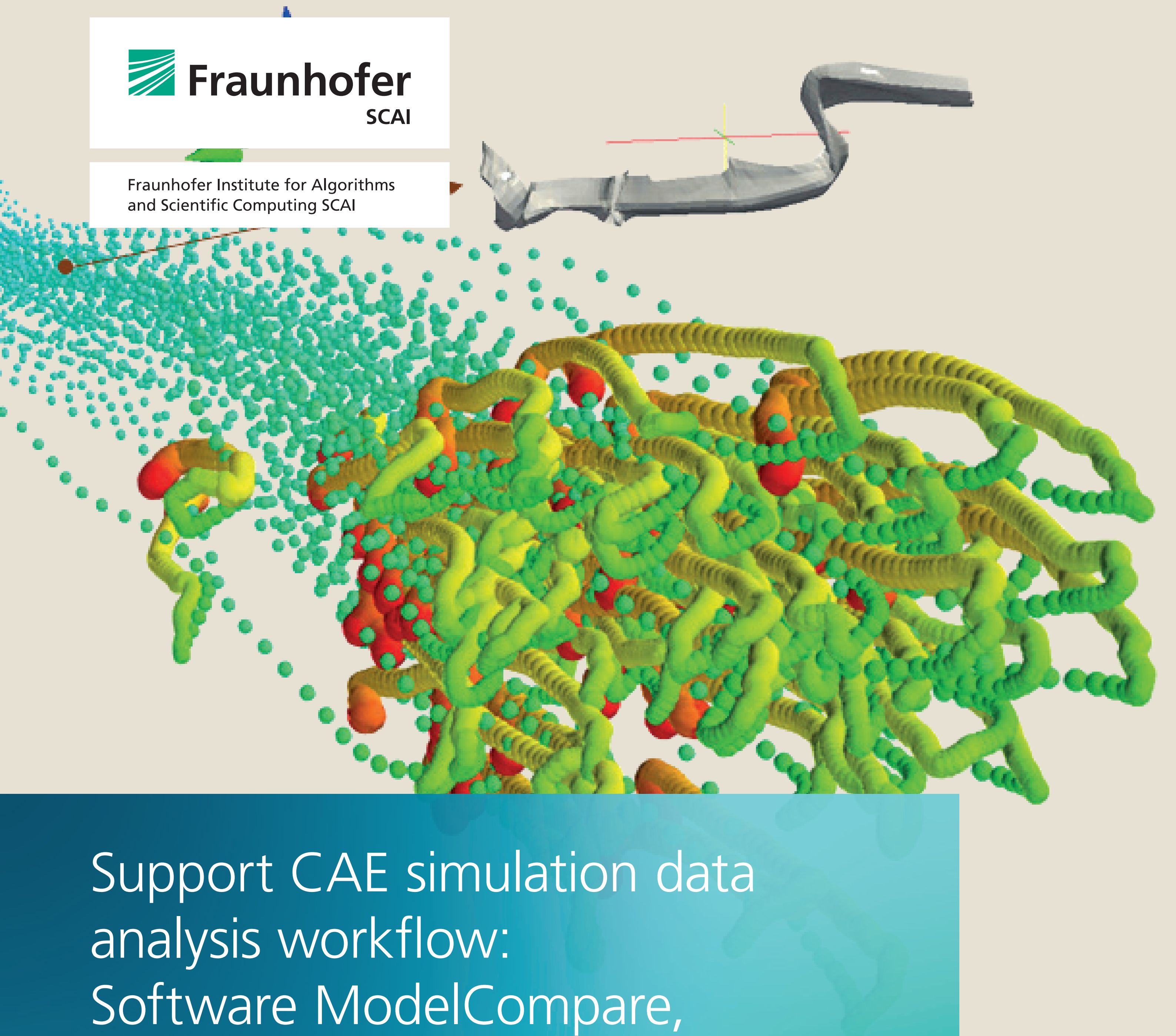
Fraunhofer Institute for Algorithms
and Scientific Computing SCAI



Support CAE simulation data analysis workflow: Software ModelCompare, SimCompare, and SimExplore

Design measure and event detection for car crash simulations made fast and easy

Drowned in CAE-Data?

Assist engineers in their daily development process

Computer-Aided Engineering (CAE), based on reliable numerical simulations, is a core pillar in many engineering domains.

The growth of computing power and modeling improvements have increased the amount and complexity of data from finite element (FE) simulations. Whereas the requirements on the product behavior, or external regulations, have drastically increased.

However, the data growth, limited available engineering time, and insufficient software tools often prevent the adequate exploration of all the simulation results.

For example, CAE model size limits the number of simulations a CAE engineer will simultaneously load in post-processing software. The manual comparison of these design variants becomes cumbersome and is limited to only a few simulations.

At Fraunhofer SCAI, we develop and provide software to assist engineers in their daily development process.

