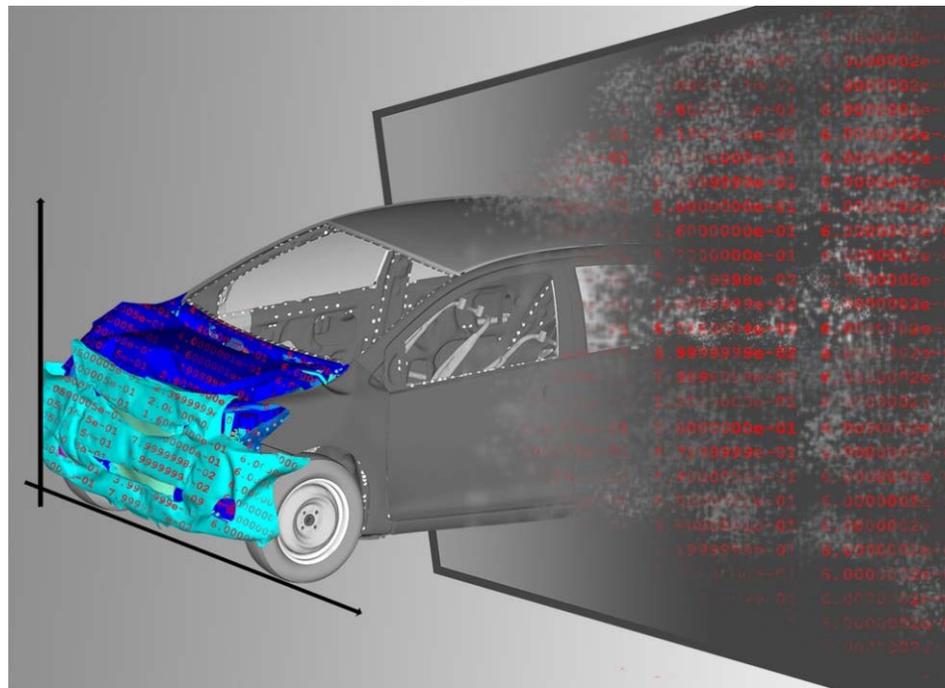

Effiziente und interaktive Auswertung großer Mengen von CAE Modellvarianten



Prof. Dr. Jochen Garcke, Universität Bonn, Fraunhofer SCAI
Rodrigo Iza Teran , Fraunhofer SCAI
Abteilung Numerische datenbasierte Vorhersage

Fraunhofer Institute for Algorithms and Scientific Computing SCAI

Director: Prof. Dr. Michael Griebel

Topics

- Development of innovative methods in the field of Computational Science, including their implementation and the provision of products for the industrial take-up
- Optimization in logistics, production and planning
- Data mining and information extraction in chemistry, biology, medicine

Data

- Staff (2014): 140 (including postgraduates and students)
- Budget (2014): € 11 mio
- Share of industrial revenues (2014): 50 percent
- Share of total revenues (2014): 75 percent

SCAI Research Areas and Products

Multiphysics

Dr. Johannes Linden, Klaus Wolf (deputy)

High Performance Computing

Dr. Johannes Linden, Dr. Thomas Soddemann (deputy)

Optimization

Dr. Ralf Heckmann

Fast Solvers

Dr. Klaus Stüben

Bioinformatics

Prof. Dr. Martin Hofmann-Apitius, Marc Zimmermann

High Performance Analytics

Dr. Tanja Clees

Virtual Material Design

Dr. Jan Hamaekers

Numerical Data-Driven Prediction

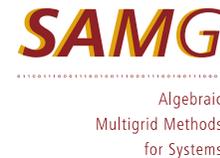
Prof. Dr. Jochen Garcke

Computational Finance

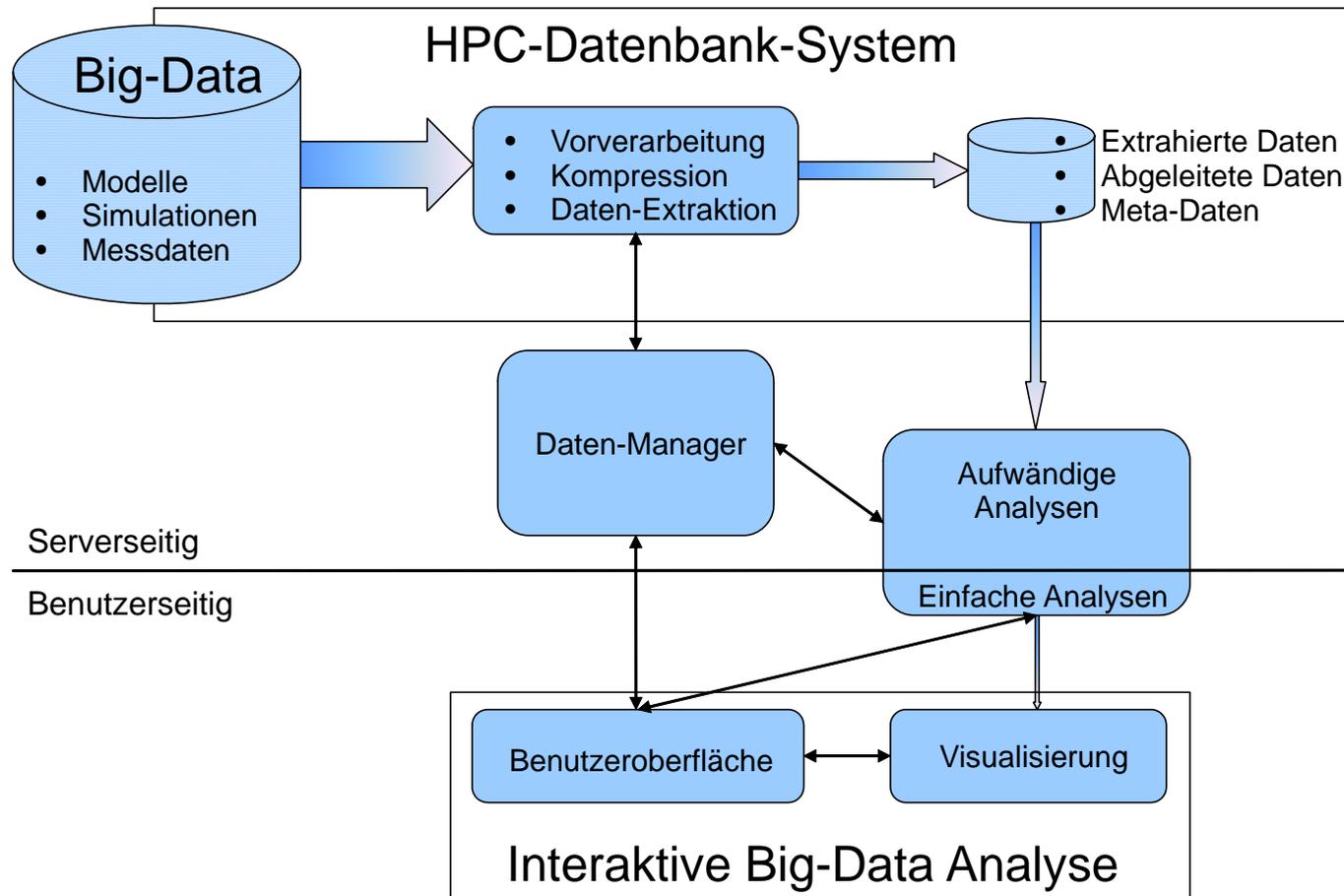
Prof. Dr. Thomas Gerstner

Meshfree Multiscale Methods

Prof. Dr. Marc Alexander Schweitzer



Analyse von Daten aus der Simulation



- BMBF Big Data-Projekt VAVID (Vergleichende Analyse von ingenieurrelevanten Mess- und Simulationsdaten)
- Partner: SCAI, BoschRexroth, GE, GNS, SCALE, SIDACT, TU Dresden, assoziiert: AUDI, VW

Scharen von numerischen Simulationsdaten

- deutlicher Zuwachs in der Zahl der numerischen Simulation im virtuellen Produktentwicklungsprozess (z.B. Automobilindustrie, WEA, Ölreservoir)
- Postprocessing-Tools zur Untersuchung **eines (oder weniger)** Simulation
- für Hunderte bis Tausende numerische Simulationen von Varianten ?
- Datenvolumen: (Zahl der Simulation x Gitterpunkte x Zeitschritte)
 - ein Bauteil eines Zeitschritts liegt in $R^{50.000}$
 - ein Zeitschritt einer Simulation liegt in $R^{1.000.000}$
 - ein Simulationsergebnis liegt in $R^{100.000.000}$
- Notwendigkeit für effiziente Speicherung / Transfer / Zugriff
- Ziel von Fraunhofer SCAI: Bereitstellung von Datenanalysemethoden für **vergleichende, interaktive Analyse** von vielen Simulationen

Mathematische Datenanalyse

- Datenbasis wird oft in SDMs organisiert
 - Lastfälle, Modellvarianten, Bauteile, Materialparameter
 - Kennzahlen : Stirnwandintrusion, HIC-Index, ...
- Analysemethoden für wenige Eingangs- und Ausgangsdaten
- Idee: Nutzung von "rohen" Simulationsdaten zur vergleichenden Analyse
- Herausforderungen bei der Datenexploration von Simulationsergebnissen
 - Geometrieveränderungen
 - große Menge an Simulationsdaten im Zugriff / Transport
 - interaktive Navigation für viele Varianten
 - Trenderkennung in den numerischen Simulationsergebnissen
 - Korrelation zwischen datengetriebenen Trends zu Parametern und Varianten ?
- Ziel: einfacher und schneller Entwicklungsprozess
- Ansätze aus maschinellem Lernen zur Analyse von Simulationsdaten

Mathematische Datenanalyse: Dimensionsreduktion

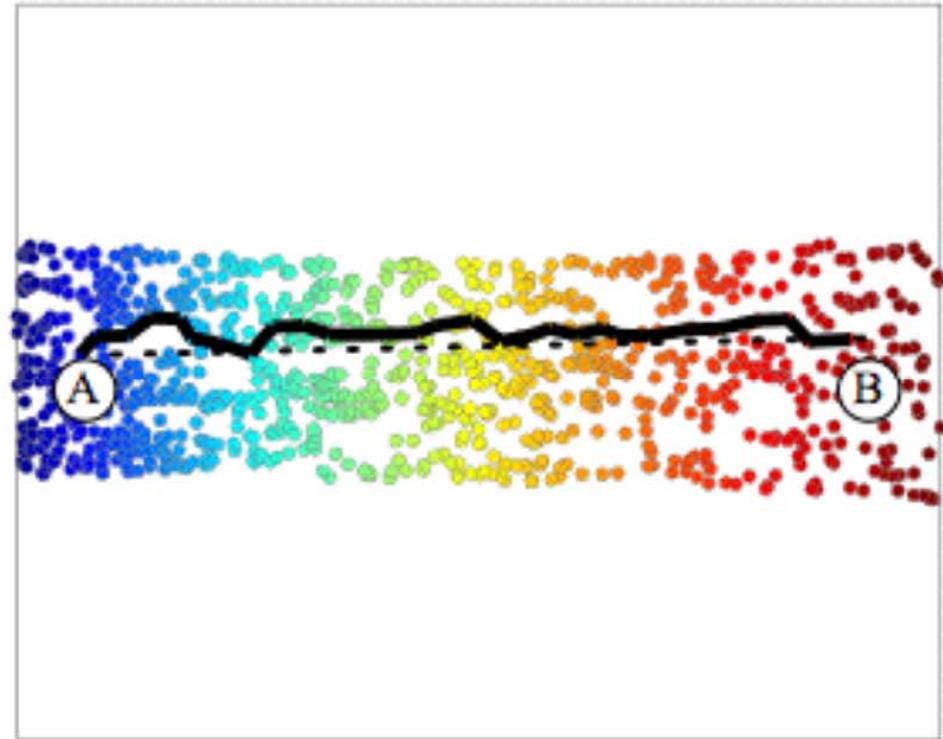
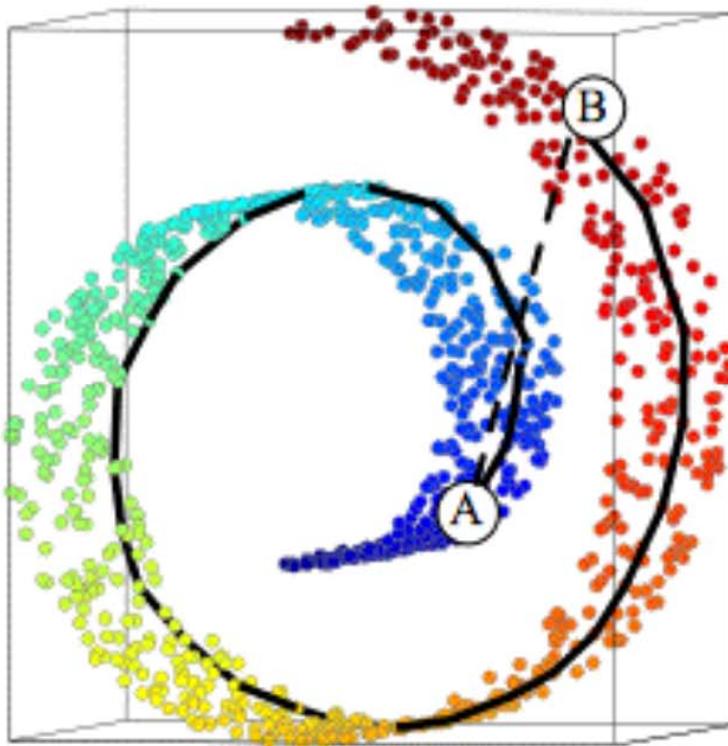
- Simulationsdaten sind hochdimensional: #Knoten pro Bauteil (oder mehr)
- einige Hundert Datenpunkte(=Simulationen/Varianten)
- reduziere Komplexität / Dimensionalität der Daten
- Hauptkomponentenanalyse (PCA) ist Basisansatz
 - einfache, oft effiziente, lineare Methode
 - aber oft zu viele Dimensionen übrig
- aus maschinellen Lernen neuartige Methoden zur nichtlinearen Dimensionsreduktion
- Kernbaustein bei nichtlinear Dimensionsreduktion
 - Abstandsmaß der Daten hängt von der Datenlage ab
- datengetriebenen, nichtlinearer Abstands begriff (anders als PCA)

Skizze des Mathematischen Hintergrund

- betrachte Finite Element Modell auf 1D-Gitter mit n Knoten $[r_1, r_2, \dots, r_n]$
- es hänge von einem Materialparameter α ab, berechnet sind M Varianten
- Simulationen S_{α_i} dargestellt als $x_i = S_{\alpha_i}(r_1, r_2, \dots, r_n) \in R^n, i = 1, \dots, M$
- Simulationen x_i liegen auf einer **intrinsisch eindimensionalen** Kurve
- $u(\alpha): R \rightarrow R^n, x_i = u(\alpha_i)$ überführt Punkte in hochdimensionalen Raum

- **Ansatz:** rekonstruiere $u(\alpha)$ approximativ auf Basis der Daten
- mit Hilfe der Daten konstruiere diskreten Operator P
- man kann zeigen: für $M \rightarrow \infty$ konvergiert P gegen 1D-Laplace-Operator
- Eigenfunktion des Laplace-Operators parametrisiert α Abhängigkeit

Nichtlineare Dimensionsreduktion



- ersetze euklidischen Abstand $\sum \sqrt{(x_i - y_i)^2}$ durch datenangepassten
- z.B. Abstand entlang eines Datengraphen, kürzester Weg entlang Daten
- Problemstellung der nichtlinearen Dimensionsreduktion
- Punkte nah in hoher Dimension bleiben nach Reduktion nah beieinander

Diffusion Maps Verfahren

▪ Eingangsdaten

- M Datensätze aus Simulationen $x_i \in R^n, i = 1, \dots, M$
- wobei n die Anzahl der Knoten/Elemente ist

▪ Prozess

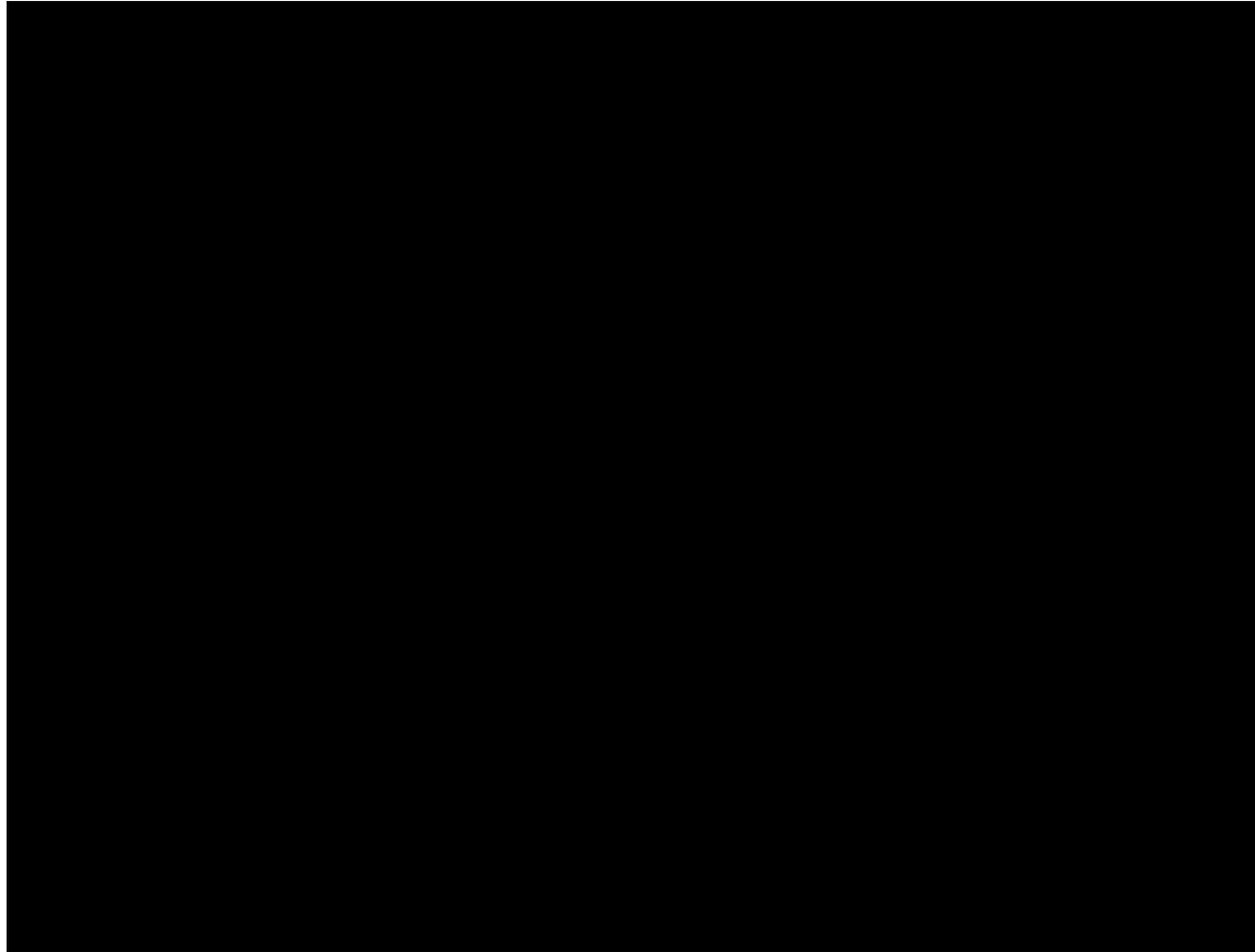
- Berechnung der Matrixeinträge $w(i, j) = \frac{\exp(-|x_i - x_j|)}{\epsilon}$
- Normalisierung
- Lösung des Eigenwertproblems
- Eigenvektoren zu den größten Eigenwerte auswählen

