Full Field Calibration (FFC) using LS-OPT

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Outline

- A selection of material calibration difficulties.
  - Are all parameters active in the test setup?
  - Are experimental results being reproduced?
  - How does one separate similar parameter influences?
  - Robustness of optimal result?
- Motivation of Full Field Calibration.
- Multi-histories
- Error measures for calibration
  - Partial Dynamic Time Warping
- Parameterisation of simulation input
- Set-up of FFC in LS-OPT
- Example of other sample geometries
- Further reading

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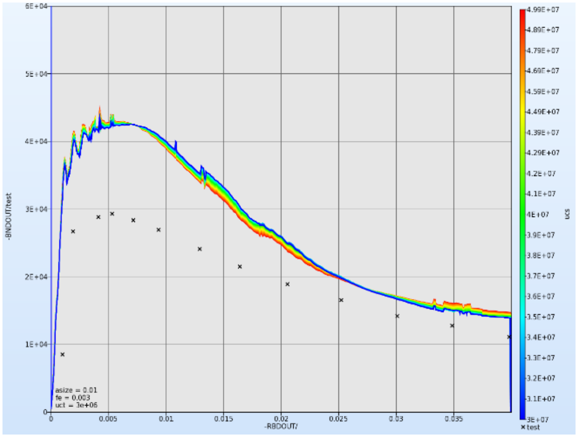
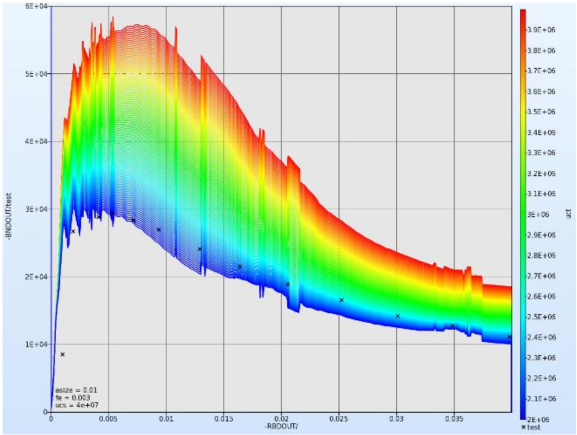
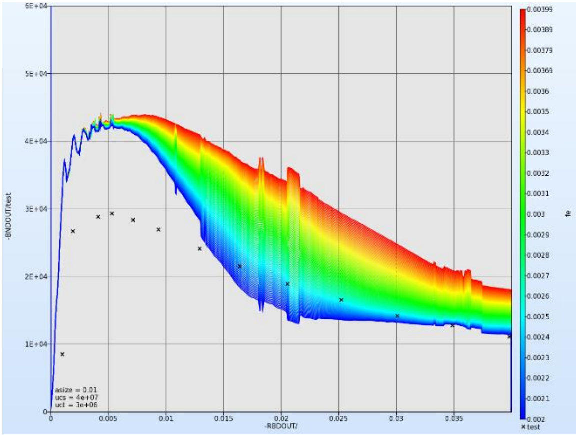
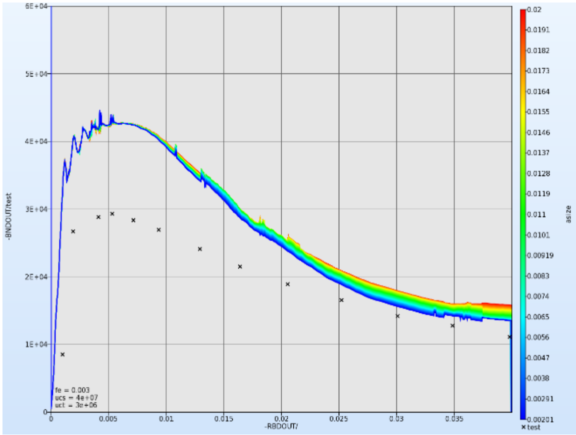
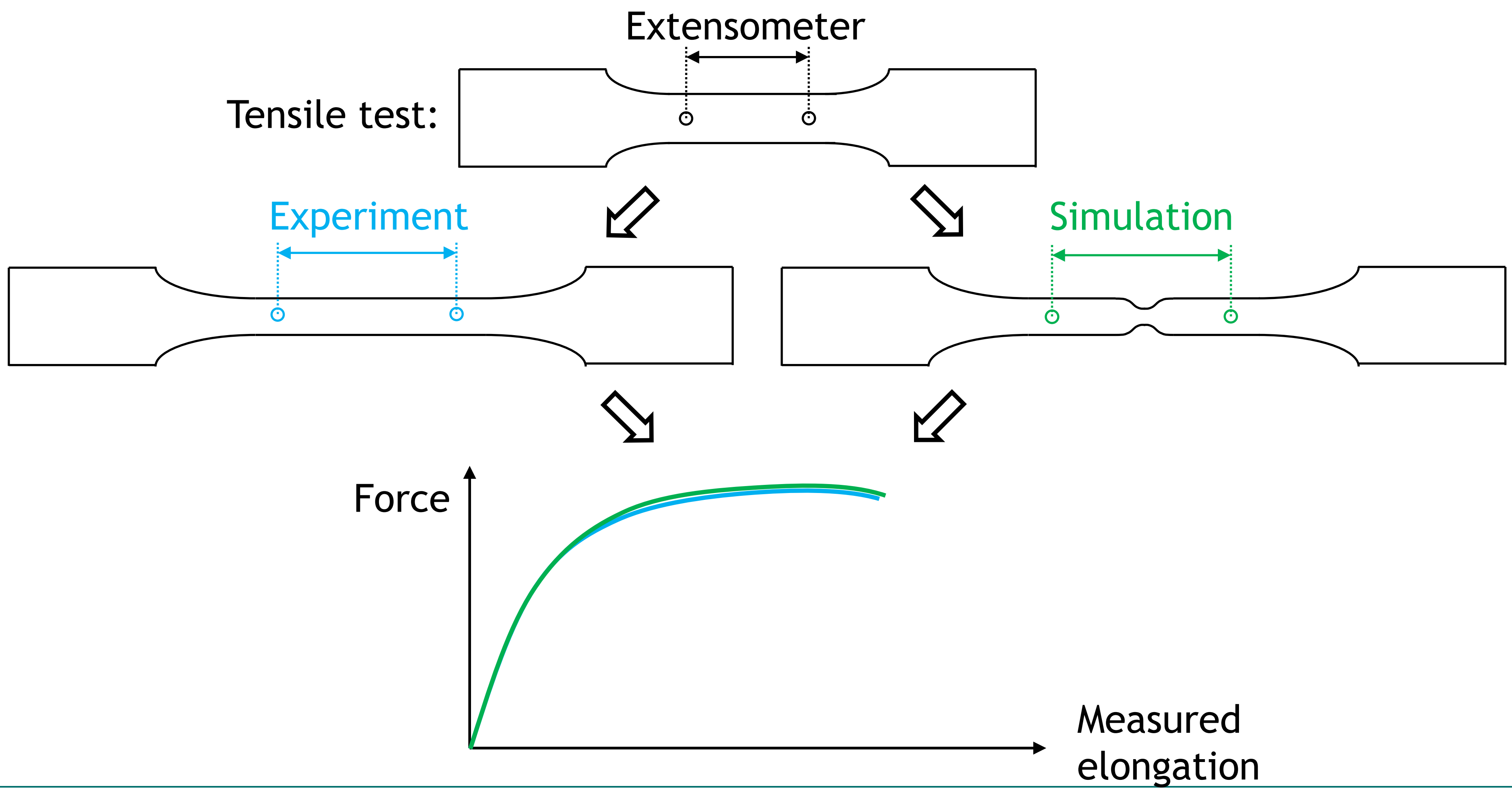
Are all parameters active in the test setup?