We employ state-of-the-art machine learning methods adapted to CAE data. Especially, we focus on the integration, representation, and use of domain knowledge in our proposed methodology.

Our comparison and exploration software tools all together allow deep insight into a set of simulations and thereby already highly simplifies the work with CAE-data.

In ongoing and envisioned future research, we work on additional aspects such as tracking events in the design development tree, semantic knowledge modeling, predicting simulation trends or outcomes, and up to recommending promising design measures. Herein, semantic modeling additionally enables the establishment of knowledge graphs. As a further example, classical post-processing starts after the simulation is completed. Nevertheless, many effects occur at an early stage of the simulation and can give valuable insights into trends. Data I/O and computing time can be reduced if they are monitored carefully. Therefore, we work on In-situ data analysis methods, where the solution data from a time step is already analyzed at run-time.

Crashworthiness development process

During the virtual product development of a car, numerous design changes are applied and analyzed by engineers.

The goal is to develop a model that fulfills pre-specified design criteria, e.g., in view of functionality, behavior, and costs.

This procedure usually results in large development trees with many design changes and corresponding simulation results.

Following a path in the obtained development tree, the differences from one simulation to the following consist of one or several design variations, resulting in numerous crash behavior changes.

These differences can be characterized essentially by local changes in a subset of the car parts.

During the development process, each design variation must be analyzed, and its influences on the crash results must be compared and evaluated.

Overall, there is a lack of simple-to-use procedures to automatically categorize design measures together with their impact on simulation results.

Framework for automatic data analysis and event detection

We have developed several tools to allow easy analysis and exploration of design variations and their impact.

- **ModelCompare** is a plug-in that compares two similarly discretized FE models and portrays and categorizes their differences in terms of geometry (mesh), materials, thickness, or connecting elements.
- **SimCompare** is a plug-in for detecting variations in crash behavior, e.g., deformations, in the results of two related simulation runs for crashworthiness analysis using FE models.
- **SimExplore** is a tool for an easy exploration and analysis of the impact of design variations. Using machine learning methods it provides an overview over many simulations, pointing out similarities and exceptions in deformations or mesh functions. It allows insight into a set of simulations and, thus, into the overall product development process.
- **DesParO** is a software toolbox enabling sensitivity analysis and robust multi-objective optimization of parameterized production processes based on a nonlinear surrogate surface model approach.

In the following pages, we highlight the capabilities of these tools.

CAE web visualization

To ease the uptake and access to modern data analysis and visualization tools in the overall design process, we envision a data organization following web semantics, which connects simulation results to attribute requirements and design limitations. Such a connection of simulation data, specifications, and documents will increase the exchange and learning rate between the disciplines involved.

For example, design engineers and attribute leaders rely on the reporting by CAE engineers in the traditional workflow. Such static reporting restricts the independent exploration of the data. The limitation arises from the dependency on available software and the required skills to use CAE tools. In such a workflow, multi-disciplinary collaboration is ensured only if the attribute leader has CAE expertise or the design engineer has a background with the requirement of that discipline. Such a lack of multi-disciplinary collaboration degrades efficient problem-solving.

We envision the web-based visualizations with CAEWebVis as an open project that allows companies to have dynamic reporting as a complimentary side option, which overcomes the current disconnected flow of data. Without much overhead, running such a service for data analysis and exploration within a company is possible. A remarkable advantage is the wide availability of such a web-based tool within the company, e.g., for CAD engineers, compared to the post-processing tool used mainly by the CAE engineers. Further, such a middle-level view overcomes the limitations on the number of simulations a CAE engineer can simultaneously load in post-processing software. Naturally, CAEWebVis will support the visualization of the results of our CAE analysis tools.

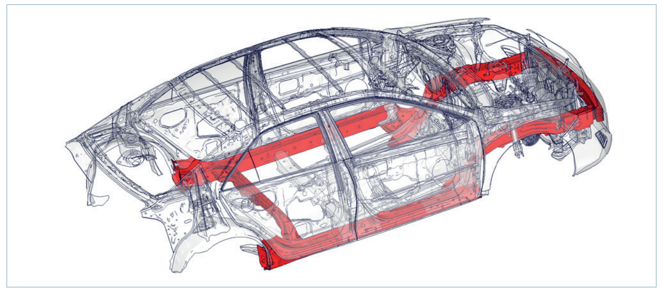
https://caewebvis.scai.fraunhofer.de

ModelCompare

FEM model comparison made fast and easy

ModelCompare is a plug-in for finite element (FE) pre-and post-processing tools. It compares two similarly discretized FE models and portrays their differences of geometry (mesh), material identifiers (ID), and thickness.

ModelCompare identifies the differences between the two models based on the geometry described by the mesh. It uses specialized mapping techniques that lead to extremely short run times.



Visualization of the thickness differences between the two chassis.

