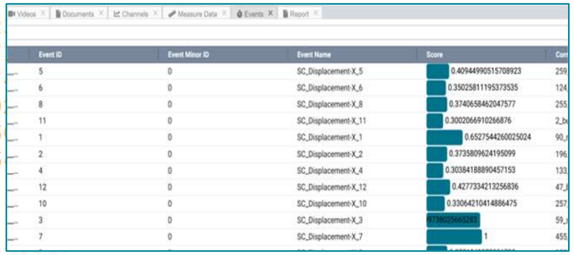
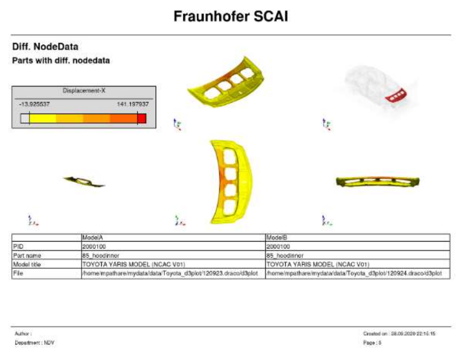




open FE- model of Toyota Yaris http://www.ncac.gwu.edu/vml/models.html

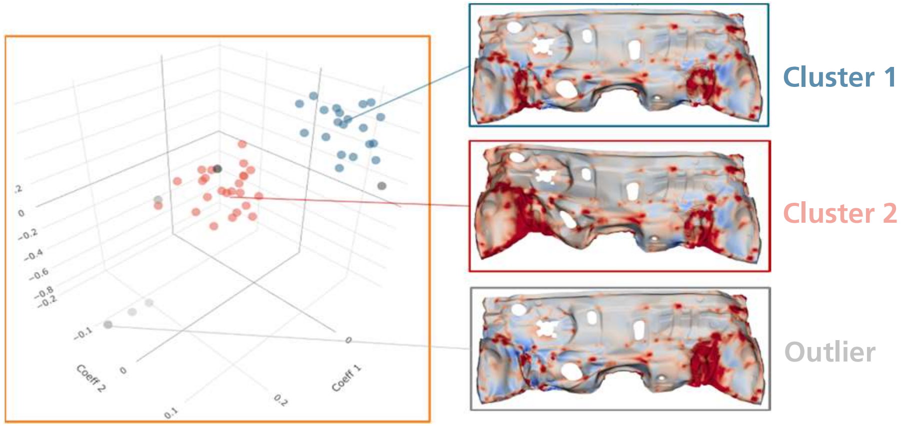
Similarity Analysis and Result Exploration

SimExplore

Comparison of multiple FEM simulation results

- analysis of the impact of model changes by overview over many simulations
- offline bulk data processing and interactive exploration
- automatic identification of **clusters** (simulations that behave similarly)
- automatic determination of **outliers** (simulations outside the clusters) and ranking of their severity
- existing results can be updated easily with a new simulation (**event indicator**)

- structured data representation (JSON)
  - can integrate ModelCompare results in dashboard
  - can be based on the capabilities of SimCompare



organization of many simulation results

- use suitable concepts of similarity to arrange (embed) simulation results in overview diagram
- we use new, patented method for the representation of simulation data (A Geometrical Method for Low-Dimensional Representations of Simulations DOI: 10.1137/17M1154205)
- can be understood as a Geometric Fourier Basis