▪ Ausgangsdaten

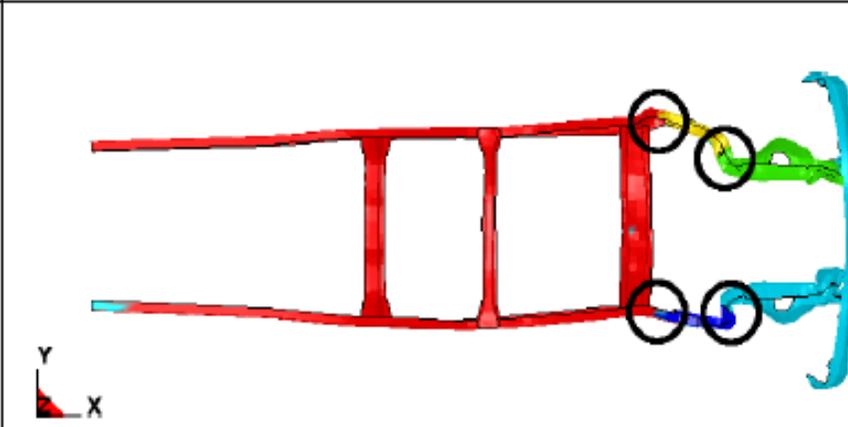
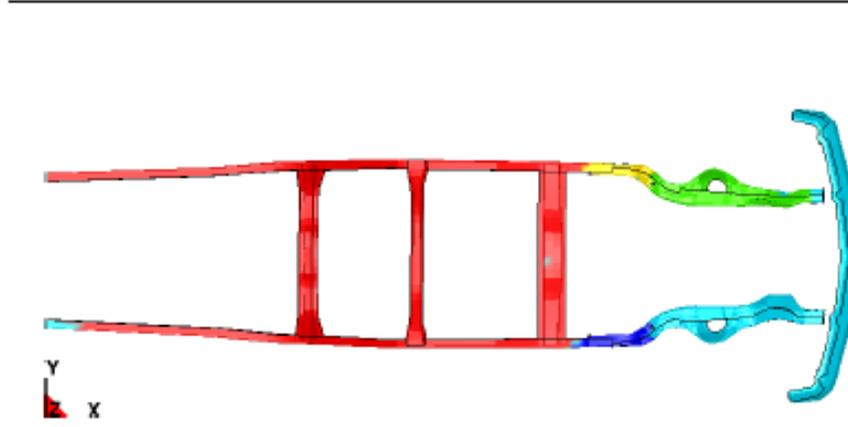
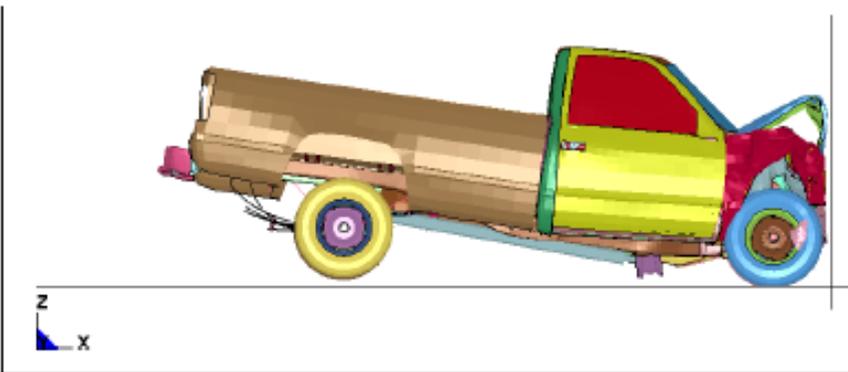
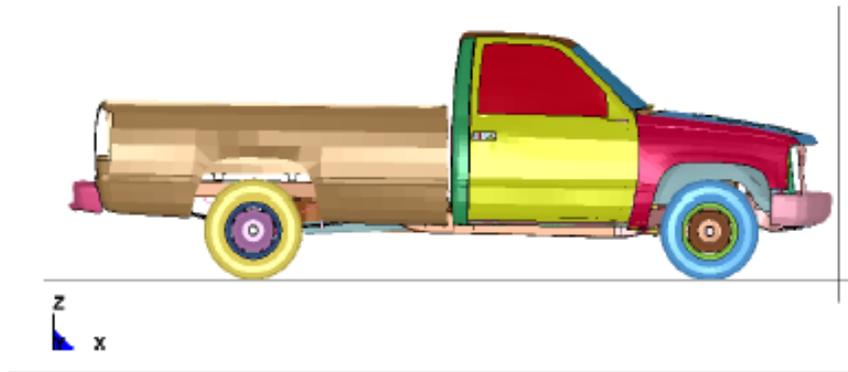
- Koeffizienten bezüglich der Eigenvektoren ergeben parametrische Koordinaten der niederdimensionalen Einbettung

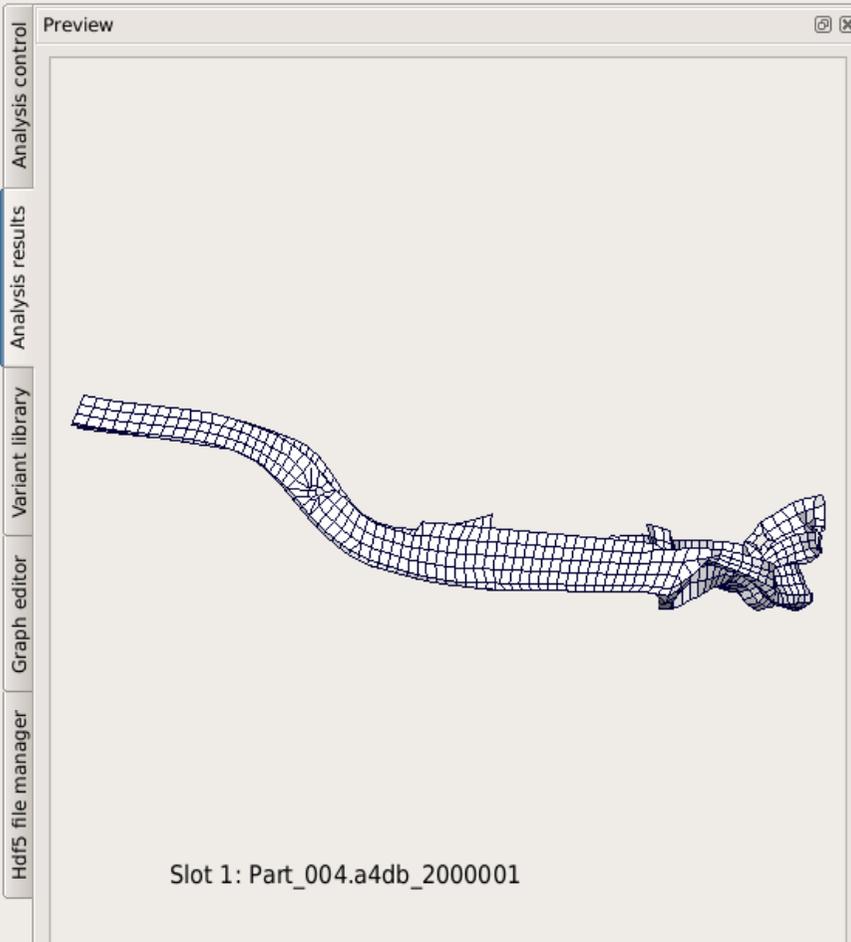
Semantische Segmentierung eines Modells

- zur Datenanalyse über Bauteilvarianten automatisierte Zuordnung
- finde zu Referenzmodell X passende Bauteile in anderen Modellvarianten



Beispiel: Chevrolet C2500 Pick-Up Truck





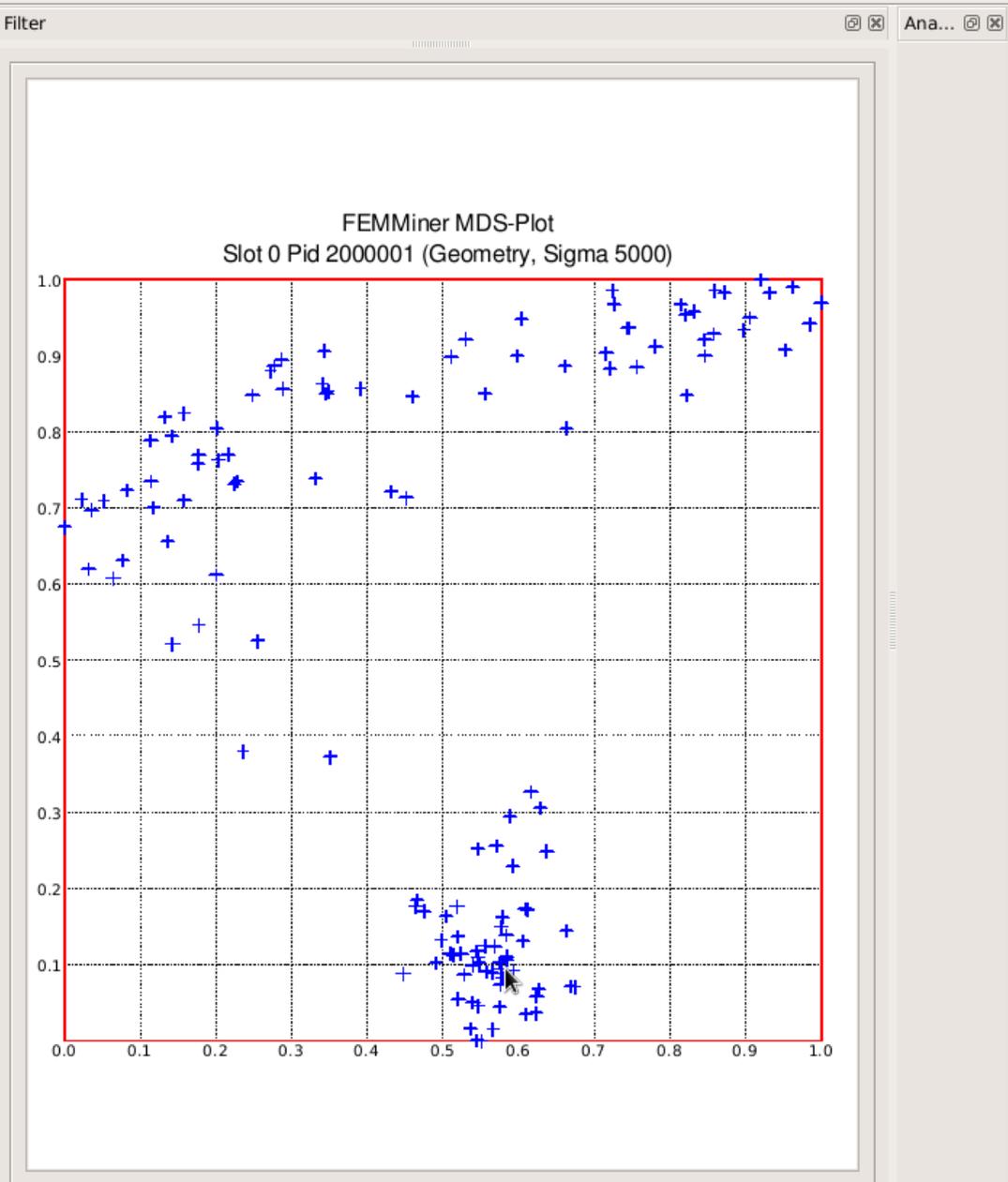
Component parts

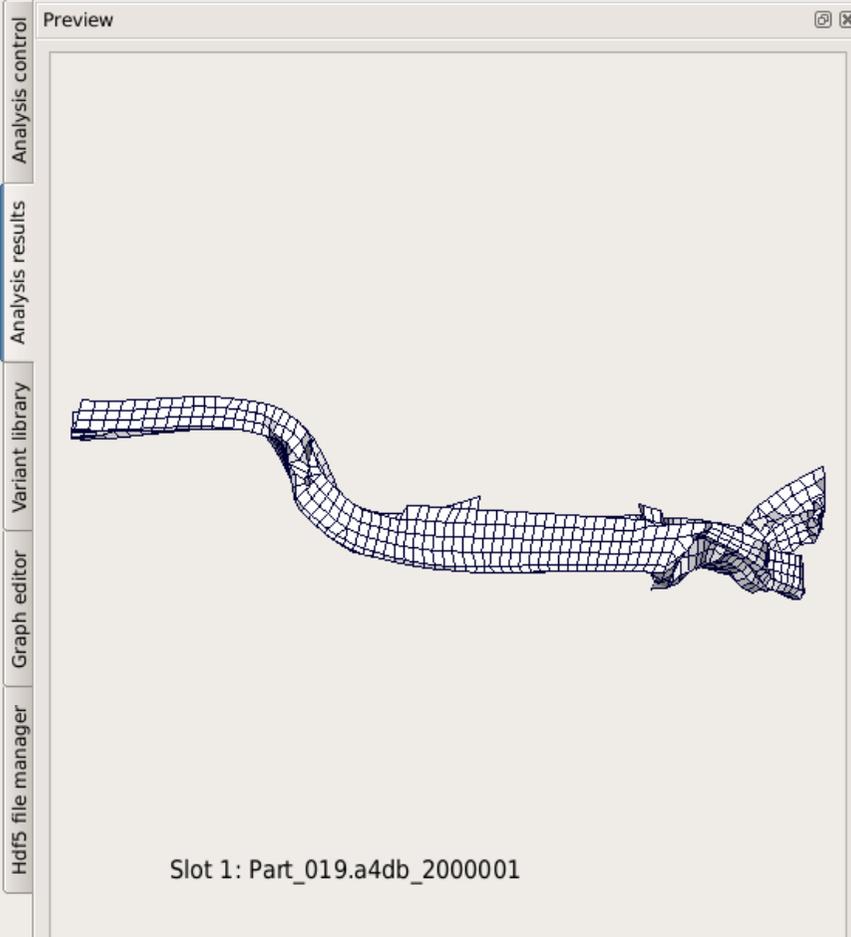
Analysis selection

Look in: /home/teran/wor

- .svn
- branches
- tags

Files of type: sqlite files (*.db)





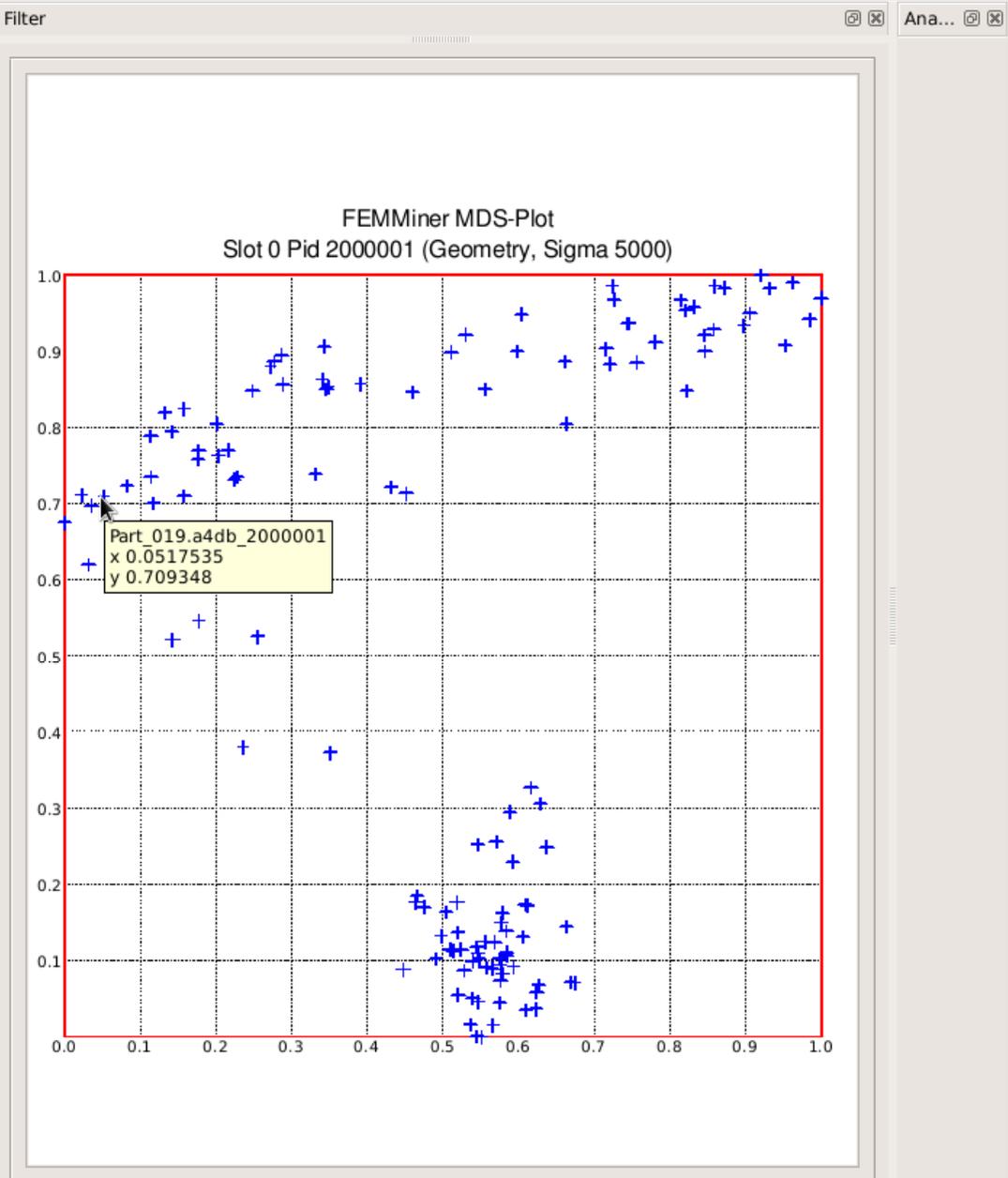
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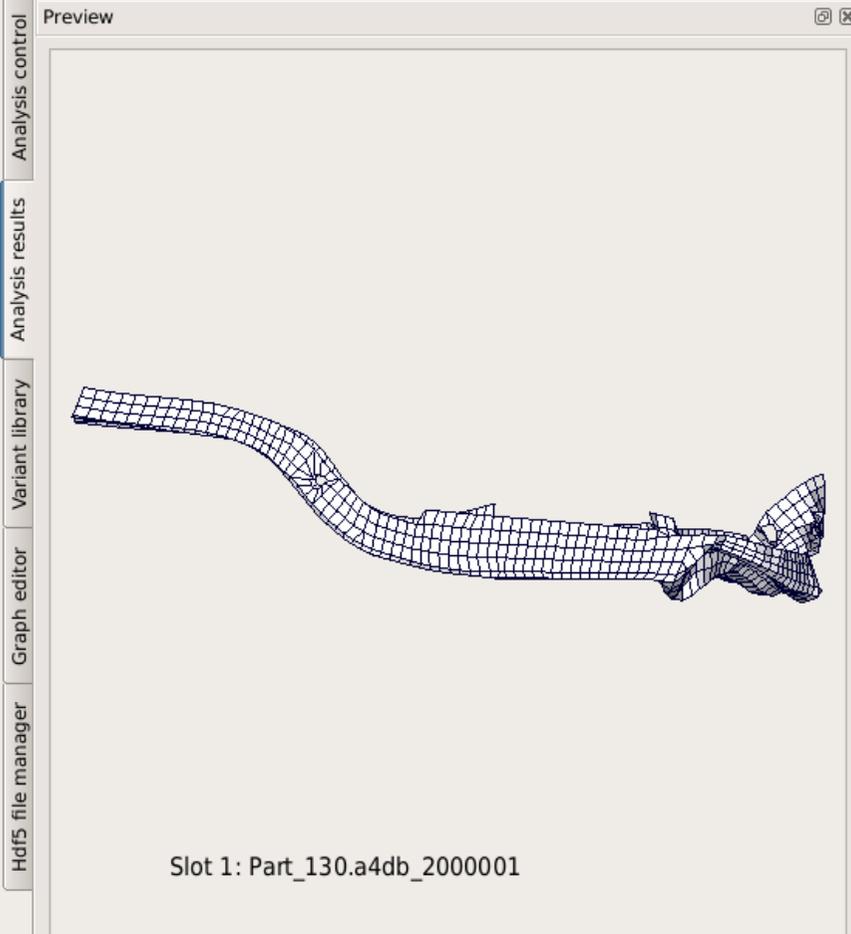
Analysis selection