User benefits

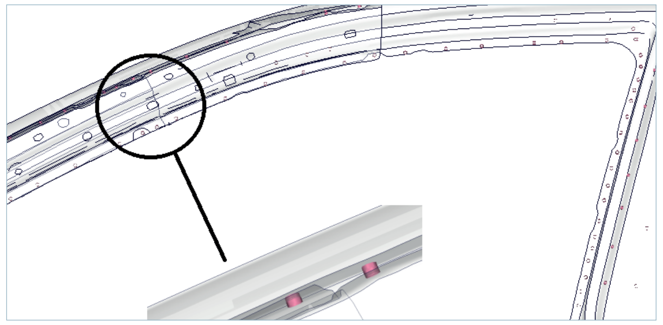
Everybody involved in computer-aided engineering (CAE) has to deal with numerous designs that vary in geometry, material, and boundary conditions. ModelCompare is a quick-look tool capable of determining the differences between two FE models, which are discretized similarly. With ModelCompare, you can quickly compare two FE models within the visualization tool used without going through the burden of manually determining the differences. A report can be generated to document the changes.

Our contribution

At Fraunhofer SCAI, we thrive at the cross-roads of mathematics and data analysis. This enables us to provide cutting-edge tools that address the everyday needs of CAE engineers. They often need to compare and identify parts from different models when they analyze different simulation results. Therefore we developed this tool as one step of an overall simulation data analysis workflow.

A seamless interface as a plug-in

ModelCompare is available as a plug-in for GNS Animator and can also be provided as a seamless, versatile interface for the visualization tool of your choice or as a stand-alone tool.



Differences in the spot welds have been detected and can be visualized together with the connecting parts.

Geometry and mesh changes
Accurate estimation and depiction of the differences in the geometry of two FE models are made based on their nodal positions. Additionally, parts with the same shape but different mesh configurations are detected and displayed.

Duplicated parts in one model
Parts with the same shape and mesh, which occur several times in a model, are identified independently of their orientation.

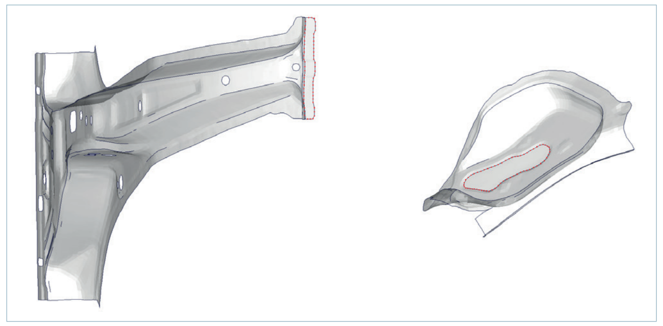
Multi-parts detection
ModelCompare identifies a part in the first model that is split into many parts in the second model as a set consisting of these parts.

New and missing parts / elements
New parts that have been added to or parts that have been removed from the model are detected and visualized. Elements missing in a part in one model, e.g., due to improper meshing, are also detected. The tool also detects if an element belongs to two different parts in the two models.

Material-ID, thickness, or function changes
Differences in material-ID, thickness, or user-specified function values between both models are detected. Here, thickness changes can be part-based or element-based, while function values can come from nodes or elements.

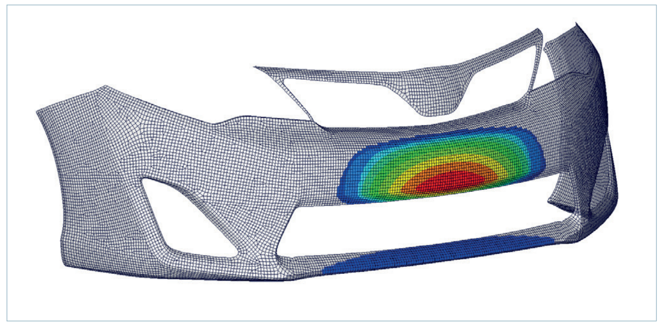
Detection of changes in spotweld, RBEs, and adhesives
Differences in the attributes of the spot welds (e.g., part identifiers, element identifiers, connected parts) along with new, missing, and moved spot welds are identified and visualized. ModelCompare can also determine the differences in the positions of the master and slave nodes of the rigid body elements (RBEs). Hexa element-based adhesives can be identified, and changes such as added, deleted, and moved adhesives can be detected.

Changes in contours and holes
Changes such as cut, extended, added, and deleted contours can be detected. Similarly, changes in planar holes, such as closed, extended, new, and shortened holes, can be detected.