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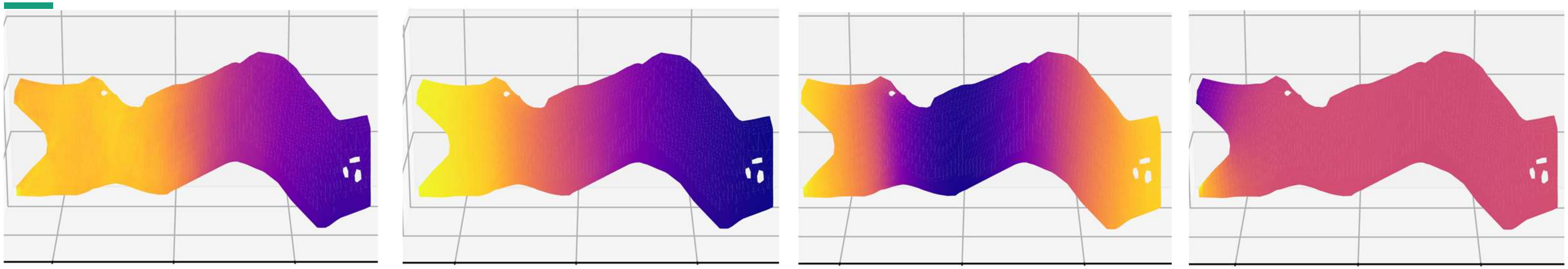
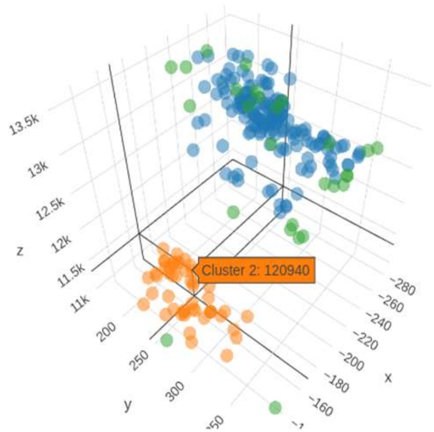
Physical Data Representation Using Surface "Fourier"-Modes

informed machine learning



- geometry aware data representation allows
  - easy overview over several simulation runs
  - data reduction that simplifies analysis pipeline



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Informed ML - A taxonomy and survey of integrating knowledge into learning systems. *IEEE TKDE, 2023.*

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Implementation of Interactive Event Detection Workflow: SimExplore

online interactive phase

Input: results from offline / batch phase

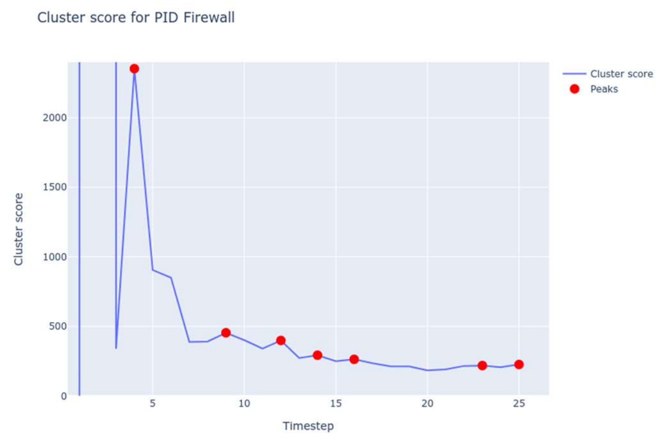
↓

cluster finder / outlier detection

↓

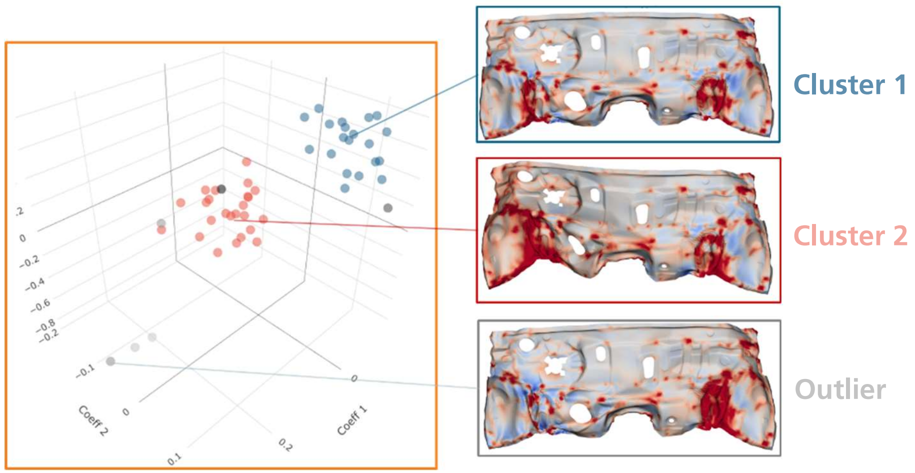
simulation clusters / outliers

SimExplore **phase 2** enabling interactive exploration



Output:

- **component score:** parts with main deviations
- simulation IDs with cluster/outlier information per part, time step and node/element function
- **outlier score** over time per (relevant) part identifies interesting time steps
- visualization via interactive dashboards