Look in: /home/teran/wor

- .svn
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Files of type: sqlite files (*.db)





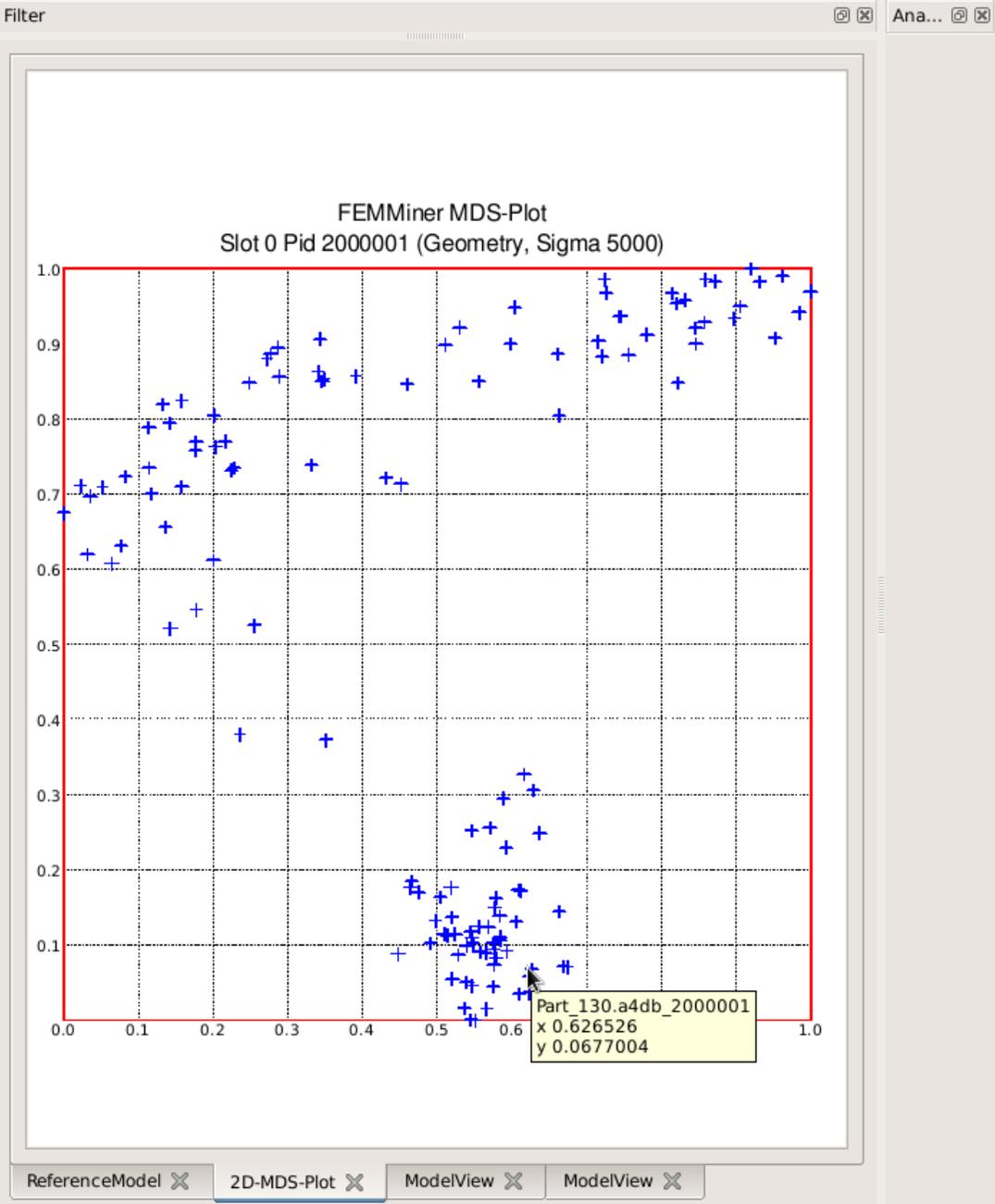
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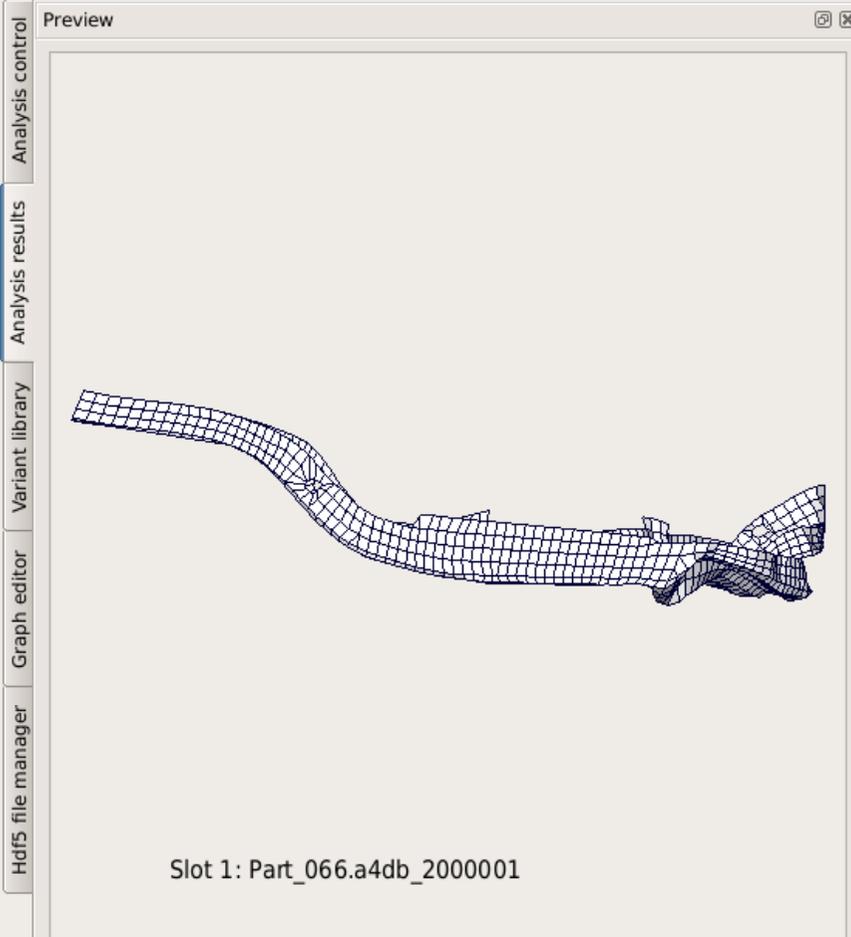
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- branches
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Files of type: sqlite files (*.db)





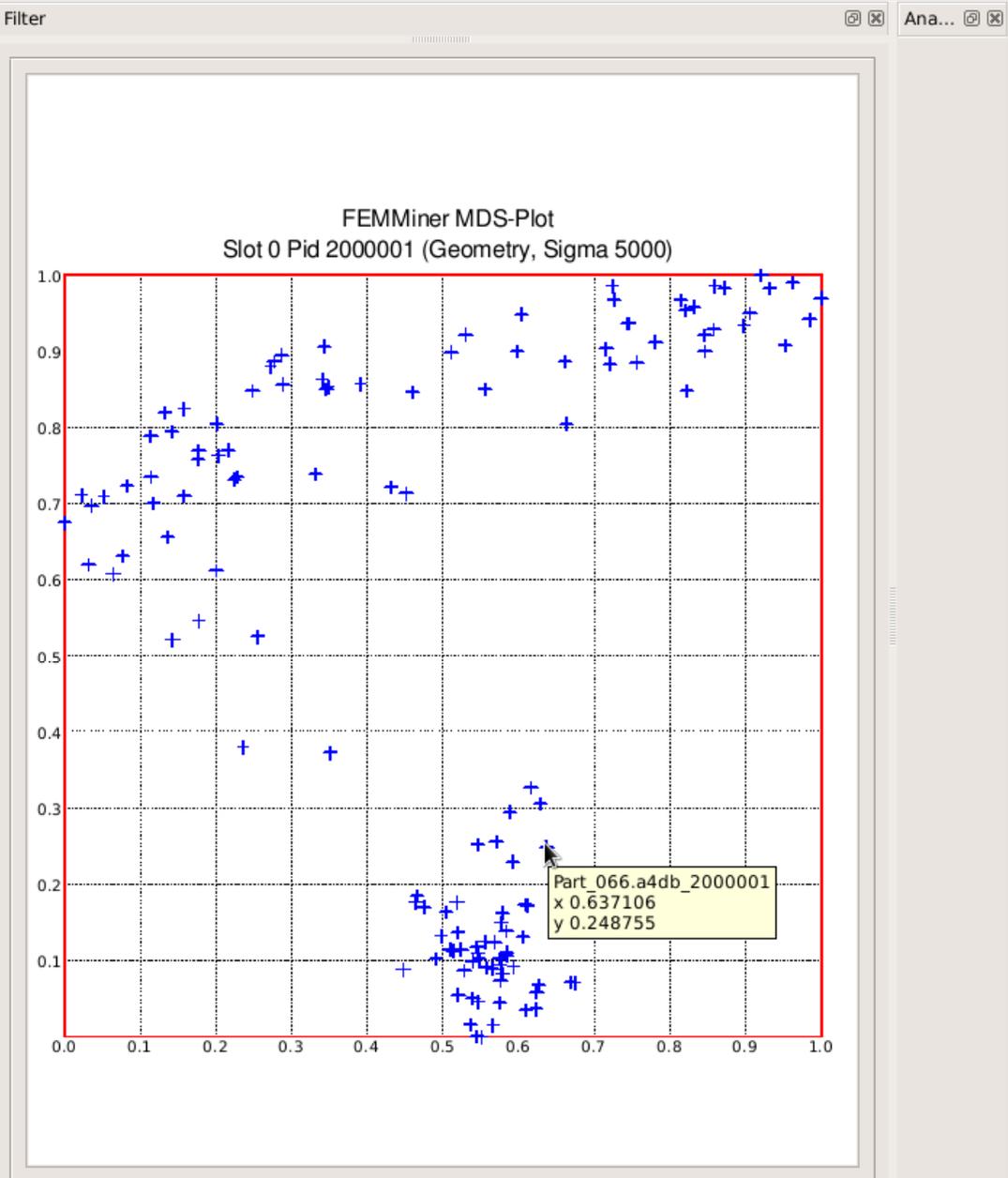
Component parts

Analysis selection

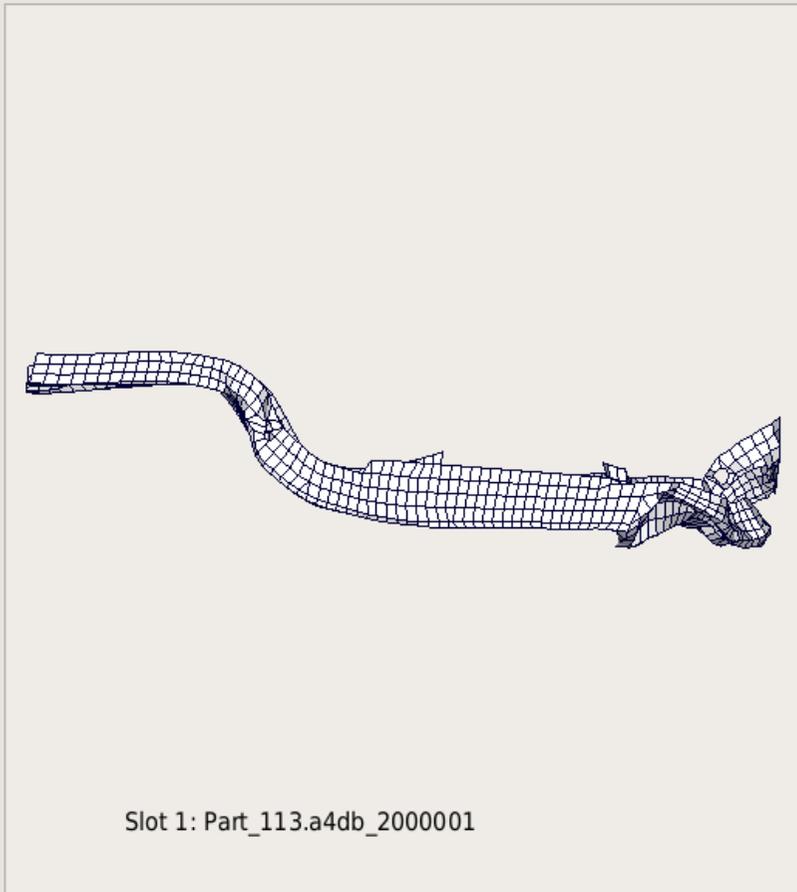
Look in: /home/teran/wor

- .svn
- branches
- tags

Files of type: sqlite files (*.db)



Preview



Component parts

Analysis selection

Look in: /home/teran/wor

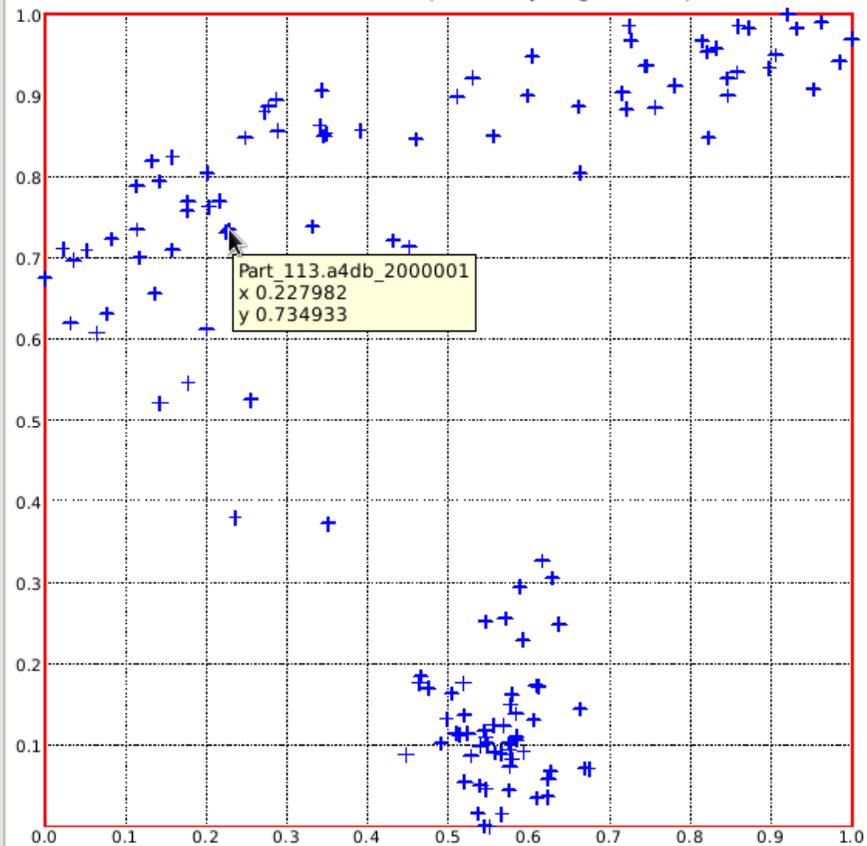
- .svn
- branches
- tags

Files of type: sqlite files (*.db)

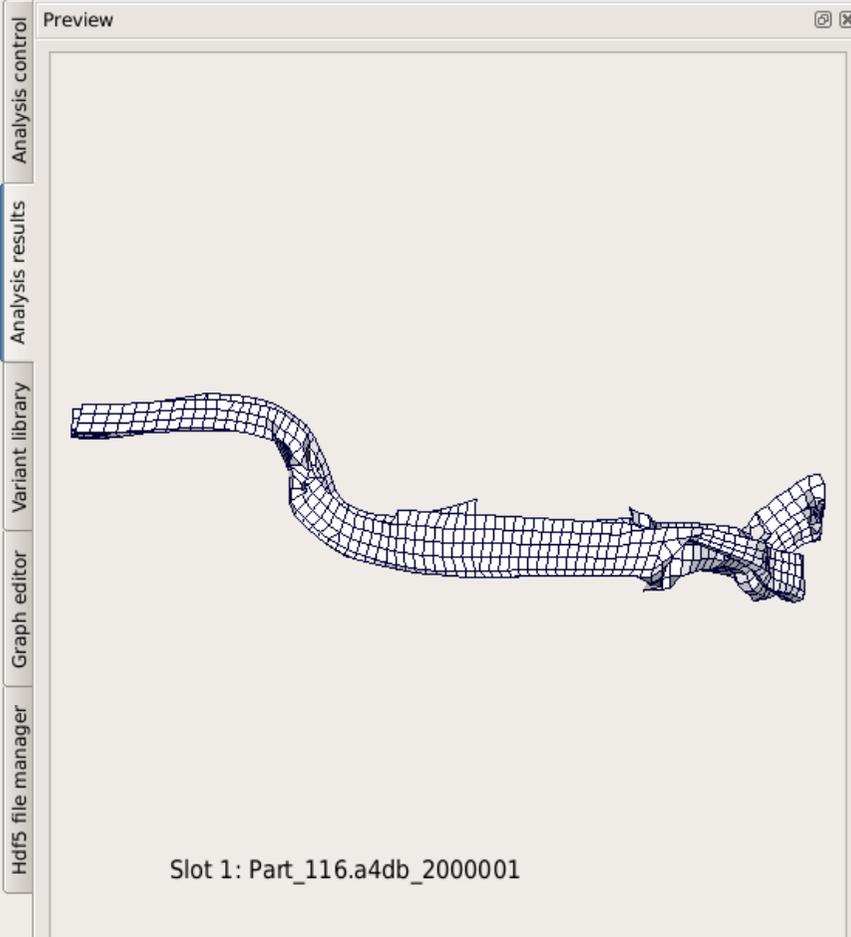
Filter

Ana...