- Only calibrate parameters that have an influence on your target response.
- Calibrate the other parameters with other responses/experiments.
- Simulate first to learn if your experiment is suitable for calibration of your parameters.

Are experimental results being reproduced?

- Using a global measure for calibration may give an undesired optimum in calibration.



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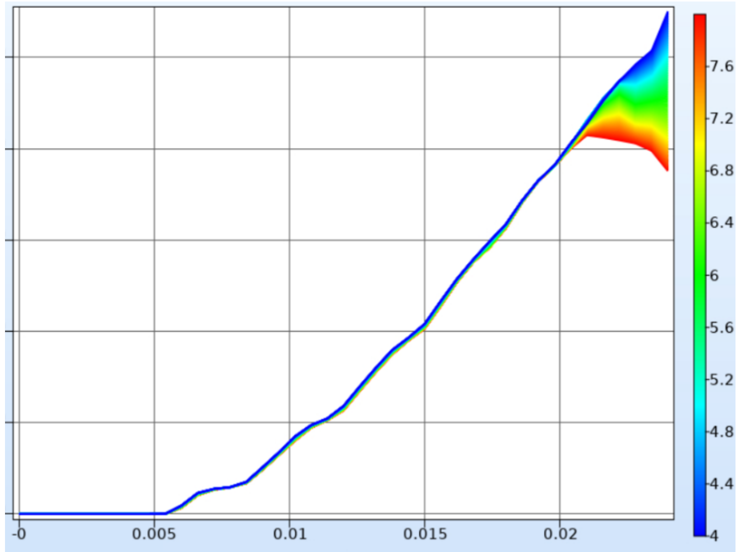
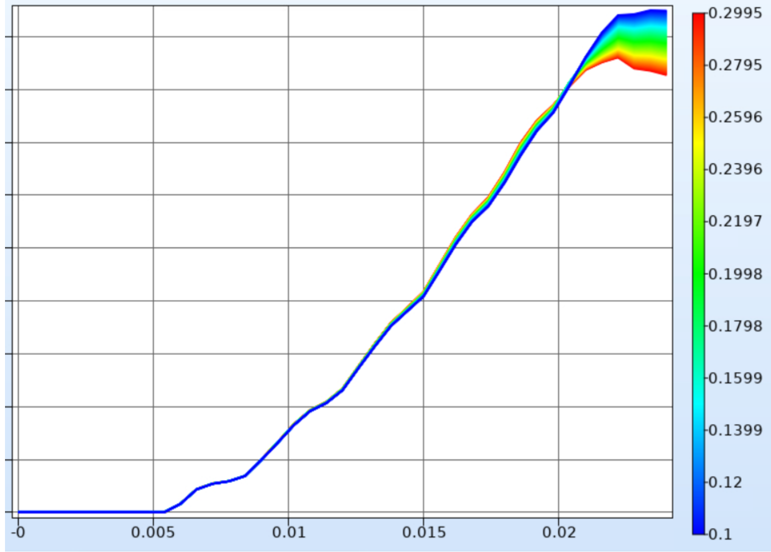
How does one separate similar parameter influences?





- Some parameters could have similar influence on a global response. How do you know if the right combination of these parameters are retrieved in an optimization?