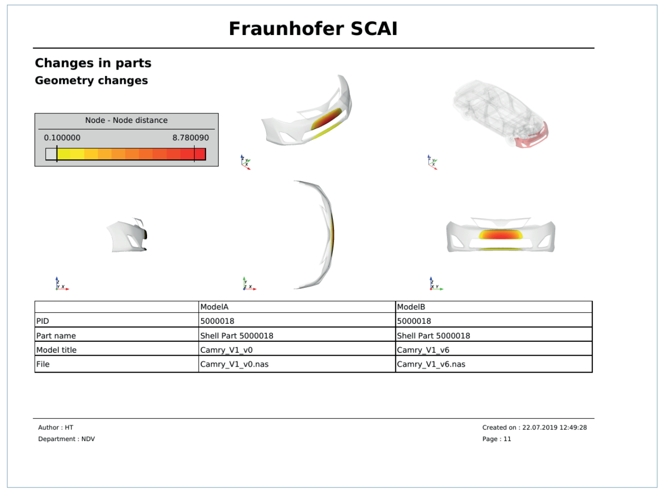


Detection of an extended contour and a closed hole in the other model.

ASCII comparison
Input files contain additional information not covered by the geometric comparison, for example, transformation blocks, comment blocks, etc. A smart ASCII difference analysis handles such input blocks. Currently, PAM-CRASH is supported, whereas others such as LS-DYNA will be added.



The bumper of the car that has been morphed in the other model has been detected as changed, and the color-coding depicts the intensity of morphing involved.



Fraunhofer SCAI

Changes in parts
Geometry changes

Node - Node distance
0.100000 8.780090

	ModelA	ModelB
PID	5000018	5000018
Part name	Shell Part 5000018	Shell Part 5000018
Model title	Camry_V1_v0	Camry_V1_v6
File	Camry_V1_v0.nas	Camry_V1_v6.nas

Author : HT
Department : NDV
Created on : 22.07.2019 12:49:28
Page : 11

A pdf report can be generated during the comparison process. The report displays the parts that geometry changes, the user settings used for comparison, and a summary of the other changes.

Contact

Mandar Satyanath Pathare
Phone +49 2241 14-4007
mandar.satyanath.pathare@scai.fraunhofer.de

Distributed by
scapos AG
Schloss Birlinghoven 1
53757 Sankt Augustin
Germany
info@scapos.com
www.scapos.com

Model Compare

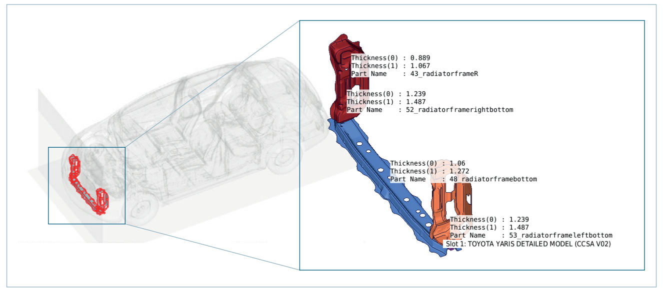
SimCompare

Towards automatic event detection for crash simulations

SimCompare is a tool for detecting events – in this context, deviations, such as anomalies or strange variations in deformations – arising in the results of similar simulation runs for crashworthiness analysis using finite element (FE) models. It provides a comparison of two FE simulation results based on multiple, arbitrary node/element data functions, e.g., displacements, plastic strains, or failed elements, over a range of time steps. The parts with the largest differences are automatically highlighted based on several comparison measures and an appropriate threshold.

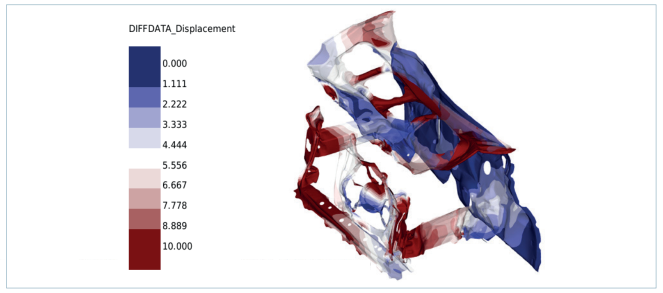
User benefits

In computer-aided engineering (CAE), numerous design changes are applied within the overall design development process until the final model satisfies all design criteria. Each design change has to be analyzed and its influences on the simulation results have to be compared and evaluated. SimCompare is a tool to easily analyze the impact of design changes in terms of data functions.



Exemplary design change: the thickness of the parts is increased by 20 % in the lower load path. Note that with the SCAI-Software ModelCompare such design changes are detected and can be documented.

SimCompare automatically highlights the most relevant parts over time together with local hotspots with respect to design changes. Thus, users are provided insight starting with only two simulations, without the burden of manually determining the differences or the necessity of setting up a simulation database. To document the influences of design changes, a report can be generated which is automatically adjusted for each analysis setup.