FEMMiner MDS-Plot
Slot 0 Pid 2000001 (Geometry, Sigma 5000)



ReferenceModel X 2D-MDS-Plot X ModelView X ModelView X



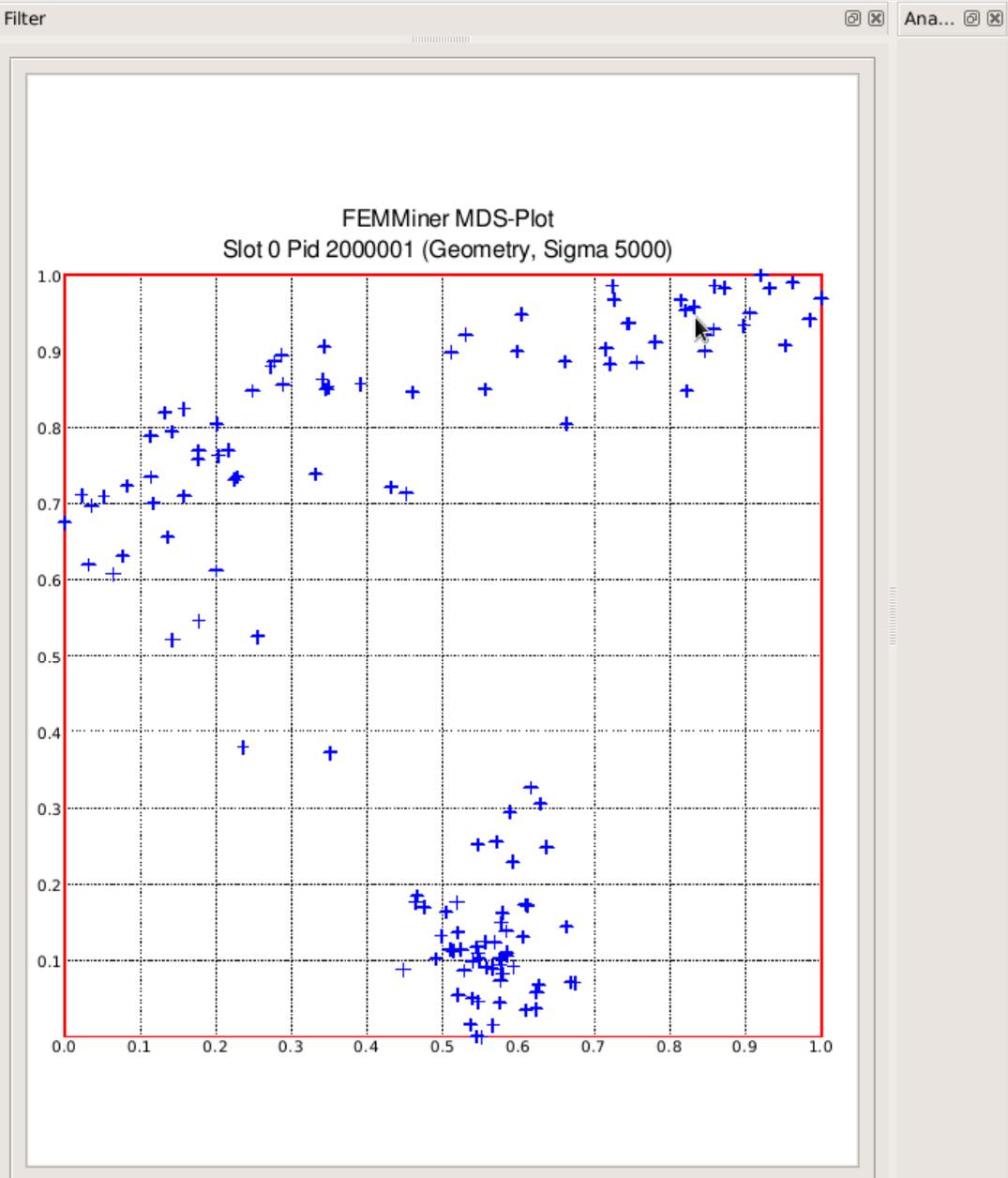
Component parts

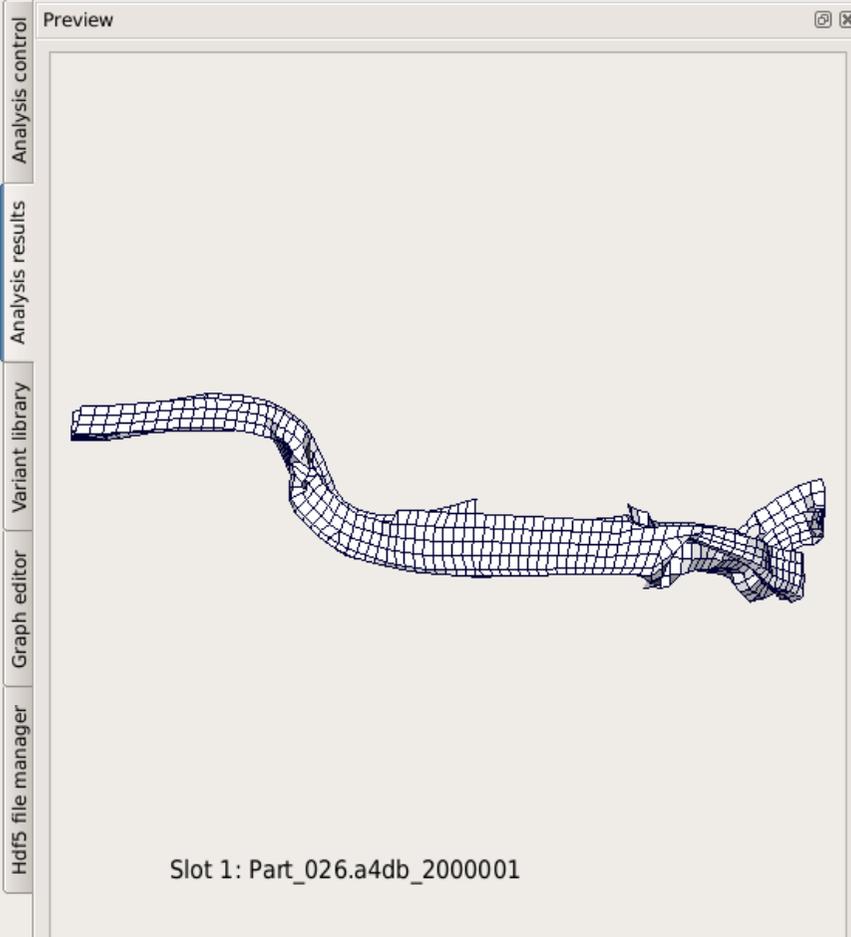
Analysis selection

Look in: /home/teran/wor

- .svn
- branches
- tags

Files of type: sqlite files (*.db)





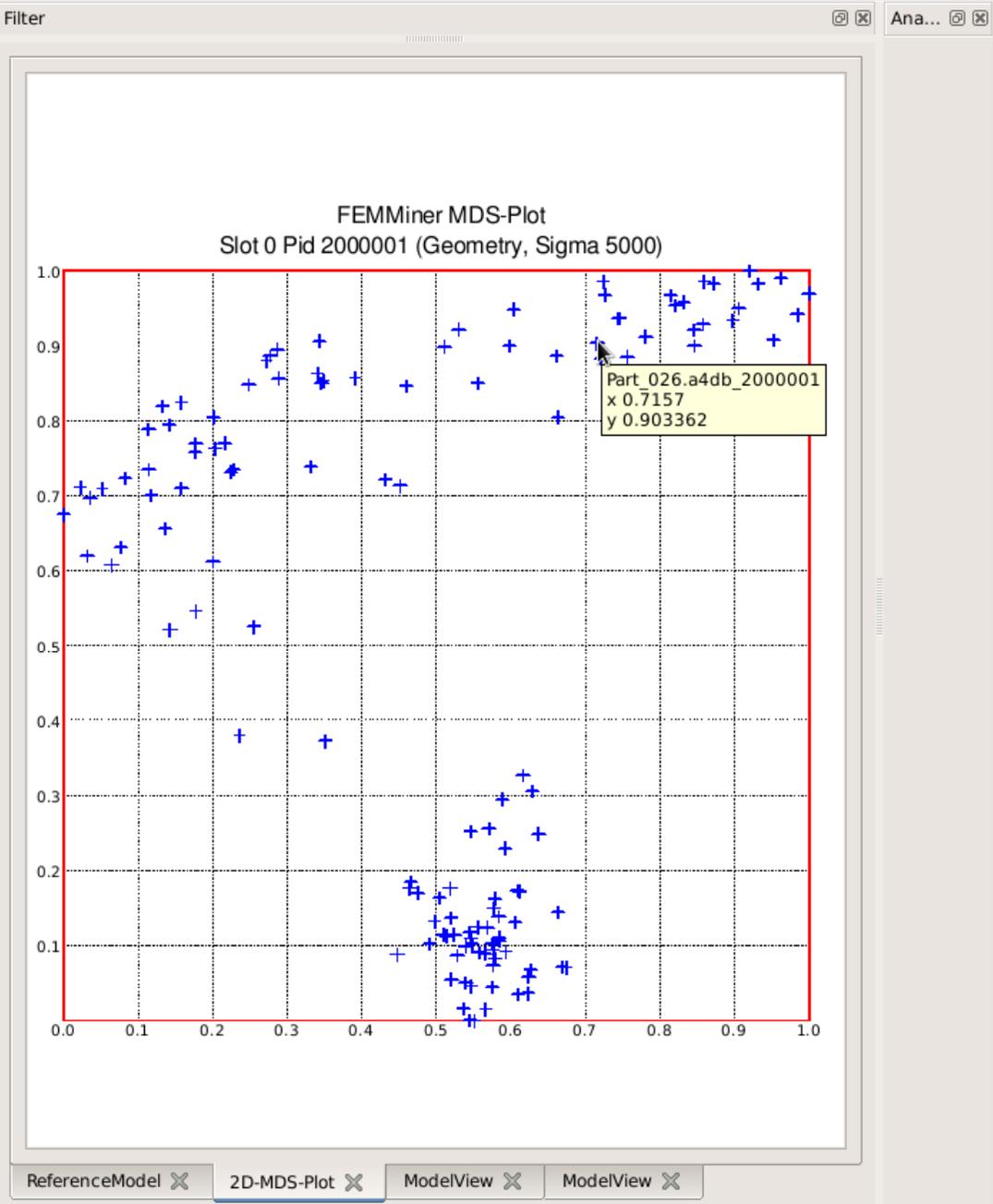
Component parts

Analysis selection

Look in: /home/teran/wor

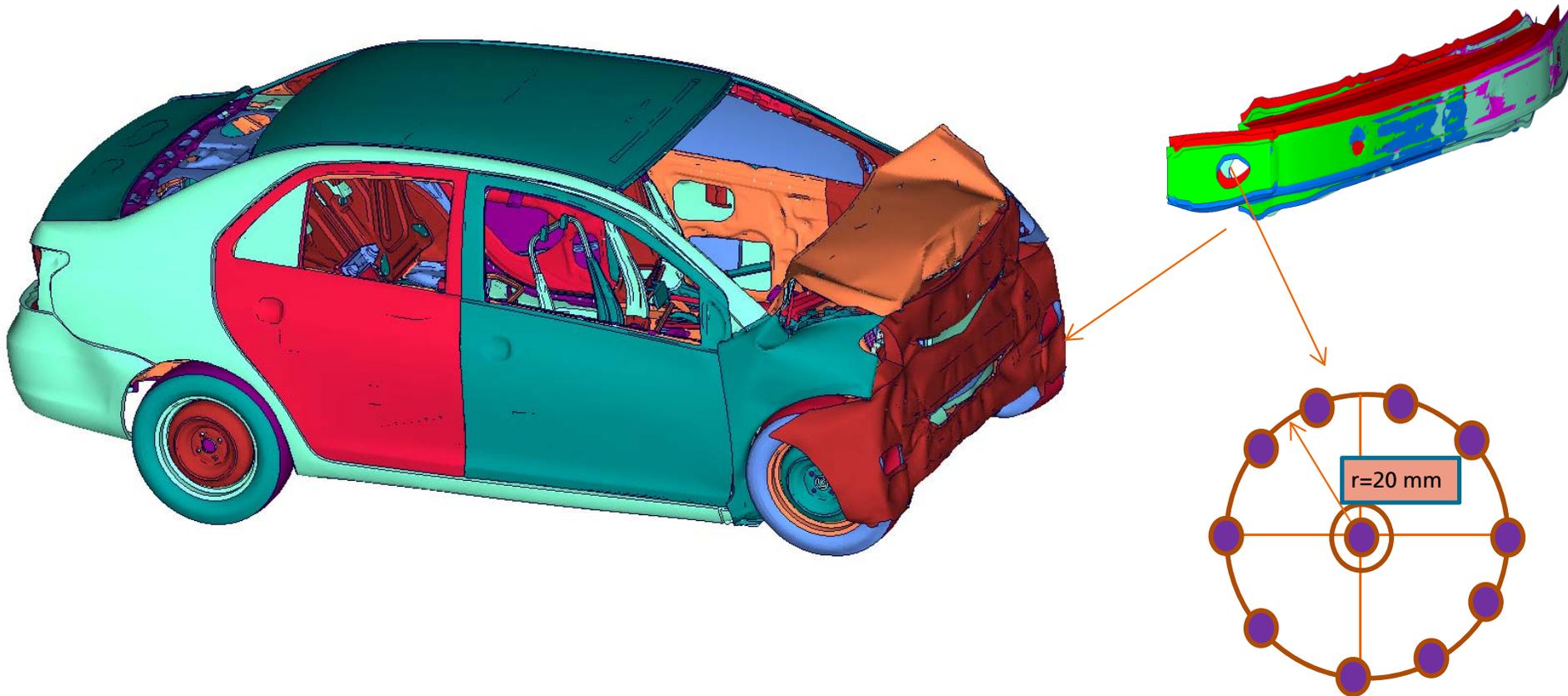
- .svn
- branches
- tags

Files of type: sqlite files (*.db)

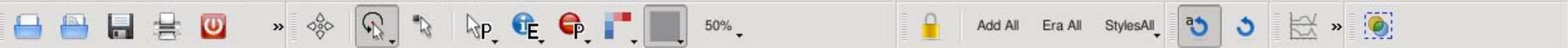


Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßfänger

Positionsvarianten

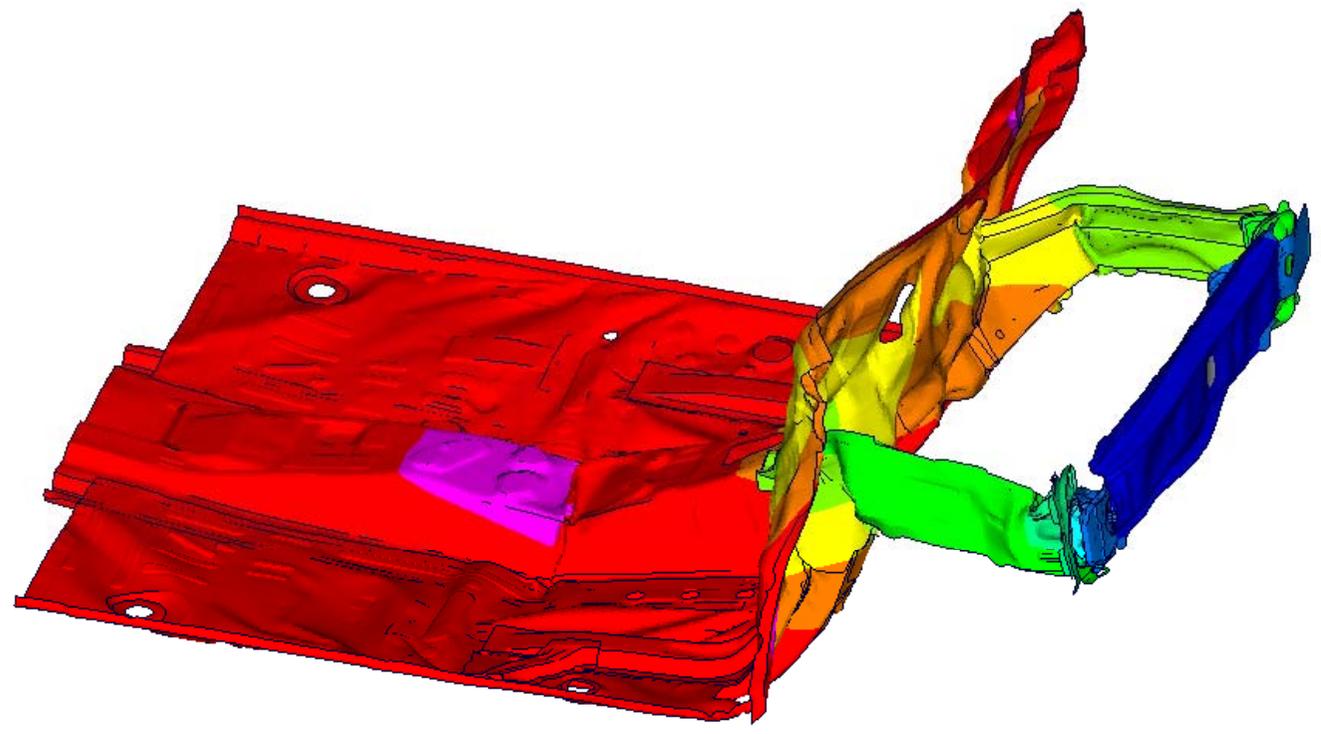
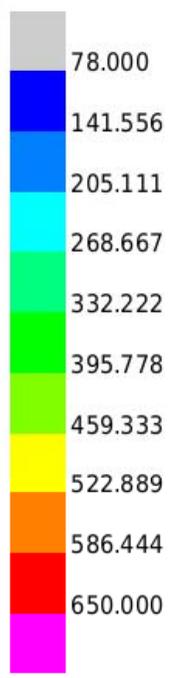