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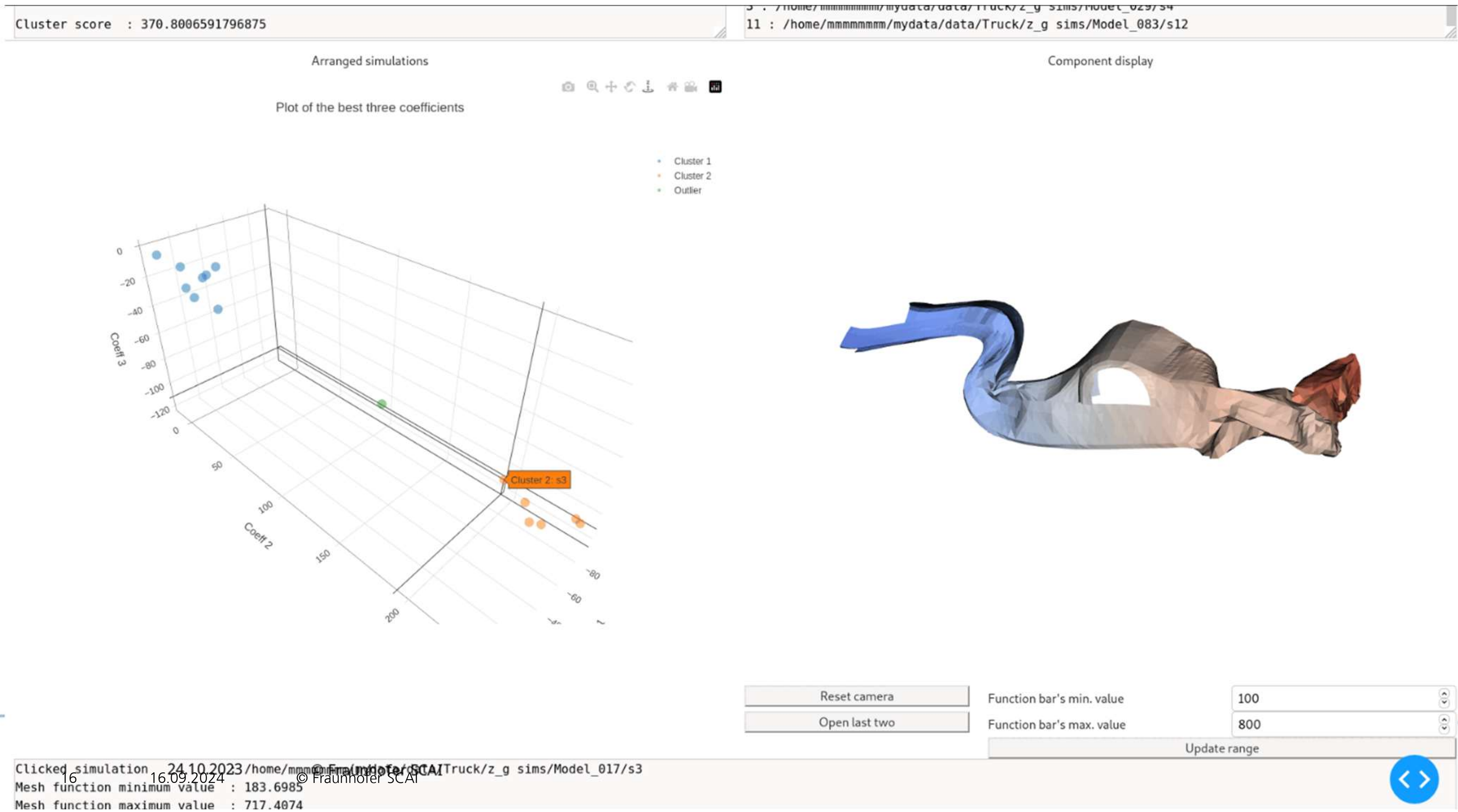
SimExplore: Interactive Analysis