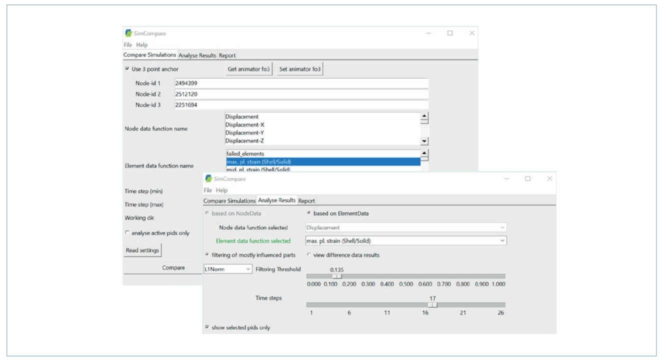
The lower load path part thickness has changed. We expect a switch in the load path energy absorption. SimCompare detects structural parts in the middle and upper load path responsible for load path energy absorption based on the largest deviations in total displacements between the two simulations at 30ms.

Automatic event detection

The SimCompare developers at Fraunhofer SCAI combine mathematics and machine learning to integrate existing application knowledge into data analysis methods. This enables us to provide SimCompare as an important step towards automatic event detection in an overall simulation data analysis workflow. Our tool allows to systematically analyze a design tree and to detect deviations caused by design changes. SimCompare can be used hand-in-hand with the SCAI tool ModelCompare for the identification of design measures realized through model adaptation.

A seamless interface as a plug-in

SimCompare is available as a plug-in for GNS Animator or as stand-alone batch tool. Results are visualized directly within Animator. Thus, the CAE engineer needs no additional tool and can easily integrate the SimCompare analysis into a well-established analysis workflow.



SimCompare Animator Plug-in

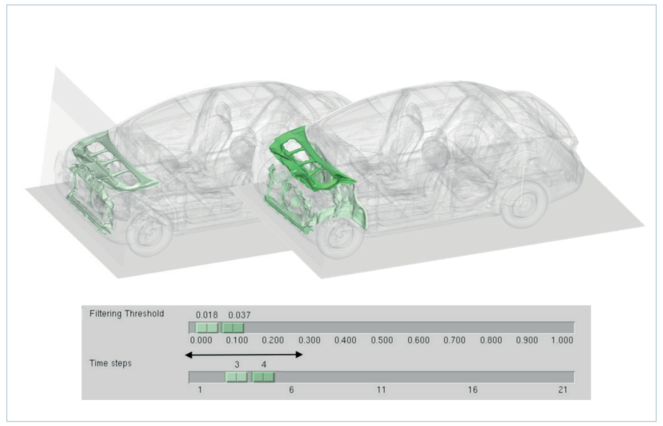
Comparison based on node and element data functions
Arbitrary node or element data functions available in the simulation models (e.g. signed plastic strains, displacements) as well as failed elements can be selected for comparison via the plug-in GUI or by a settings file. Rigid body motion can be extracted for analyzing displacements by setting corresponding anchor points. Thereby, detailed insight into local influences on, e.g., deformations, plastic strains, and stresses, can be evaluated with respect to a certain design change (measure).

Filtering of the most influenced parts
Differences are computed partwise for similarly discretized FE models. SimCompare uses specialized and well-established mapping techniques known from the SCAI tool ModelCompare. This enables comparisons of models with changed or combined parts. Filtering the most affected parts is supported interactively and automatically enabled in order to detect influences of design changes systematically. Moreover, the SimCompare GUI supports interactively browsing the results over time. Thus, the software informs the user on what events occur locally (part ids and location) and when events occur (time range).

Several metrics for different purposes
Several comparison measures (metrics) are available to focus on global or local influences. On request, these can be extended to other engineering-based metrics, including expert knowledge.

Visualization of local events
SimCompare visualizes deviations on both models, node- and elementwise in deformed state. Exceptionally, the visualization of differences in element failure is realized on the non-deformed mesh with failed elements visible. This feature simplifies the detection of local hotspots. The software shows the whole vehicle or the relevant parts to get an overview of design change impacts.

Automatic report generation / storing of results
Automatic pdf report generation makes it easy to archive analysis results. Additionally, all differences are stored node-/elementwise for loading in the preprocessor tool. The comparison results are stored partwise in structured JSON files supporting further post-processing. Therewith, the integration of results in a Simulation-Data-Management (SDM)-tool of your choice is highly simplified.



Interactive filtering of the most influenced parts over time – left: threshold 0.018, timestep 3 (20ms), seven parts selected; right: threshold 0.037, timestep 4 (30ms), nine parts selected

Contact

Dr. Daniela Steffes-lai
Phone +49 2241 14-4053
daniela.steffes-lai@scai.fraunhofer.de

Distributed by
scapos AG
Schloss Birlinghoven 1
53757 Sankt Augustin
Germany
info@scapos.com
www.scapos.com

SimExplore

Introducing SimExplore: a tool developed by Fraunhofer SCAI to support CAE engineers in product development and make their daily work much easier.

We employ state-of-the-art machine learning methods adapted to CAE data. The SimExplore workflow consists of two steps, where an offline batch process is followed by interactive exploration and analysis. The approach is available as a standalone tool and is designed for integration with other software clients.

SimExplore provides for a set of simulations

- an automated process to detect the most affected parts,
- an automatic identification of clusters, which are simulations that behave similarly,
- an automatic determination of outliers, which are simulations that behave very differently,
- an interactive visualization for many simulations,
- an interactive inspection of design variations.