- Variationen erstellt im BMBF-Projekt FEMMiner zusammen mit GNS mbH

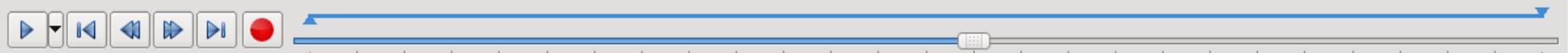


0 : TOYOTA YARIS MODEL (NCAC V01) Displacement Total Displacement

Total-Displacement



Slot 0: TOYOTA YARIS MODEL (NCAC V01) - State 14 at time 0.065000



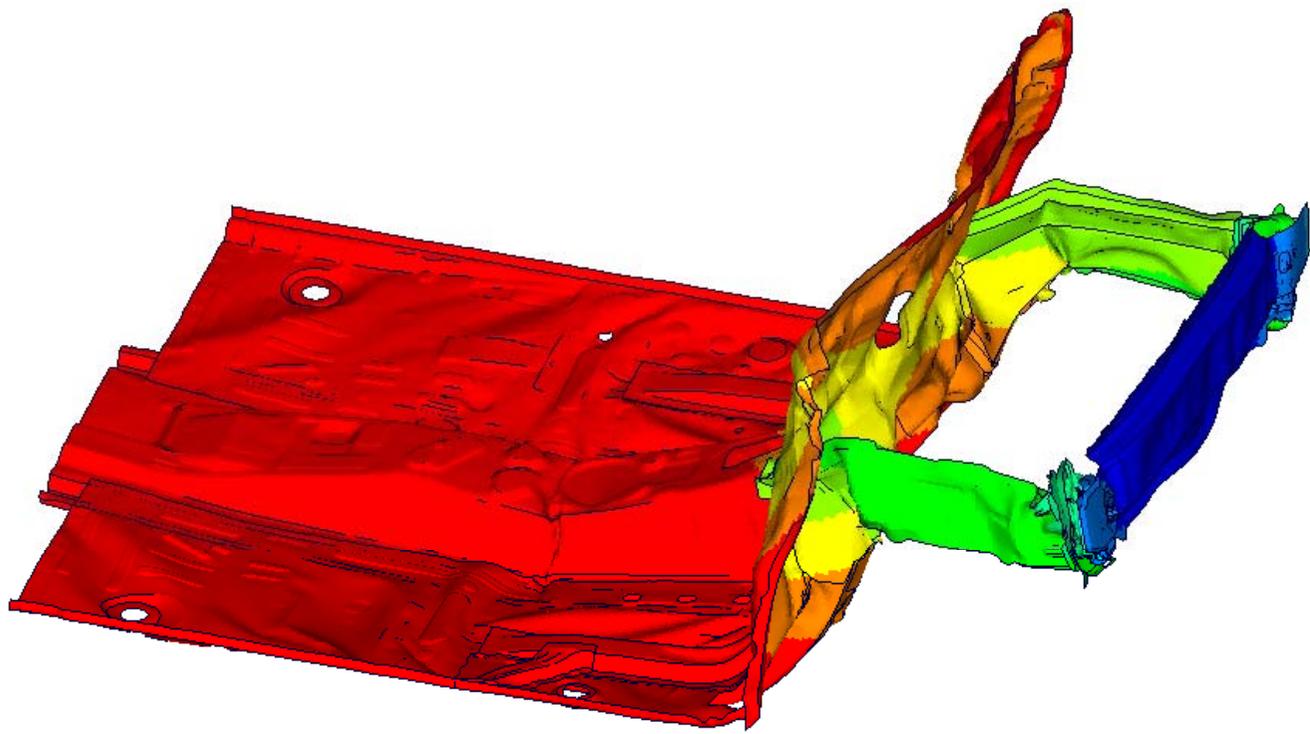
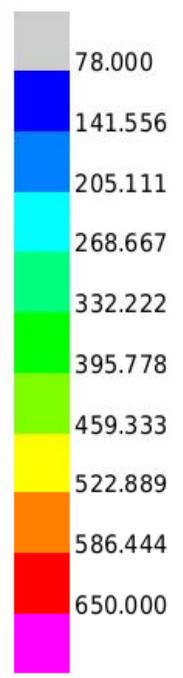
Synchronize visible/active status

Id	Name	C	A	V
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1	TOYOTA YARIS MODEL (NCAC V01) (2)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2	TOYOTA YARIS MODEL (NCAC V01) (4)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
3	TOYOTA YARIS MODEL (NCAC V01) (6)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4	TOYOTA YARIS MODEL (NCAC V01) (8)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
		All	<input type="checkbox"/>	<input checked="" type="checkbox"/>

```
ackl slo 3  
era slo 4  
ackl slo 2  
era slo 3  
ackl slo 1  
era slo 2  
ackl slo 0  
era slo 1
```

Command:

Total-Displacement



Slot 1: TOYOTA YARIS MODEL (NCAC V01) - State 14 at time 0.065000

Timeline controls including play, stop, and navigation buttons.

Synchronize visible/active status

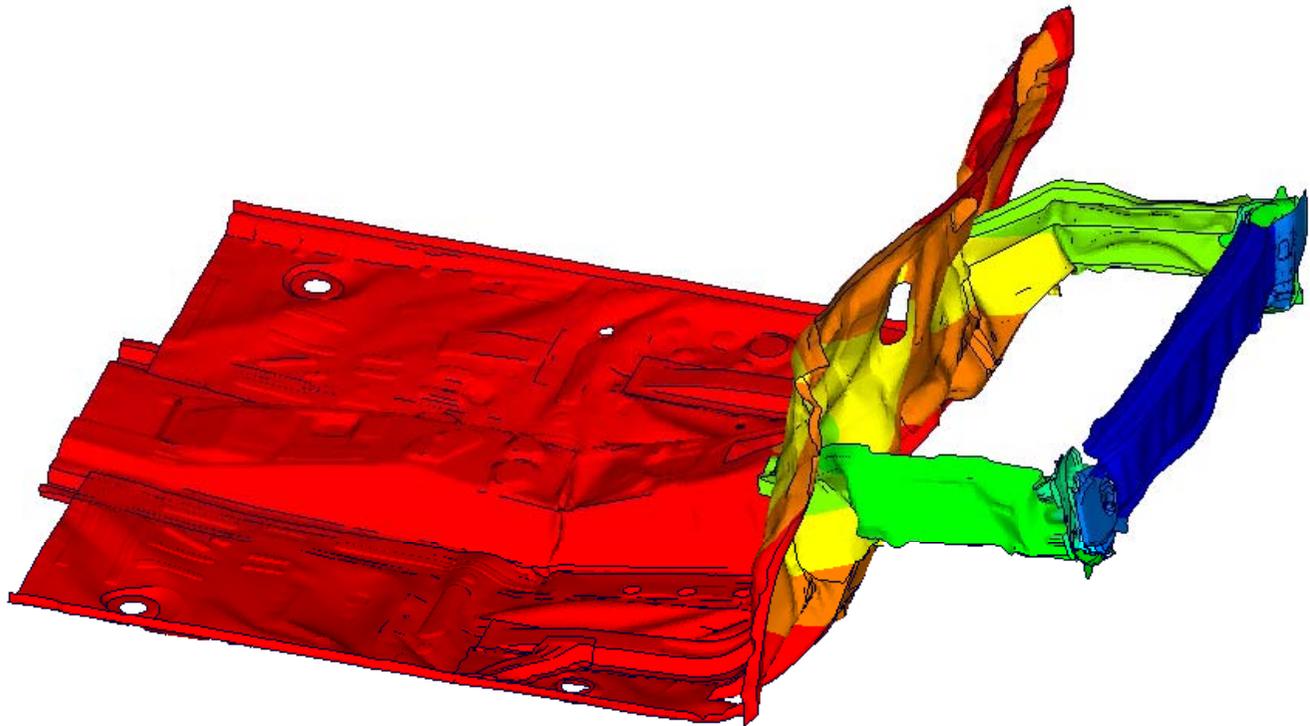
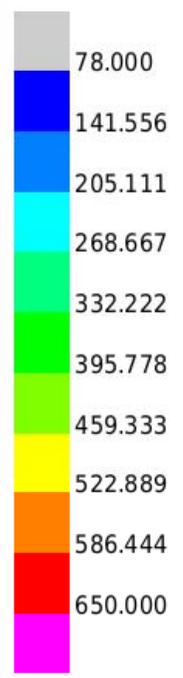
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1	TOYOTA YARIS MODEL (NCAC V01) (2)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
2	TOYOTA YARIS MODEL (NCAC V01) (4)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	TOYOTA YARIS MODEL (NCAC V01) (6)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	TOYOTA YARIS MODEL (NCAC V01) (8)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		All	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Slot list and command input area.

- ackl slo 2
- era slo 3
- ackl slo 1
- era slo 2
- ackl slo 0
- era slo 1
- ackl slo 1
- era slo 0

Command: _____

Total-Displacement



Slot 2: TOYOTA YARIS MODEL (NCAC V01) - State 14 at time 0.065000

Timeline and Command Panel

Timeline: [Play] [Stop] [Previous] [Next] [Home] [End]

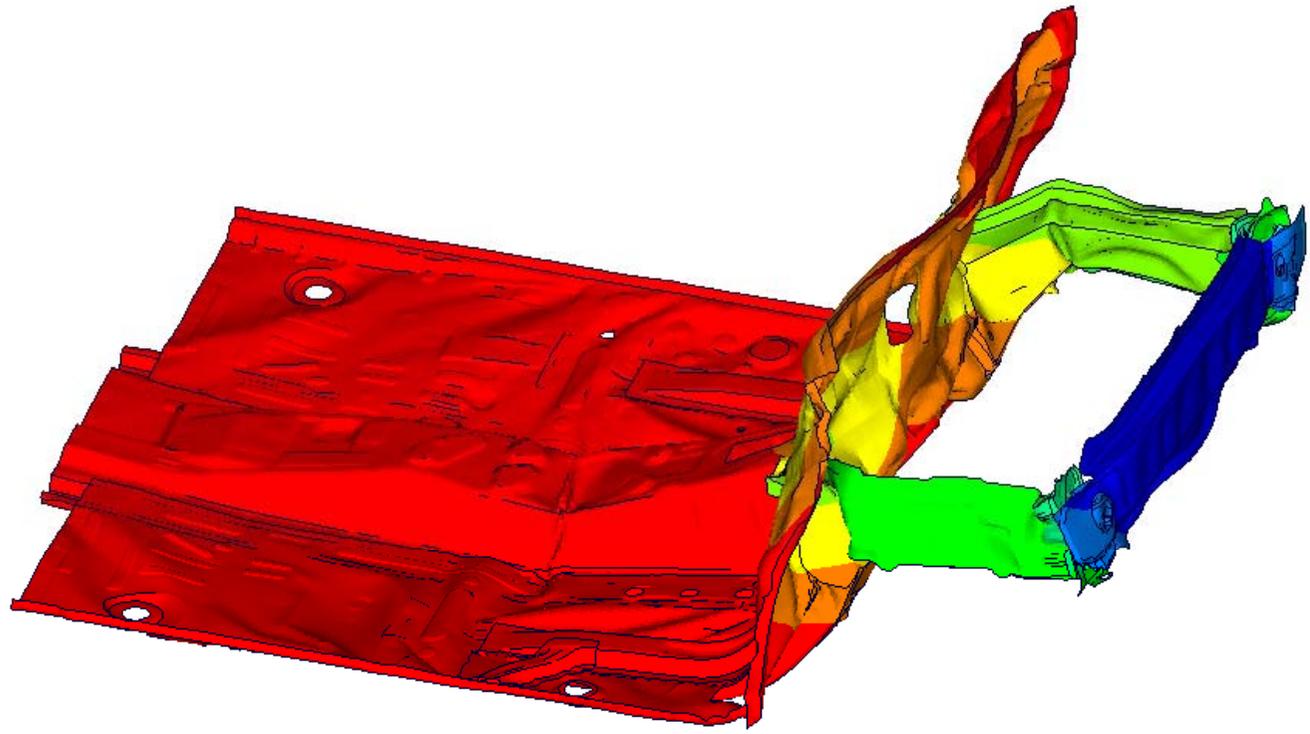
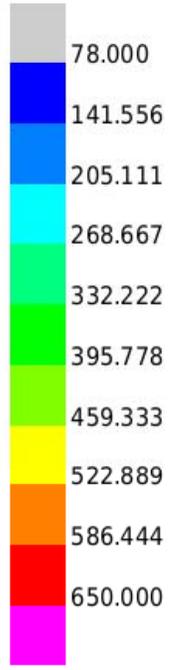
Synchronize visible/active status

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1	TOYOTA YARIS MODEL (NCAC V01) (2)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	TOYOTA YARIS MODEL (NCAC V01) (4)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
3	TOYOTA YARIS MODEL (NCAC V01) (6)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	TOYOTA YARIS MODEL (NCAC V01) (8)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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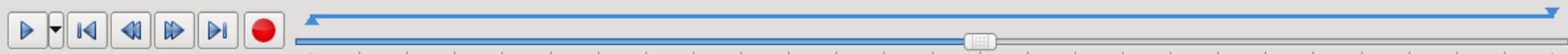
```
ackl slo 1
era slo 2
ackl slo 0
era slo 1
ackl slo 1
era slo 0
ackl slo 2
era slo 1
```

Command: _____

Total-Displacement



Slot 3: TOYOTA YARIS MODEL (NCAC V01) - State 14 at time 0.065000



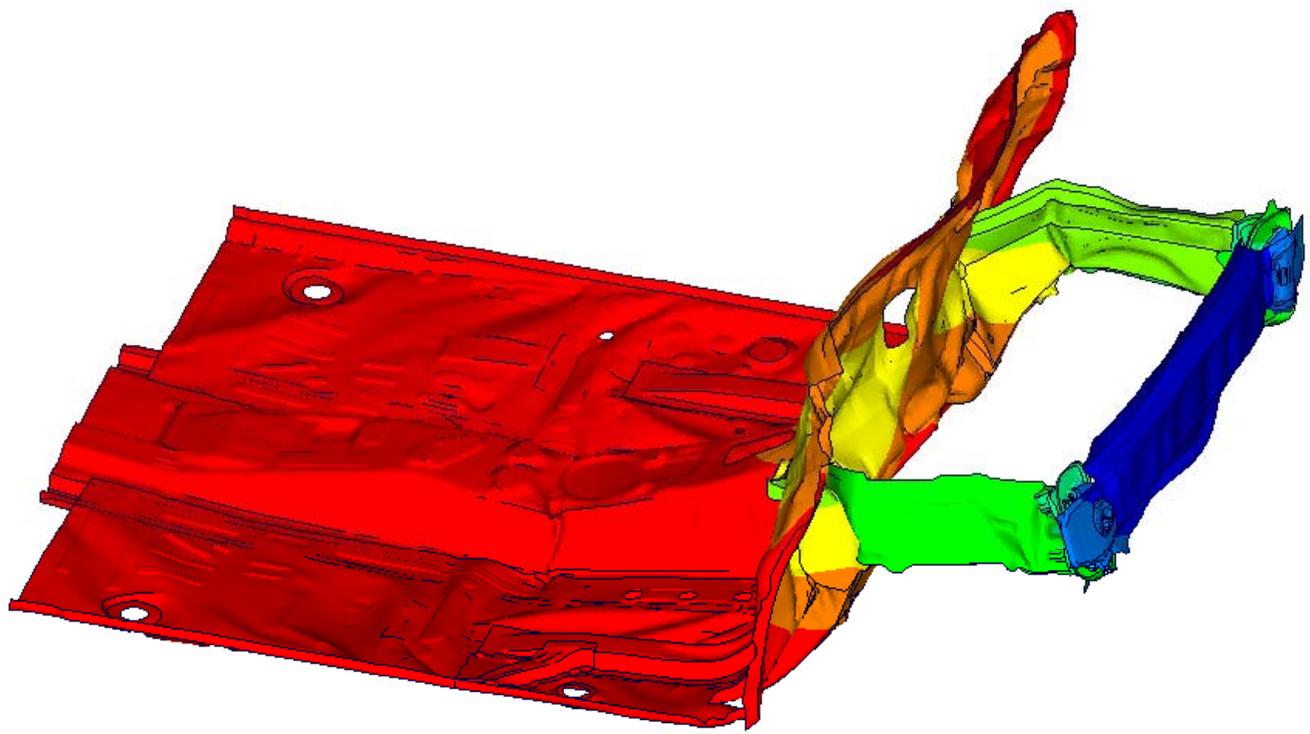
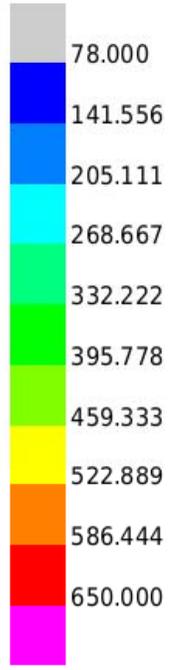
Synchronize visible/active status

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2	TOYOTA YARIS MODEL (NCAC V01) (4)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	TOYOTA YARIS MODEL (NCAC V01) (6)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
4	TOYOTA YARIS MODEL (NCAC V01) (8)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		All	<input type="checkbox"/>	<input checked="" type="checkbox"/>

```
ackl slo 0  
era slo 1  
ackl slo 1  
era slo 0  
ackl slo 2  
era slo 1  
ackl slo 3  
era slo 2
```

Command:

Total-Displacement



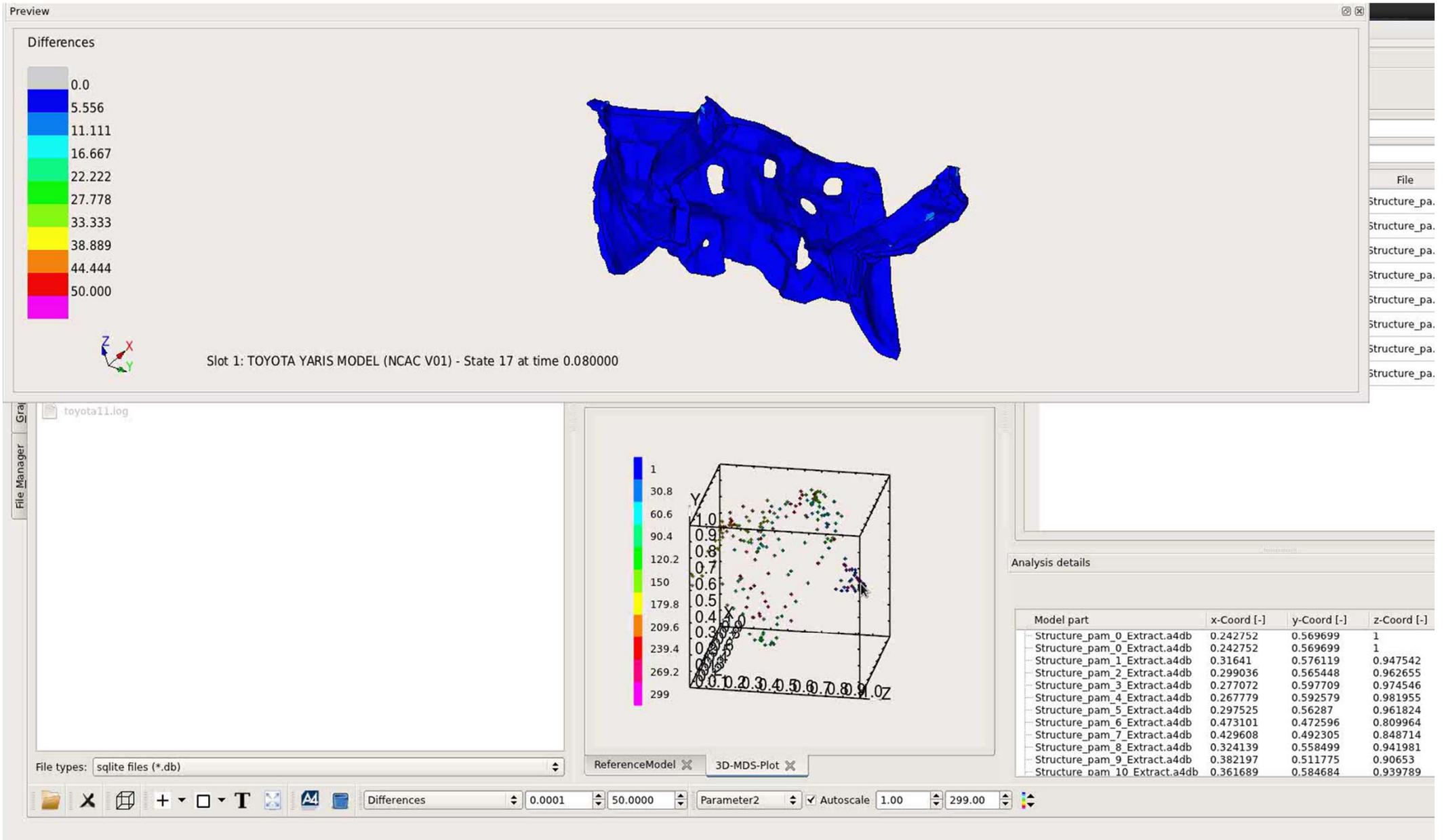
Slot 4: TOYOTA YARIS MODEL (NCAC V01) - State 14 at time 0.065000

Timeline controls including play, stop, and navigation buttons.

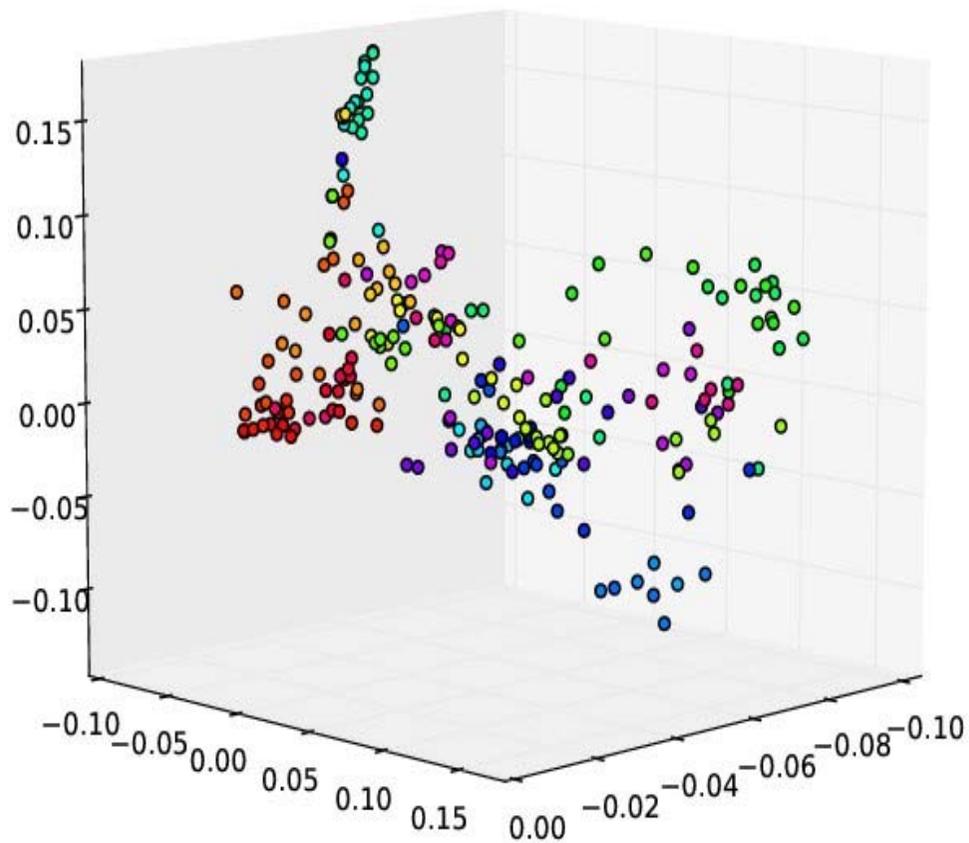
Synchronize visible/active status

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2	TOYOTA YARIS MODEL (NCAC V01) (4)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	TOYOTA YARIS MODEL (NCAC V01) (6)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	TOYOTA YARIS MODEL (NCAC V01) (8)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

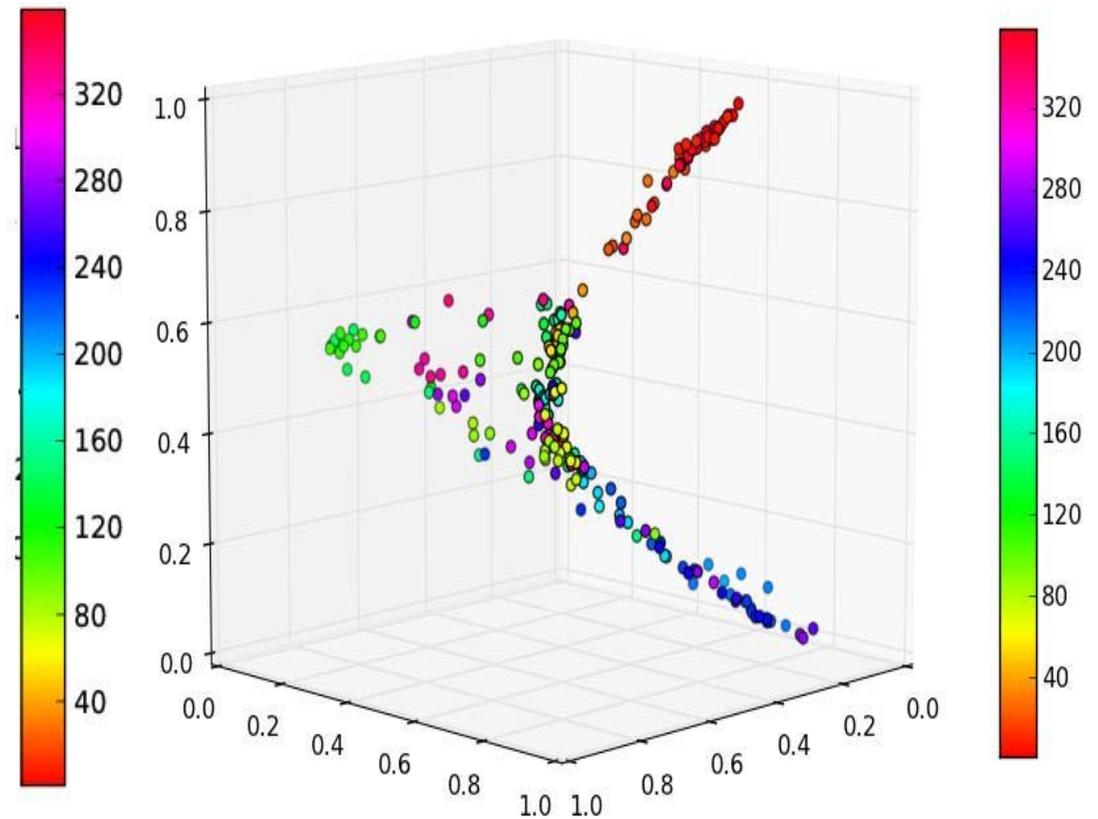
```
ackl slo 1  
era slo 0  
ackl slo 2  
era slo 1  
ackl slo 3  
era slo 2  
ackl slo 4  
era slo 3
```



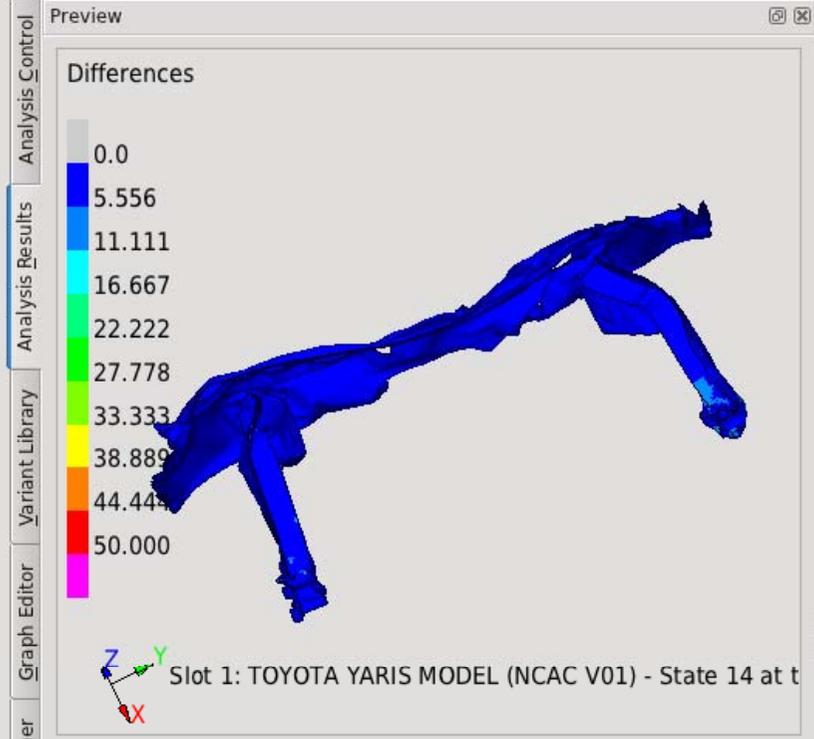
Vergleich lineare gegen nichtlineare Methoden



Lineare PCA



Nichtlineare Methode



Component parts

Femminer project selection

Look in: /home/teran/.dataviewer/analysis

- Param2.db
- Param2.log
- Pero.db
- Pero.log

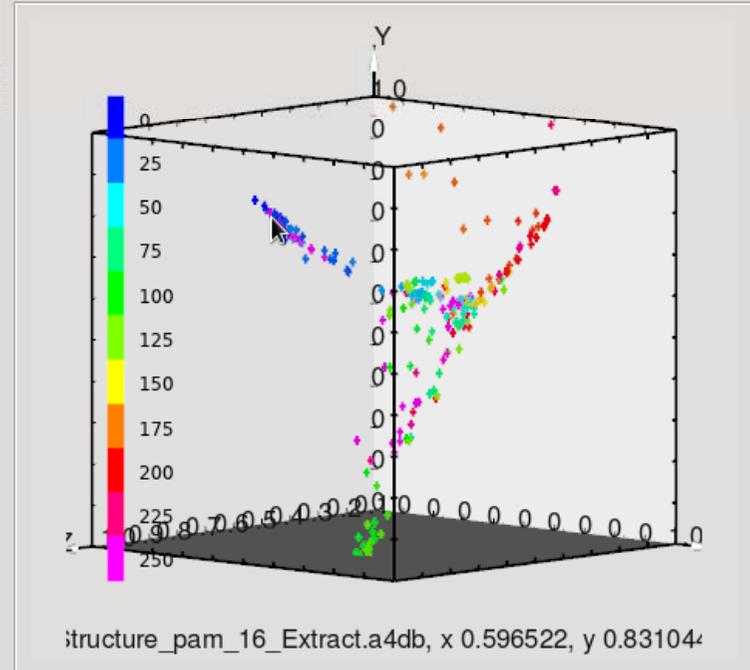
File types: sqlite files (*.db)

Filter

Analysis details

Model part

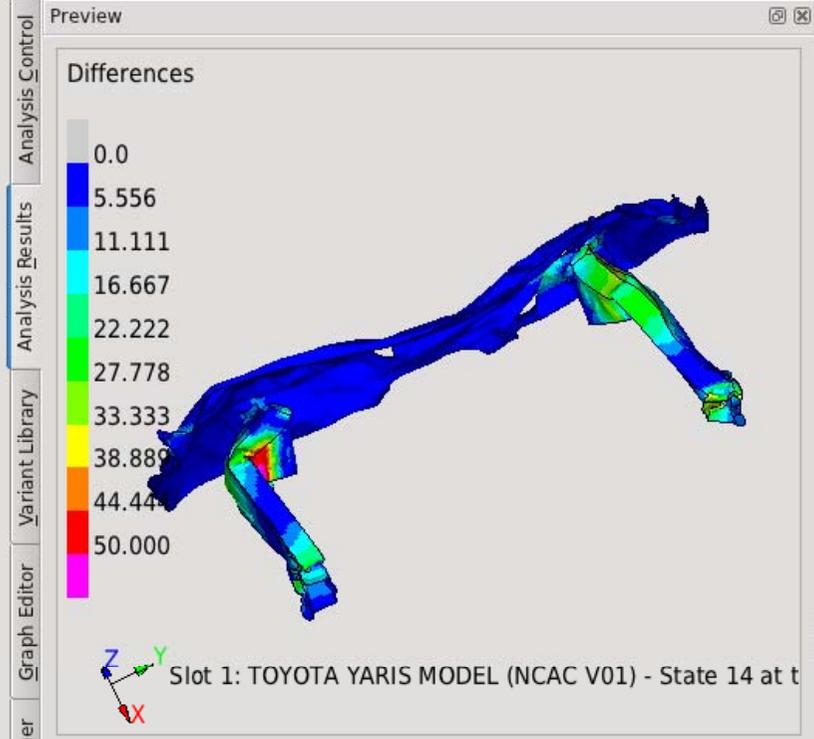
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- Structure_pam_2_Extract
- Structure_pam_3_Extract
- Structure_pam_4_Extract
- Structure_pam_5_Extract
- Structure_pam_6_Extract
- Structure_pam_7_Extract
- Structure_pam_8_Extract
- Structure_pam_9_Extract
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- Structure_pam_17_Extract
- Structure_pam_18_Extract
- Structure_pam_19_Extract
- Structure_pam_20_Extract
- Structure_pam_21_Extract
- Structure_pam_22_Extract
- Structure_pam_23_Extract
- Structure_pam_24_Extract
- Structure_pam_25_Extract
- Structure_pam_26_Extract
- Structure_pam_27_Extract
- Structure_pam_28_Extract
- Structure_pam_29_Extract
- Structure_pam_33_Extract
- Structure_pam_35_Extract
- Structure_pam_37_Extract
- Structure_pam_38_Extract
- Structure_pam_39_Extract
- Structure_pam_40_Extract
- Structure_pam_41_Extract
- Structure_pam_42_Extract
- Structure_pam_43_Extract
- Structure_pam_44_Extract
- Structure_pam_45_Extract
- Structure_pam_46_Extract
- Structure_pam_47_Extract
- Structure_pam_48_Extract
- Structure_pam_49_Extract
- Structure_pam_50_Extract
- Structure_pam_52_Extract
- Structure_pam_53_Extract



ReferenceModel X 3D-MDS-Plot X

Differences: 0.0001 50.0000

Parameter2: 0.00 250.00



Analysis details

- Model part
- Structure_pam_1_Extra
 - Structure_pam_2_Extra
 - Structure_pam_3_Extra
 - Structure_pam_4_Extra
 - Structure_pam_5_Extra
 - Structure_pam_6_Extra
 - Structure_pam_7_Extra
 - Structure_pam_8_Extra
 - Structure_pam_9_Extra
 - Structure_pam_10_Extra
 - Structure_pam_11_Extra
 - Structure_pam_12_Extra
 - Structure_pam_13_Extra
 - Structure_pam_14_Extra
 - Structure_pam_15_Extra
 - Structure_pam_16_Extra
 - Structure_pam_17_Extra
 - Structure_pam_18_Extra
 - Structure_pam_19_Extra
 - Structure_pam_20_Extra
 - Structure_pam_21_Extra
 - Structure_pam_22_Extra
 - Structure_pam_23_Extra
 - Structure_pam_24_Extra
 - Structure_pam_25_Extra
 - Structure_pam_26_Extra
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 - Structure_pam_29_Extra
 - Structure_pam_33_Extra
 - Structure_pam_35_Extra
 - Structure_pam_37_Extra
 - Structure_pam_38_Extra
 - Structure_pam_39_Extra
 - Structure_pam_40_Extra
 - Structure_pam_41_Extra
 - Structure_pam_42_Extra
 - Structure_pam_43_Extra
 - Structure_pam_44_Extra
 - Structure_pam_45_Extra
 - Structure_pam_46_Extra
 - Structure_pam_47_Extra
 - Structure_pam_48_Extra
 - Structure_pam_49_Extra
 - Structure_pam_50_Extra
 - Structure_pam_52_Extra
 - Structure_pam_53_Extra