Behavior Detection Workflow: After Several Simulations

post-processing of several simulation results

Input: results from initialization phase

↓

cluster finder / outlier detection

↓

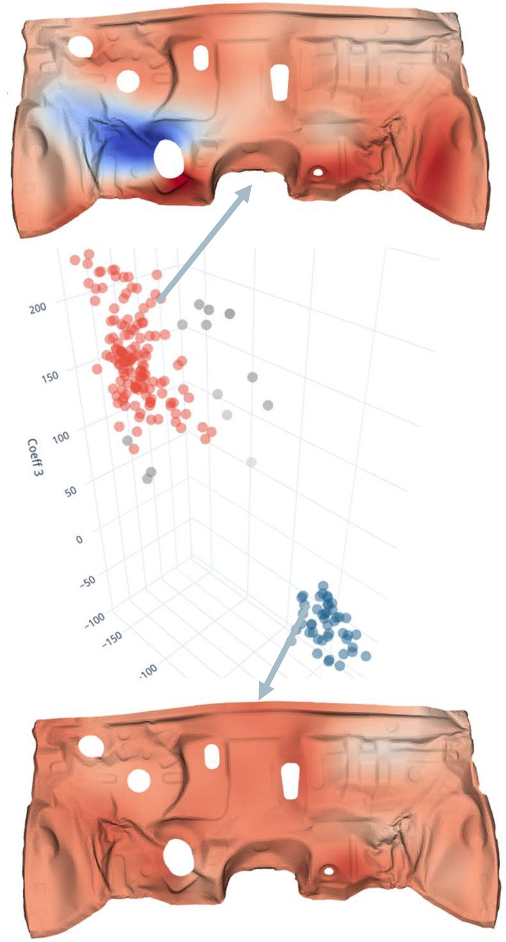
simulation clusters / outliers

SimExplore

analysis phase
enabling automated event detection

Output:

- analysis results with cluster/outlier information per part, time step and node/element function
- **outlier score** indicates if there are “interesting” parts (and time steps) deviating “strongly” from earlier simulations generated so far in development process



Cluster Indicator:

- clustering algorithm identifies distinct behaviors
- explorative visualization allows confirmation of cluster by engineer
- for engineering task focus on interesting cluster, e.g. for optimization per cluster

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Anomaly Detection Workflow: After Each Simulation

offline post-processing of each simulation

Input: results from initialization phase

↓

cluster finder / outlier detection

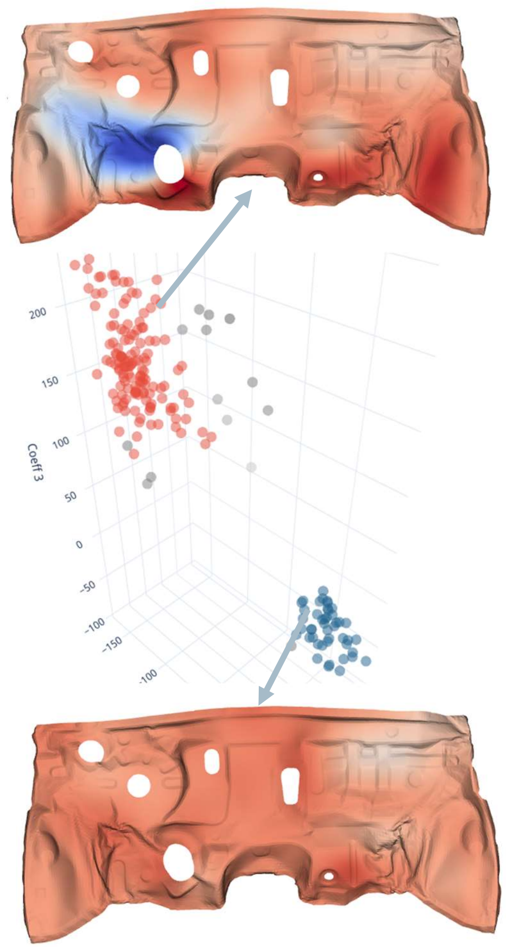
↓

simulation clusters / outliers

SimExplore **post-phase** enabling automated event detection

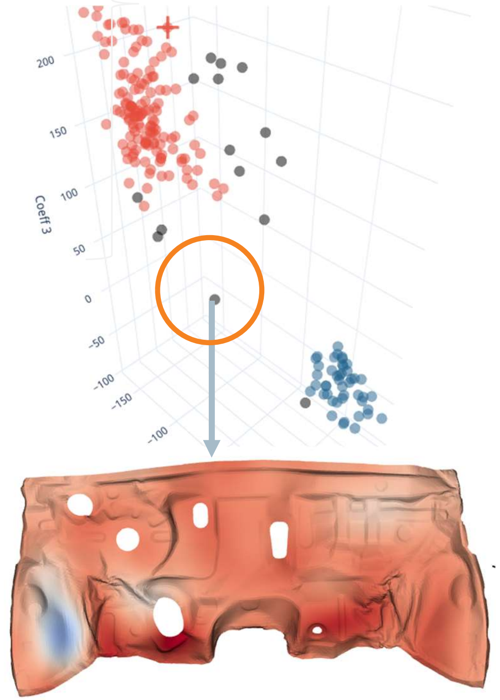
Output:

- analysis results with cluster/outlier information per part, time step and node/element function
- **outlier score** indicates if there are "interesting" parts (and time steps) deviating "strongly" from earlier simulations generated so far in development process



Event Indicator:

- new simulation is between existing behavior modes
- good or bad ?



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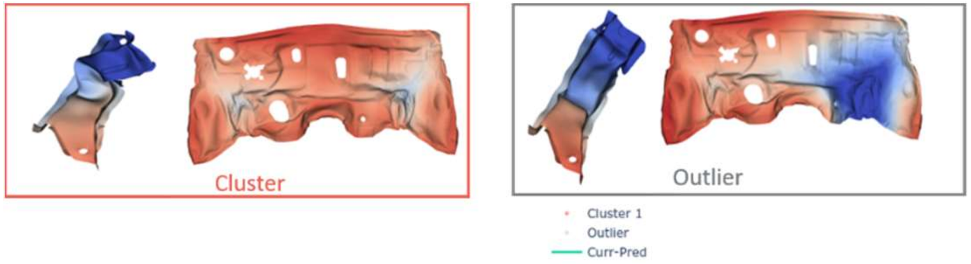
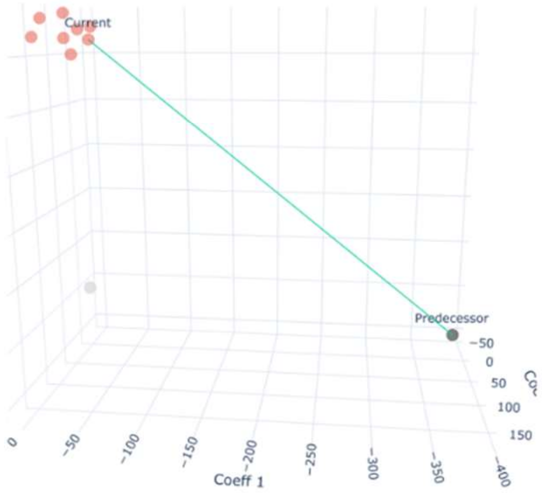
Correlations between model changes and events

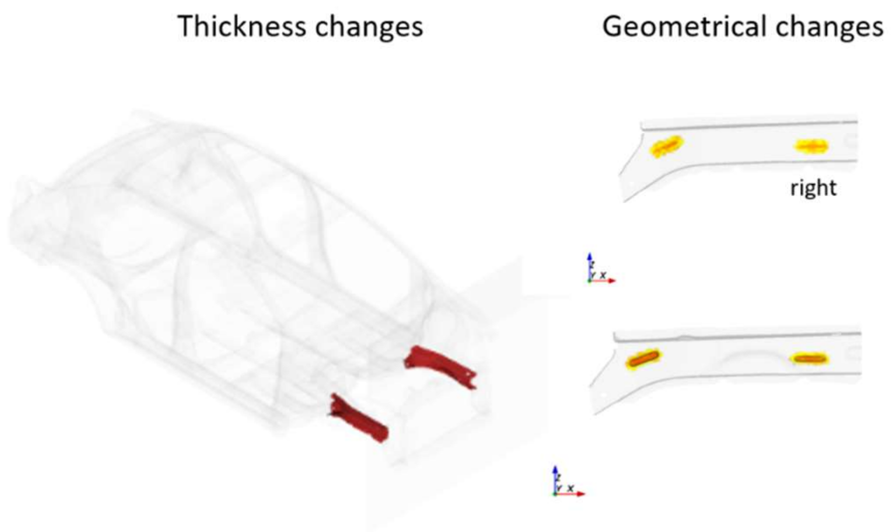
Case Study Toyota Yaris

Comparison of current simulation with its predecessor

- High distance in embedding space indicates very different behaviour
- All applied changes detected with ModelCompare
- **Simultaneous view** of input and output changes is enabled
- Embedding allows **correlation analysis** between (scalar) changes and resulting deformation patterns of parts