Most affected parts

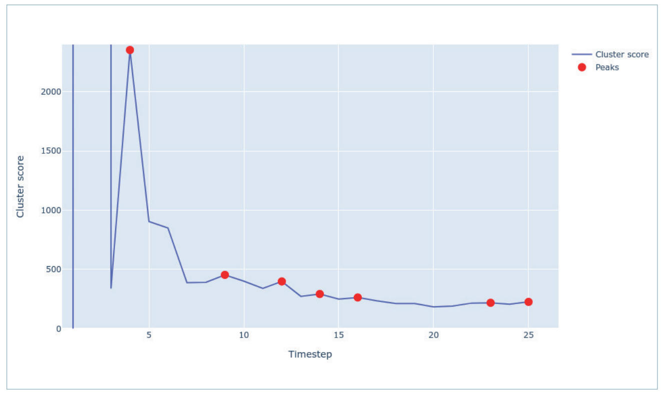
In the SimExplore workflow one can first optionally use SCAI's SimCompare to compare all simulations with a reference simulation. This analysis, which determines changes in the behavior of deformations or other mesh functions, is performed on all the parts. The most affected parts across all the two-sided comparisons can be collected according to a user-defined threshold and then selected for further analysis. Alternatively, user selected parts can be included in the analysis.

Geometry-driven representation

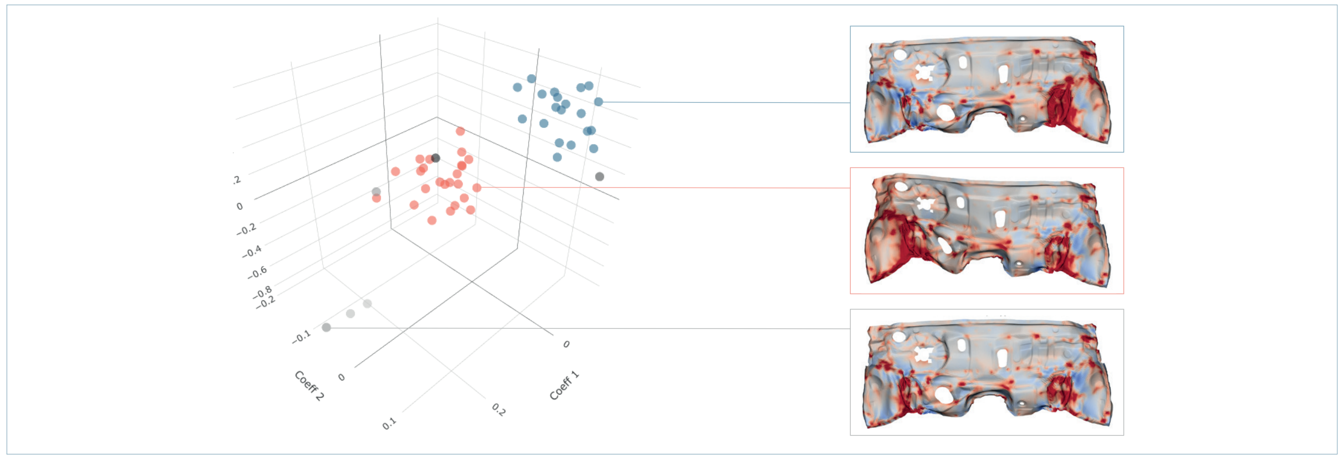
We use our specially developed, patented dimensionality reduction technique to compute geometry-driven features representing displacements or mesh functions of the selected parts. Using these geometric features, a clustering algorithm is applied to identify clusters, and outliers. Since the geometric features depend only on the geometry, they can be used for comparative analysis starting from two simulations, which is a significant advantage over other machine learning approaches.

Simulations or parts with the largest deviations

To further automate the process of identifying exceptions, an outlier score is calculated for each simulation. The outlier score is mainly based on the distance of the simulation from the cluster mean with respect to the deformations or other selected mesh functions. After an aggregation over all time steps and a normalization, the outlier score allows a ranking of the simulations with respect to their deviations from the other analyzed simulations. In addition to a score per simulation, we developed a component score that helps to find patterns in the deviations per component across all simulations and all time steps.



An optimized representation per part and time step that gives the best separation into clusters is automatically determined. Based on this, a score is obtained that highlights to the engineer interesting time steps for similarity analysis.



An exploration of many simulations and a fast 3D preview is possible with our dimensionality reduction methodology. Such a representation assists in clustering many simulations or detecting outliers, allowing a significant speed-up in the CAE post-processing.

Interactive exploration

The interactive SimExplore component allows the user to seamlessly analyze different parts or part combinations. The visual representation of the simulations as points in a scatter plot provides an intuitive overview of the similarities and exceptions with respect to the chosen functions. Users can select any function and parts for detailed interactive analysis. Clicking on a simulation quickly displays the corresponding part and mesh function in a 3D preview, allowing an easy-to-use exploration of the simulation results. Additional information for a given simulation or part can be interactively accessed, including a direct link to the GNS Animator.