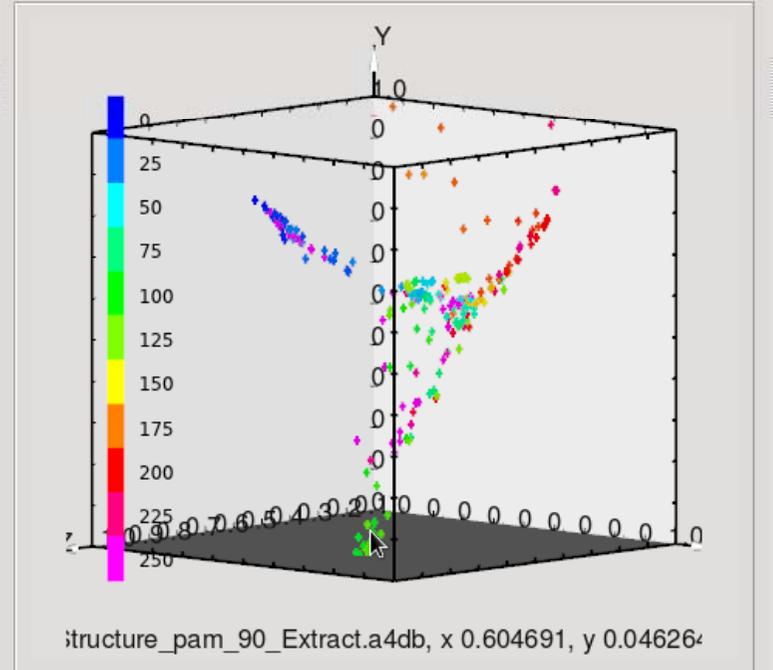
Component parts

Femminer project selection

Look in: /home/teran/.dataviewer/analysis

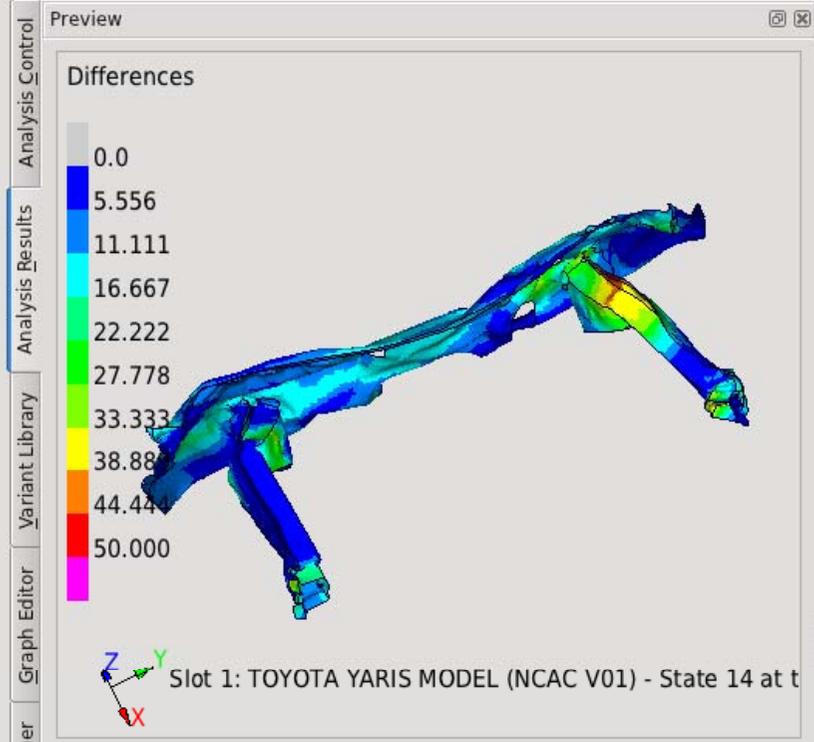
- Param2.db
- Param2.log
- Pero.db
- Pero.log

File types: sqlite files (*.db)



ReferenceModel X 3D-MDS-Plot X

Differences 0.0001 50.0000 Parameter2 0.00 250.00



Component parts

Femminer project selection

Look in: /home/teran/.dataviewer/analysis

- Param2.db
- Param2.log
- Pero.db
- Pero.log

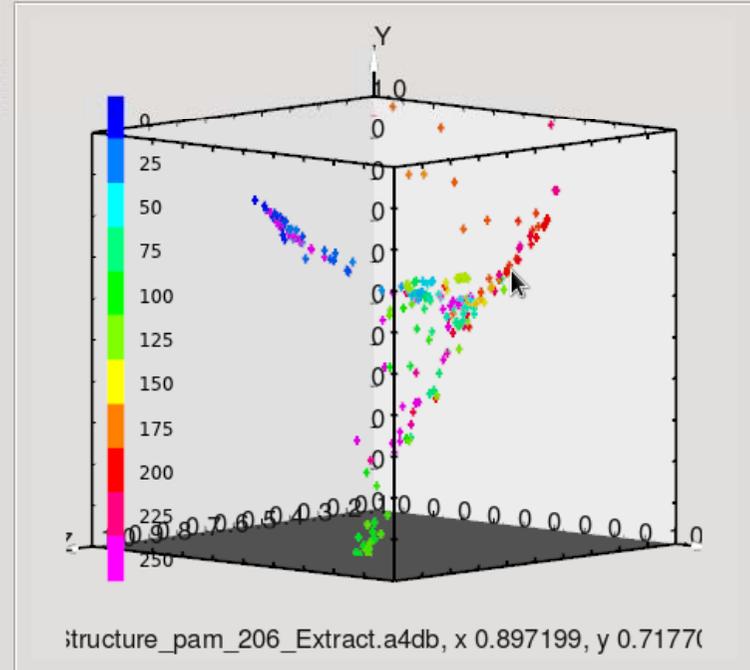
File types: sqlite files (*.db)

Filter

Analysis details

Model part

- Structure_pam_1_Extract
- Structure_pam_2_Extract
- Structure_pam_3_Extract
- Structure_pam_4_Extract
- Structure_pam_5_Extract
- Structure_pam_6_Extract
- Structure_pam_7_Extract
- Structure_pam_8_Extract
- Structure_pam_9_Extract
- Structure_pam_10_Extract
- Structure_pam_11_Extract
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- Structure_pam_53_Extract

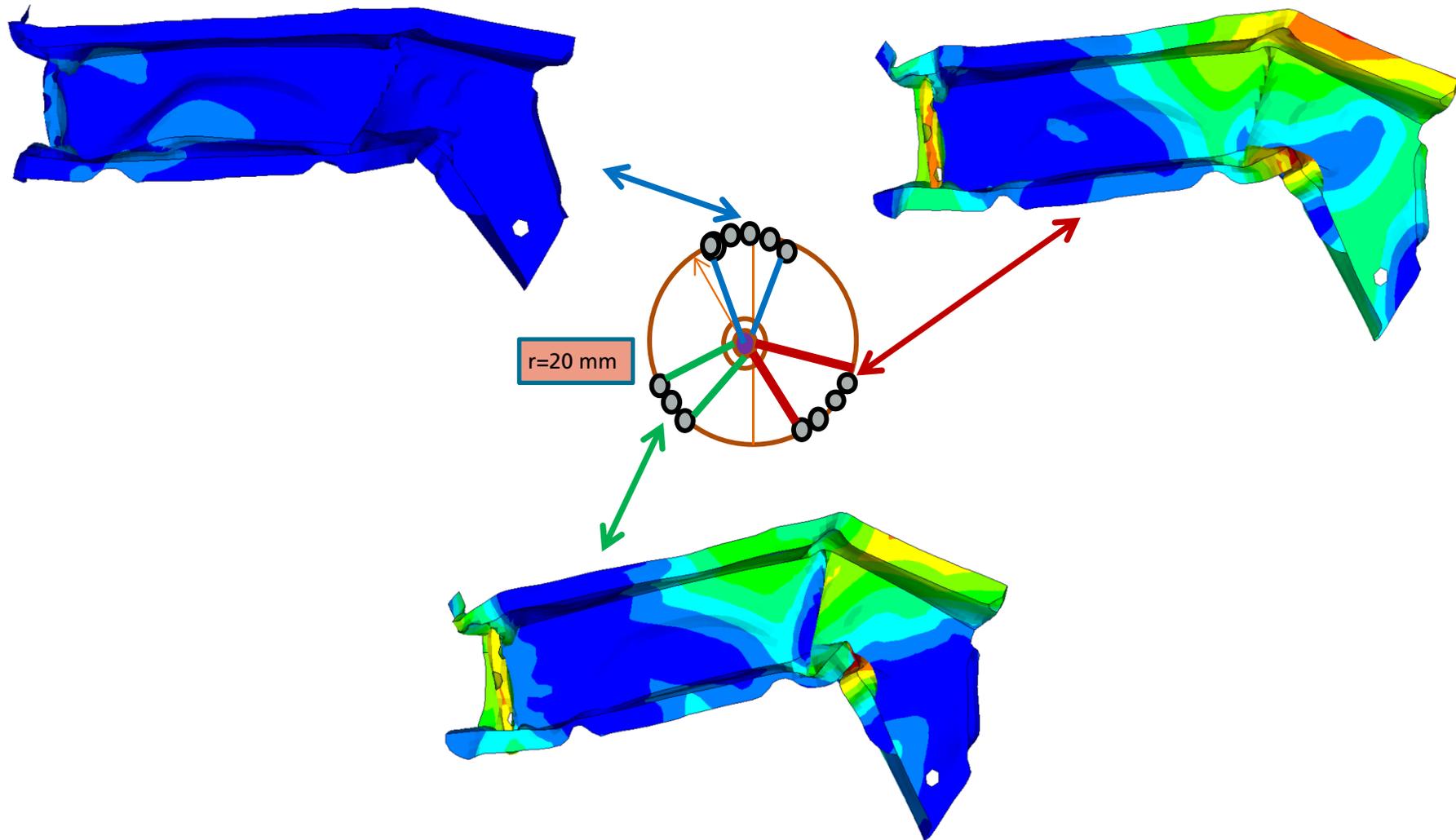


ReferenceModel X 3D-MDS-Plot X

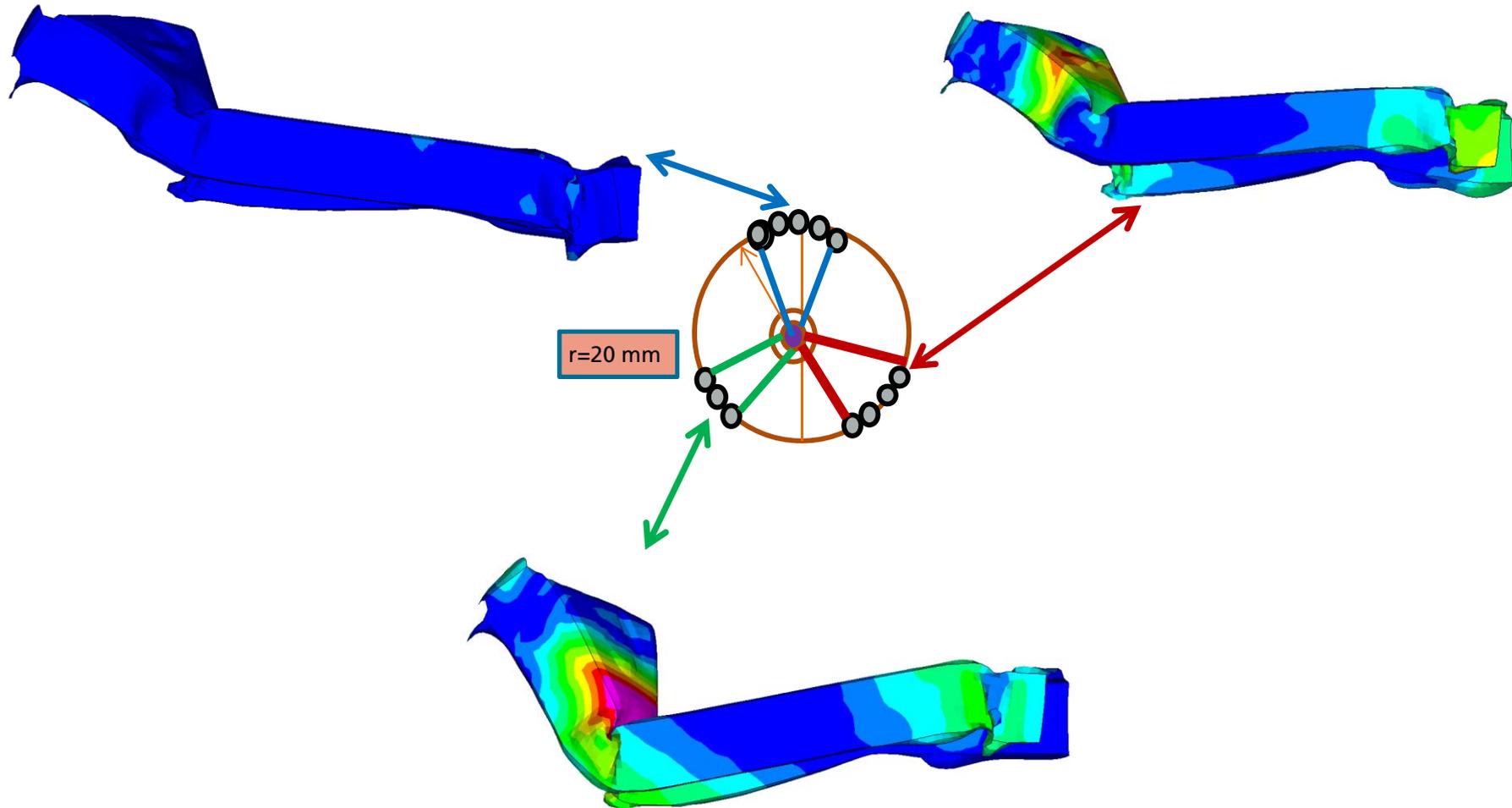
Differences: 0.0001 50.0000

Parameter2: 0.00 250.00

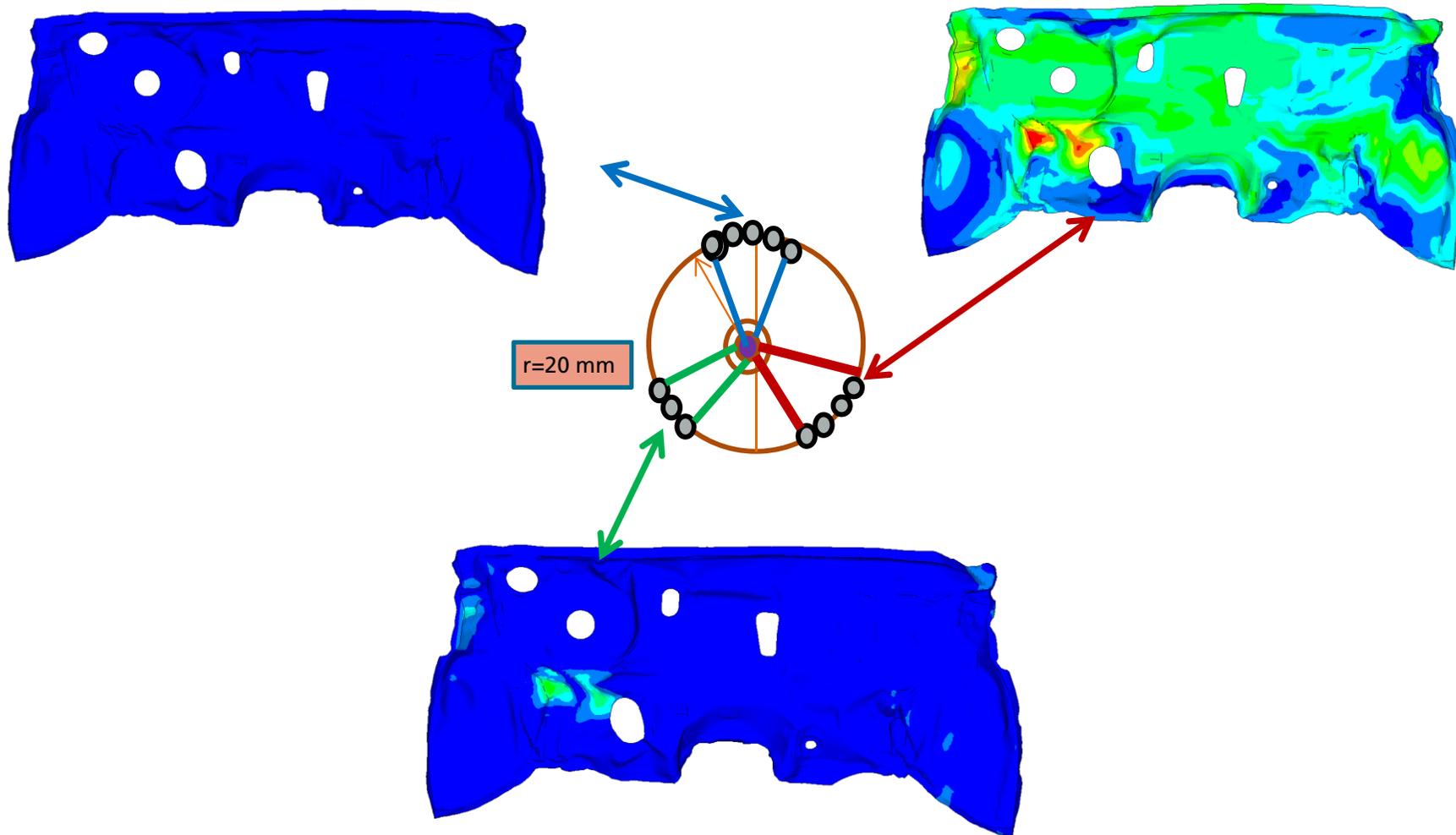
Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