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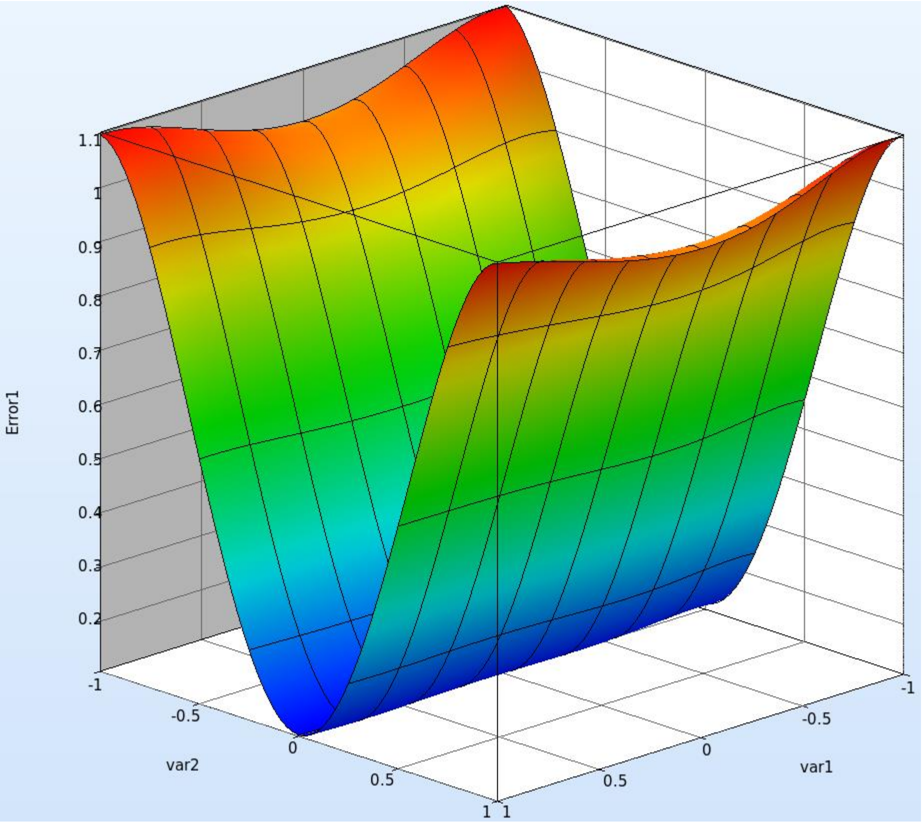
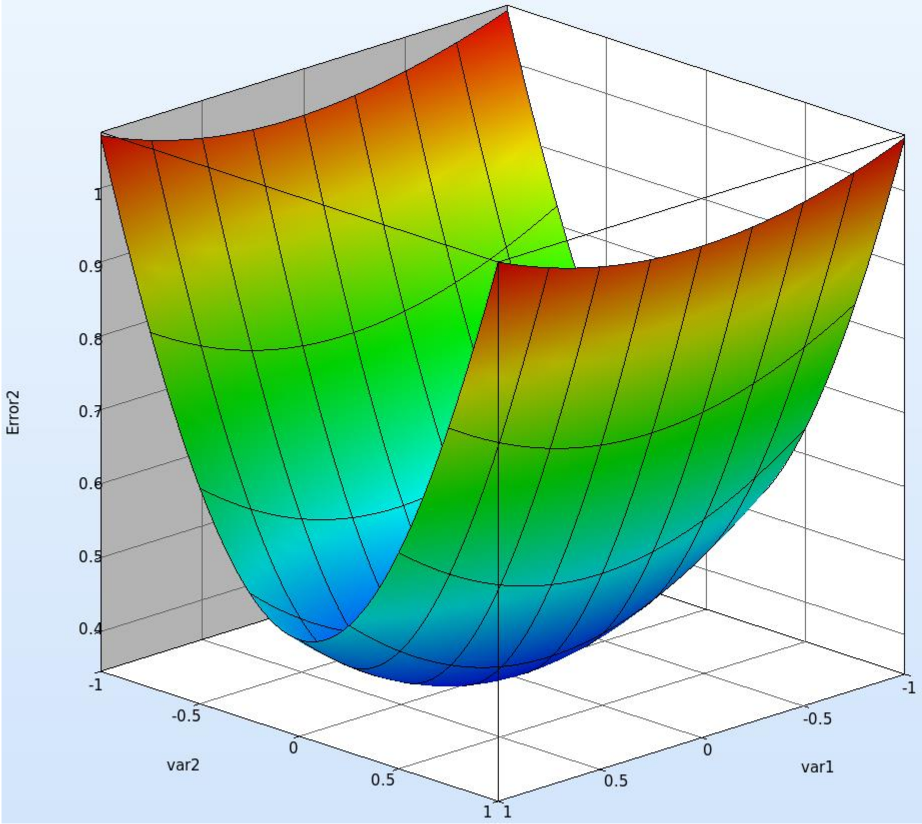
Robustness of optimal result?

- What we also hope that FFC can bring, is a more clear optimal point, where there is a superior value for all variables regarding the error measure.



FFC



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Motivation of Full Field Calibration (FFC)

- General: “*Digital image correlation and tracking is an optical method that employs tracking and image registration techniques for accurate 2D and 3D measurements of changes in images.*” Wikipedia - Digital image correlation and tracking

- With Digital Image Correlation (DIC), there is no need to mount strain gauges on test specimens, as these can be applied at any location afterwards.
- DIC is virtually independent of test specimen size, geometry, material type or deformation rate, as long as appropriate images can be captured by the camera equipment.
- Complex material models have many parameters and only global data might not be sufficient.
- Information contained in local phenomena such as necking and barreling are missed with global data.