Design variations

SCAI's ModelCompare identifies the changes in a given model compared to a pre-selected model, e.g., the reference or the predecessor. These design variations can also be explored in the interactive part of SimExplore, providing a holistic approach for evaluating the consequences of design measures.

Batch data processing and interactive analysis

The workflow is divided into a computationally intensive non-interactive part and an interactive exploration part. The batch processing involves, for example, the determination of the most affected parts, the computation of the geometry-driven data-representation or the pre-computation of additional information for later visual exploration. Additionally, new simulations can be added to an existing explorative analysis with low computational effort. SimExplore's workflow steps can work independently or be integrated into any simulation data-management system.

User benefits

Overall, SimExplore provides an automatic identification of clusters and detection of outliers, combined with a rapid visualization and interactive analysis for many simulations. The ability to interface directly with the preferred post-processor eases the detailed analysis of identified special simulations. The calculated similarity information enables an overview of many simulation results, where the integration of model variations allows the inspection of corresponding design changes - a breakthrough in the way post-processing and simulation analysis can be performed.

Contact

Dr. Rodrigo Iza Teran
Phone +49 2241 14-4064
victor.rodrigo.iza.teran@scai.fraunhofer.de

Distributed by
scapos AG
Schloss Birlinghoven 1
53757 Sankt Augustin
Germany
info@scapos.com
www.scapos.com

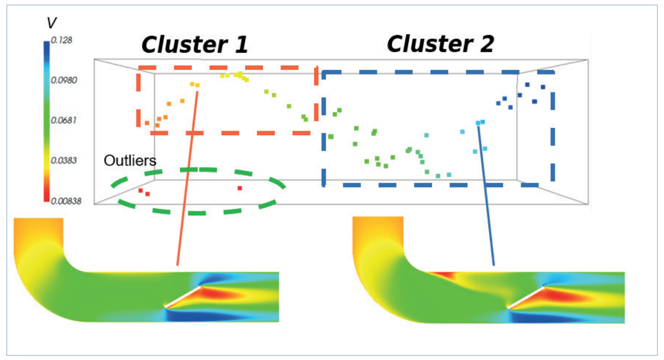
SimExplore

DesParO

Interactive, multi-objective robust design-parameter studies and optimization

Understanding robust design

A design is called robust if small changes in the initial conditions will only have little impact on the results. The robustness and quality of production processes and products suffer from variations occurring in various parameters relating to defining features such as material properties, process parameters, and variations in geometry. Analyzing and controlling the effects of these variations help to find robust and optimal settings under realistic conditions.



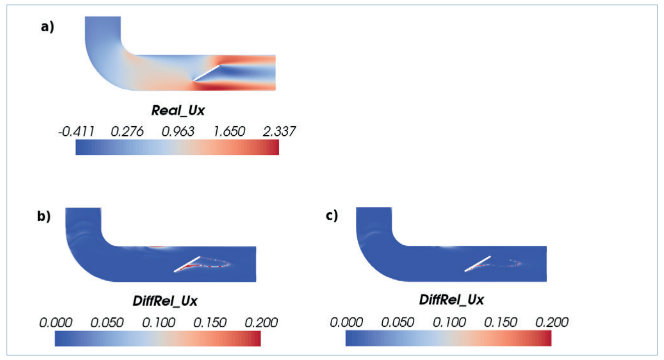
Two clusters found by the SimExplore tool for CFD simulations of the velocity field, with two input parameter variations (each point represents one simulation). Two surrogate models were built using DesParO based on this information.