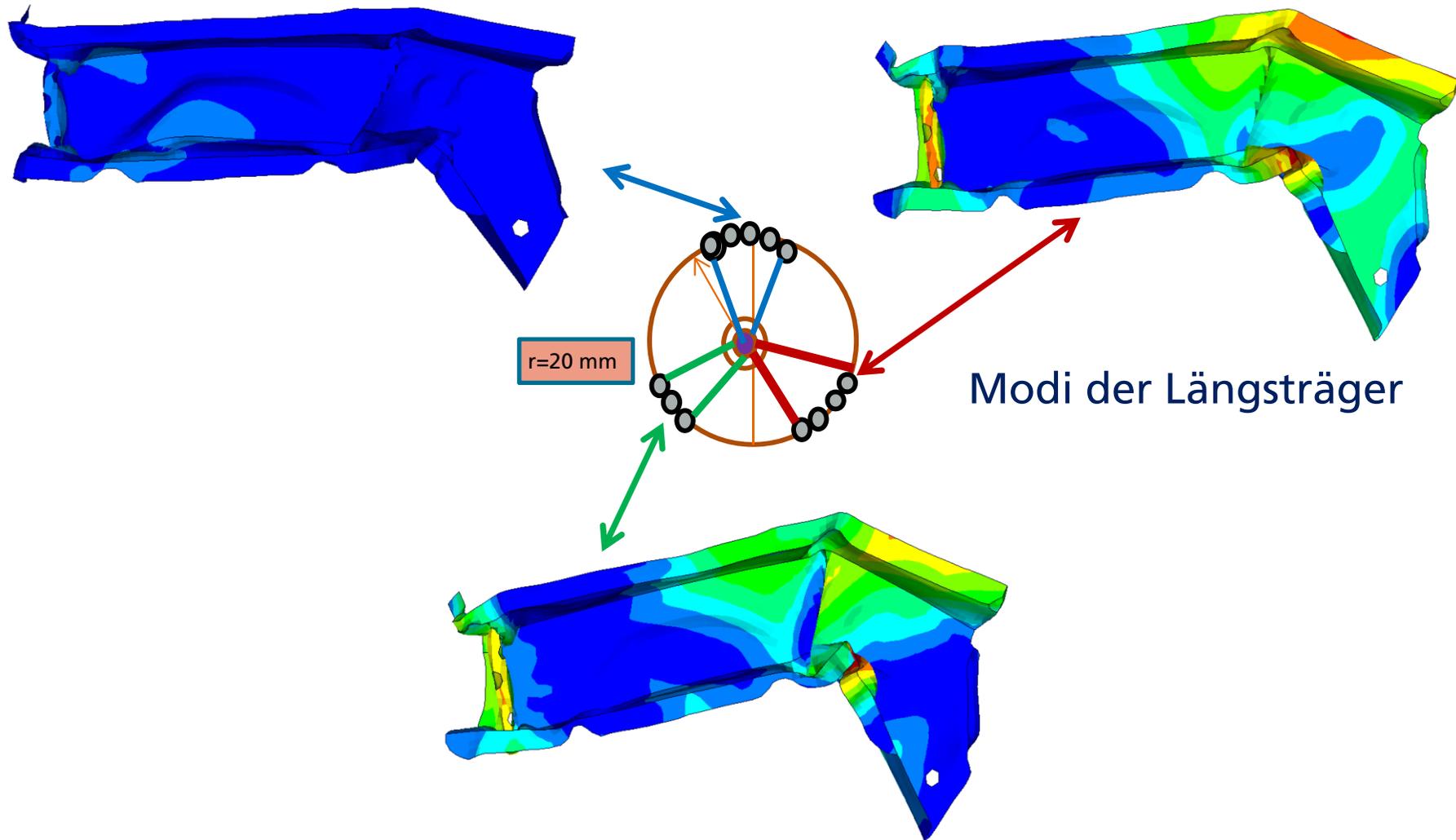
Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



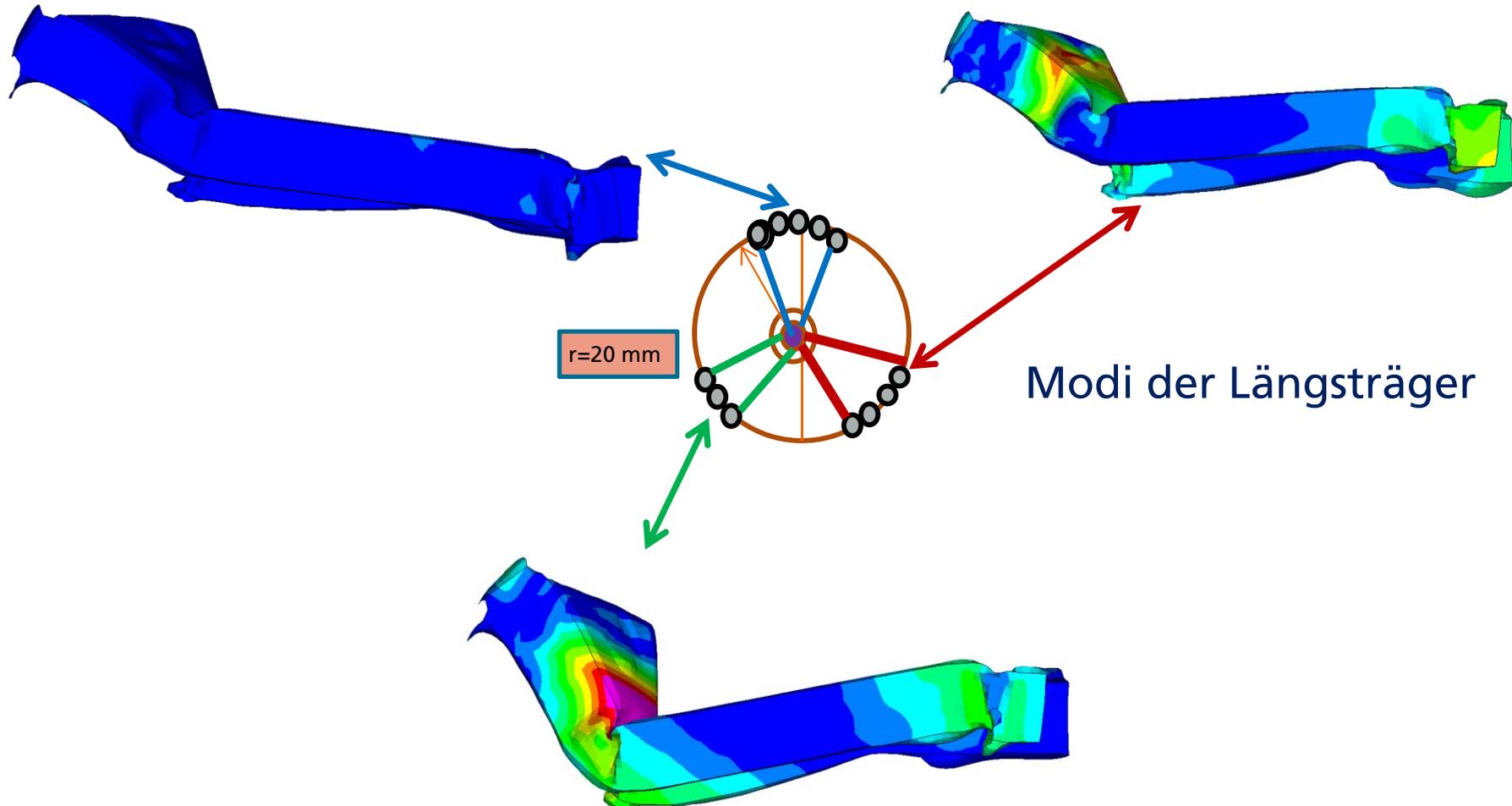
Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



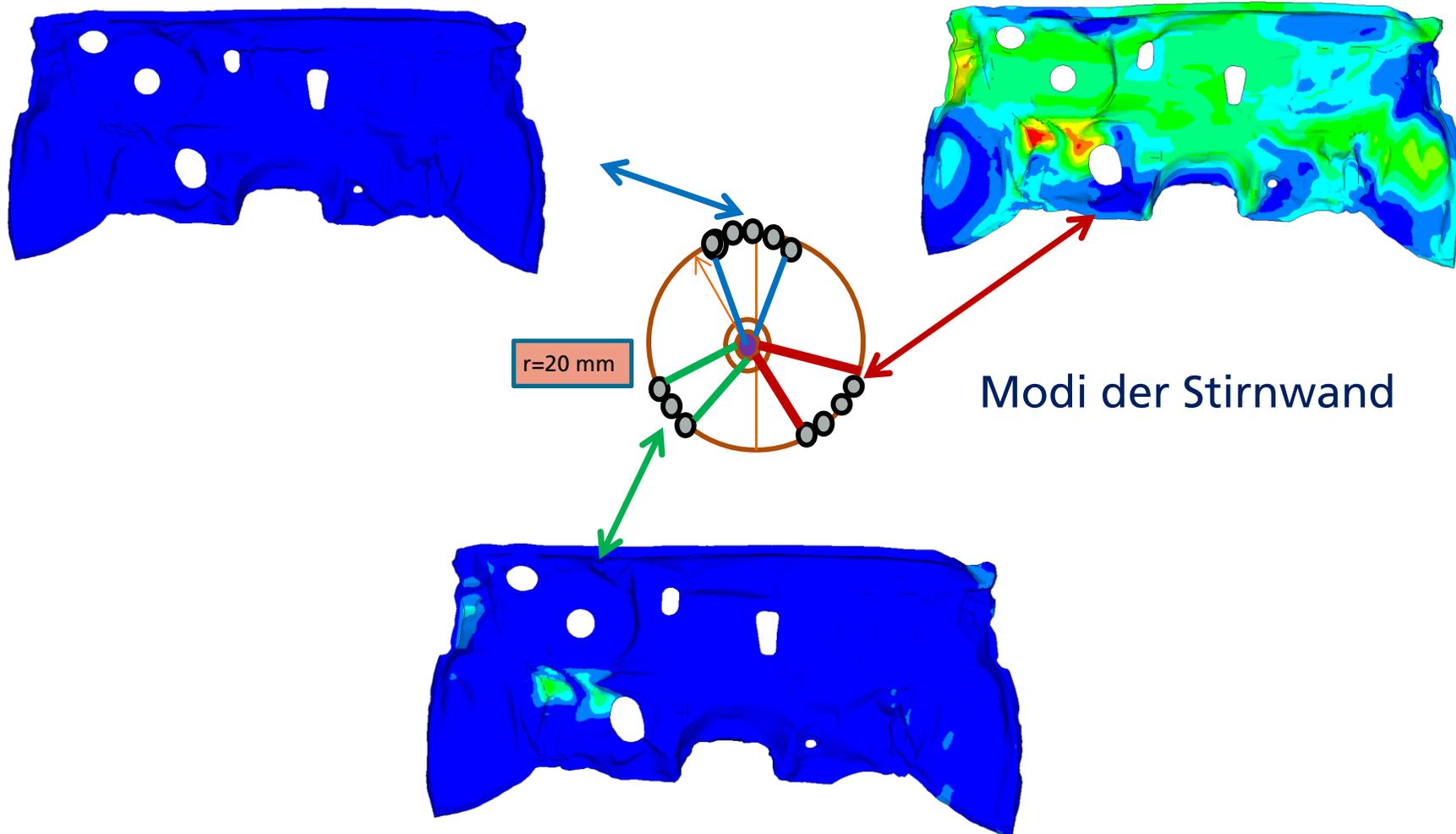
Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



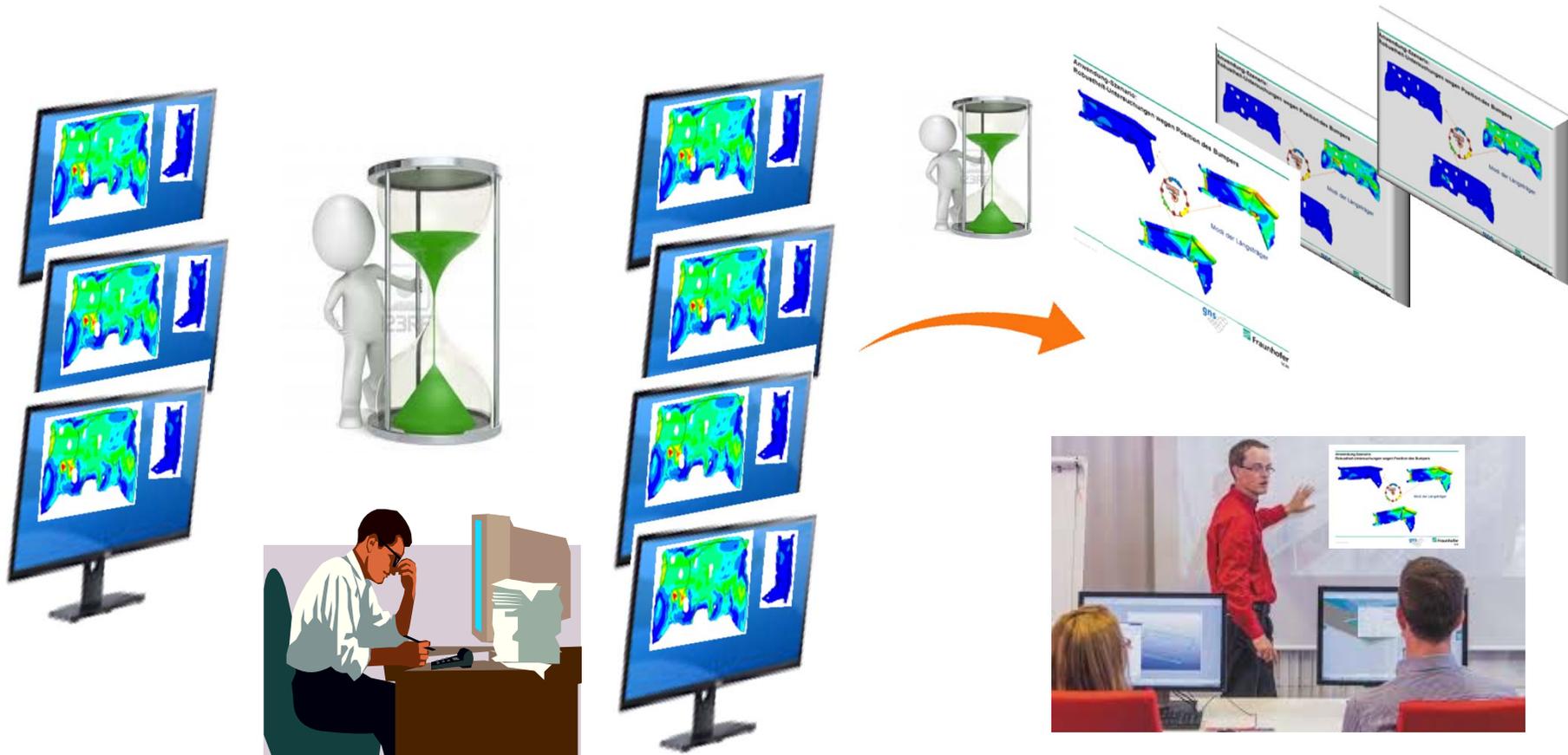
Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



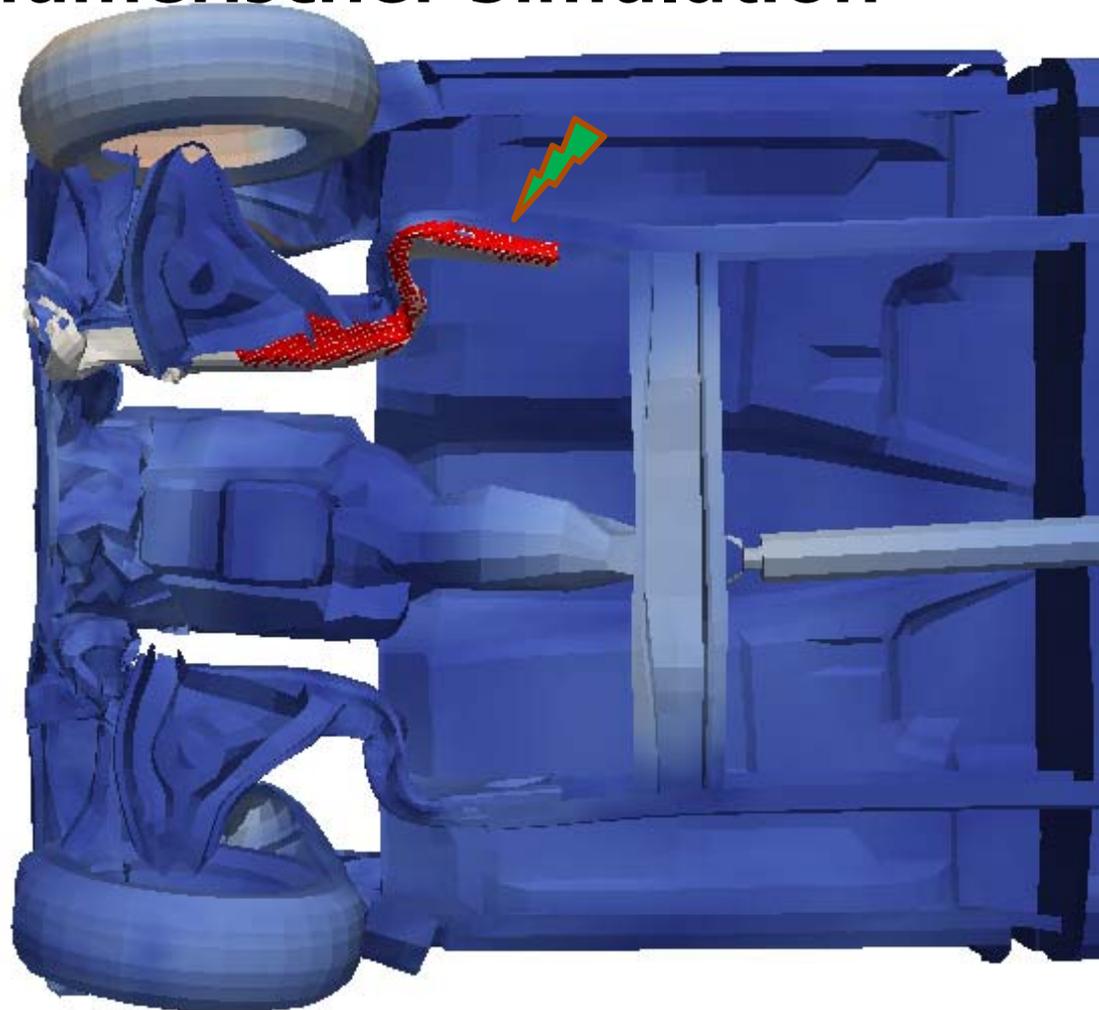
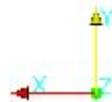
Anwendungsbeispiel: Robustheitsuntersuchung bezüglich der Position der Stoßstange



Vereinfachte und beschleunigte Analyse

Ausblick: Abgleich zwischen realem Crash-Experiment und numerischer Simulation

- **Zur Verfügung:**
3D-Messung der Verformung als Punktwolke
- **Fragestellung:**
Finde die zur Punktwolke (am besten) passende Simulation



Zusammenfassung

- Analyseansatz umfasst
 - automatisierte Vorverarbeitung der Daten
 - interaktive Analyse
 - Einbeziehung von Geometrien, d.h. volle Simulationsdaten
 - einfacher Vergleich von Bauteilverformungen in Varianten
- Zeitaufwand des Entwicklungsingenieurs wird deutlich reduziert
- effiziente datengetriebene Analysen
- Perspektiven:
 - Methodenweiterentwicklung ("richtiges" Abstandsmaß)
 - schnelles Rechnen "bei" den Daten auf dem Server
 - Abgleich 3D-Videodaten einer Verformung mit Simulation
 - Quantifizierung von Ungewissheiten