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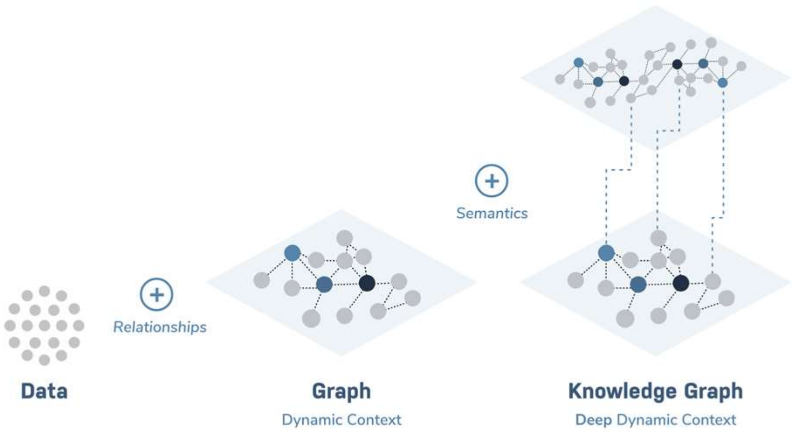
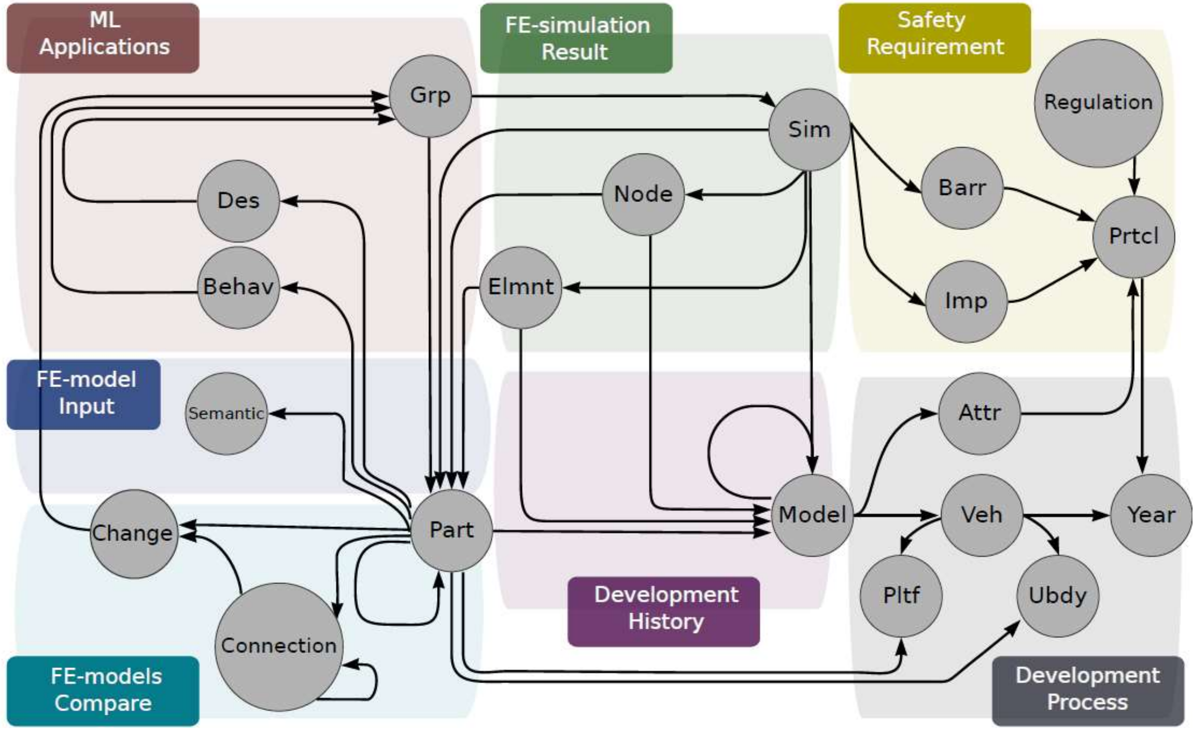
Graph-based Data Representation