User benefits

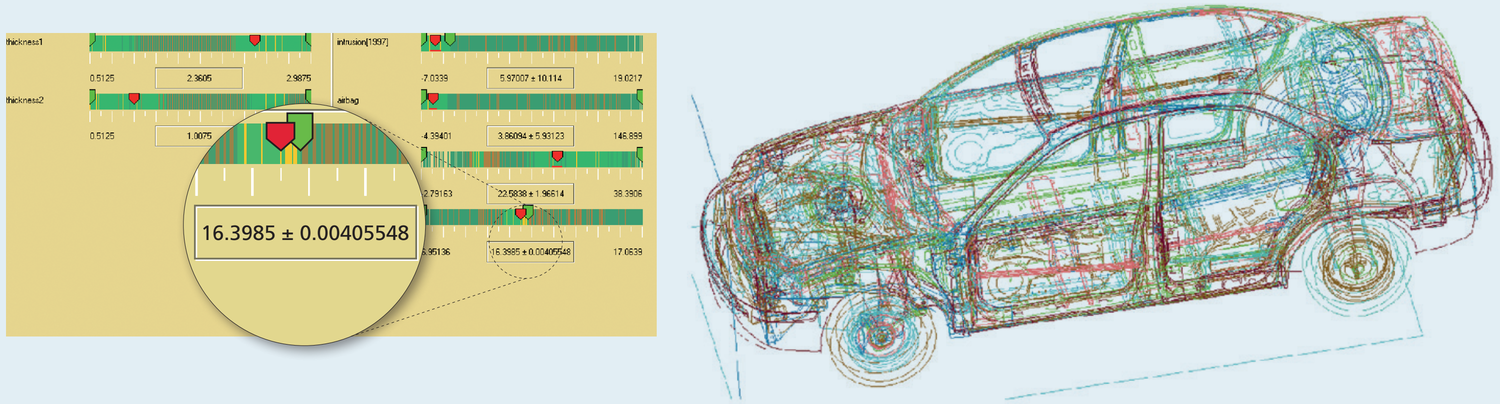
DesParO is a software toolbox enabling sensitivity analysis and robust multi-objective optimization of parameterized production processes. It provides an easy-to-use graphical user interface (GUI) for the interactive exploration of design spaces based on a nonlinear surrogate surface model approach. DesParO offers the possibility to obtain almost optimal configurations with a low number of simulation runs. For users, this is a particular time- and resource-saving benefit making the software especially suited for usage with computationally expensive simulation codes. The software is available as a stand-alone application (GUI and batch) and can be easily included as optional learning and inference module in the overall SimExplore workflow.

Features

DesParO is based on a surrogate modeling approach using radial basis functions and polynomial detrending, enabling the fully interpolation of the given data set. These surrogate models are used to predict deformations as well as any function on the mesh for a new set of input parameters within the valid parameter design space very efficiently in terms of both computing time and memory requirements.



a) Velocity distribution used for testing prediction. b) The difference between real and predicted values is based on one surrogate model generated for all the simulations. c) Difference of real and predicted values using one of the surrogate models from the many generated per cluster. An improvement in the result is observed when the surrogate model of a respective cluster is used.

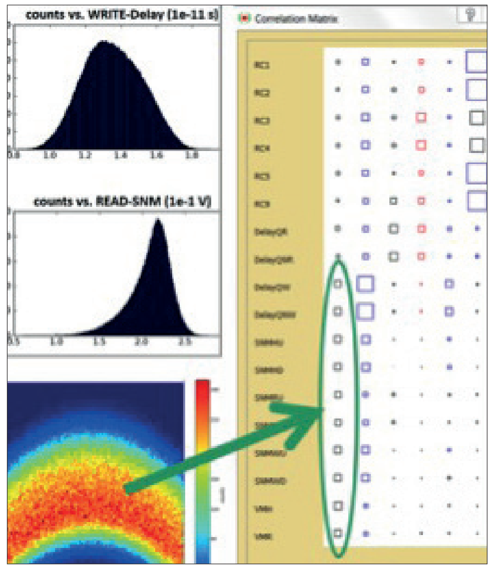


Left: DesParO GUI; right: Visualization of optimal design in DesParO

DesParO predicts not only the value of the design objective but also local tolerance limits to estimate the precision of the prediction very fast. Moreover, it provides a global nonlinear correlation analysis by recognizing a pattern of interdependencies between the optimization criteria and design variables and represents it as an easily readable color-coded diagram facilitating detailed parameter studies. In particular, the chosen surrogate model approach yields to accurate prediction results with only a low number of data points used. For users, this is a considerable advantage, especially over neural network approaches, and thus, makes DesParO optimal suited for use with CAE simulation data.

Optional integration into the SimExplore workflow

Once we have obtained a structural organization of the simulation results into clusters using SimExplore, DesParO can be used to build surrogate models for each derived cluster based on the corresponding subset of simulation results to represent the dependency between input parameters and deformations or mesh functions. This highly simplifies further investigations of the underlying correlations between measures and crash behavior. Combining the clustering approach in SimExplore and surrogate models per cluster overcomes the limits of the state-of-the-art proper orthogonal decomposition method used for predicting simulation results, especially in nonlinearities, and improves the local prediction quality. Additionally, with DesParO's correlation measures and its local tolerance and parameter sensitivity estimation, this approach can handle nonlinearities efficiently.



Correlation matrix, correlation and histogram plot

Contact

Dr. Daniela Steffes-lai
Phone +49 2241 14-4053
daniela.steffes-lai@scai.fraunhofer.de

Distributed by
scapos AG
Schloss Birlinghoven 1
53757 Sankt Augustin
Germany
info@scapos.com
www.scapos.com

(•) DesParO

Contact

Fraunhofer Institute for Algorithms and
Scientific Computing SCAI
Schloss Birlinghoven 1
53757 Sankt Augustin

Prof. Dr. Jochen Garcke
Head of Business Area Numerical
Data-Driven Prediction
Phone +49 2241 14-4015
jochen.garcke@scai.fraunhofer.de
www.scai.fraunhofer.de/en/ndv