Knowledge Graph Advantage

Building a knowledge layer that provides a new representation of data

- Quicker decision making
- Improving design guideline
- Combining structural and unstructural data





open graph-db: **github.com/Fraunhofer-SCAI/GAE-vehicle-safety**

A. Pakiman and J. Garcke. Graph modeling in computer assisted automotive development. In IEEE ICKG 2022.

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Statistical Analysis and Optimization of Parameter-Dependent Problems

adaptive DoE based on expected improvement

(•)DesParO

SimExplore

iteratively extended DoE

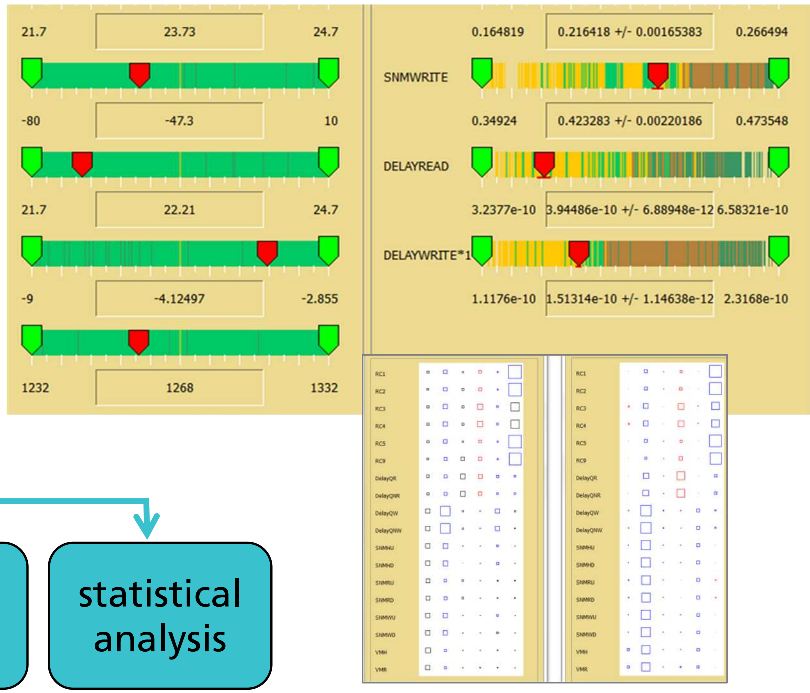
DesParO Metamodel

quality check: local model tolerances

sensitivity analysis

optimiza-tion

statistical analysis



Input: results from cluster and/or correlation analysis

cluster finder / outlier detection

simulation clusters / outliers

update phase
incrementally perform analysis with next simulation results

Hierarchical, Adaptive Metamodels:

- metamodel per behavior mode reduces data needs while improving accuracy

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Data Analysis in the Crashworthiness Development Process

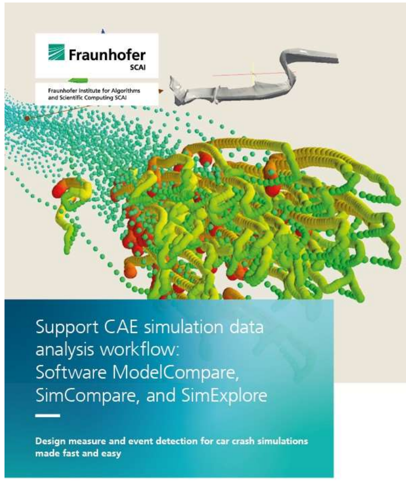
machine learning contributions and ongoing research

- ML-assistance tools **simplify handling of data from many simulations**
  - identification of behavior modes or outliers
  - investigation of correlations between design changes and results
- interactive exploration allows intuitive overview of simulation behavior
- add-on functionality for SDM (Scale) and/or post-processor (GNS Animator)

- organization of CAE process data in **graph database / knowledge graph**
  - prediction of similarity of simulations and parts
  - provide knowledge in connection with LLM

- research on **aligning simulation behavior with design changes**
  - fingerprints per development stage DoE
  - identify relevant design changes for outliers
  - make design suggestions

- research on **exploiting LLMs / foundation models in CAE**
  - how can LLMs-agents help in learning/using/steering the CAE workflow
  - are there foundation models for geometries ?



Model Compare

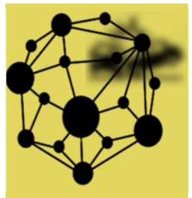
SimCompare

SimExplore

scai.fraunhofer.de/ndv

caewebvis.scai.fraunhofer.de

web-demo for head impact data



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