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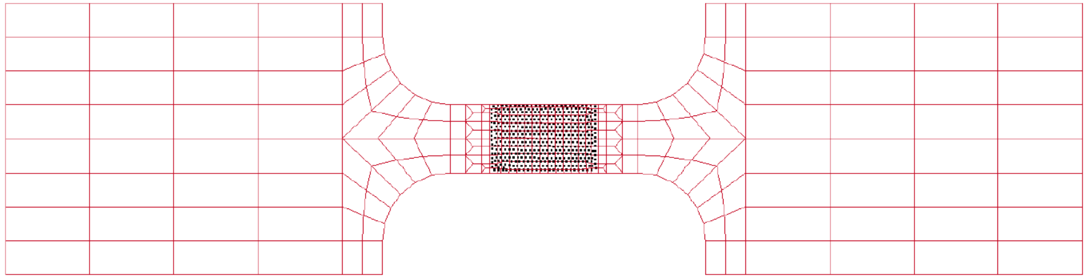
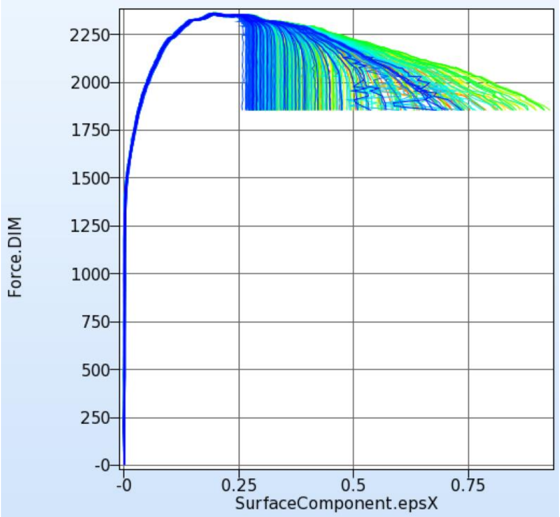
Multi-histories

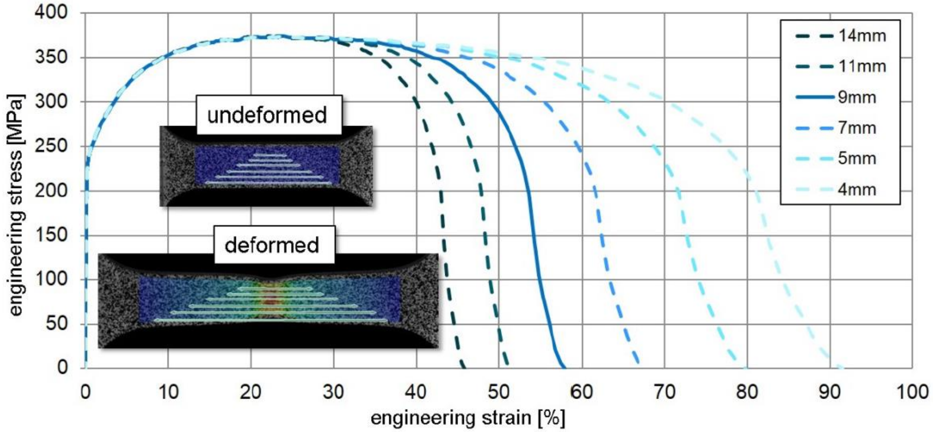
- Multi-histories, or multi-point histories, are simply history curves that are extracted at many locations.





Compare with:

Application of a Full-Field Calibration Concept for Parameter Identification of HS-Steel with LS-OPT®, Ilg C. et. Al, 15th International LS-DYNA® Conference, 2018.



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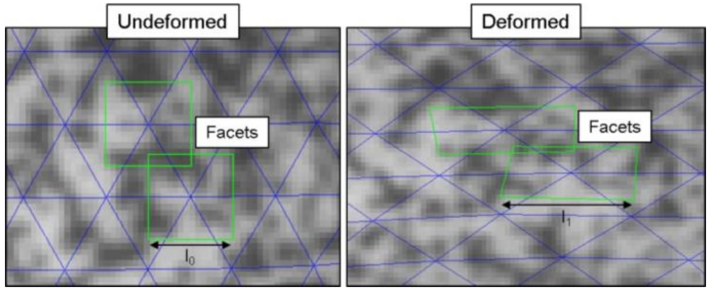
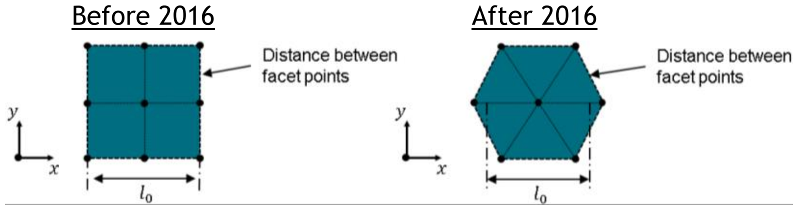
Multi-histories – experiments

- Facets are placed on the images of the specimen to calculate the deformation tensor ***F***, from which strains are calculated.



- Since 2016, the facets in *gom Correlate Professional* are hexagonal, which affects the reference length l_0 used in the strain calculations.



$l_0 \approx 2 *$ "distance between facet points" $l_0 \approx 1.5 *$ "distance between facet points"

- One can argue that the simulation model should have a mesh size not too far from the reference length from the test data.

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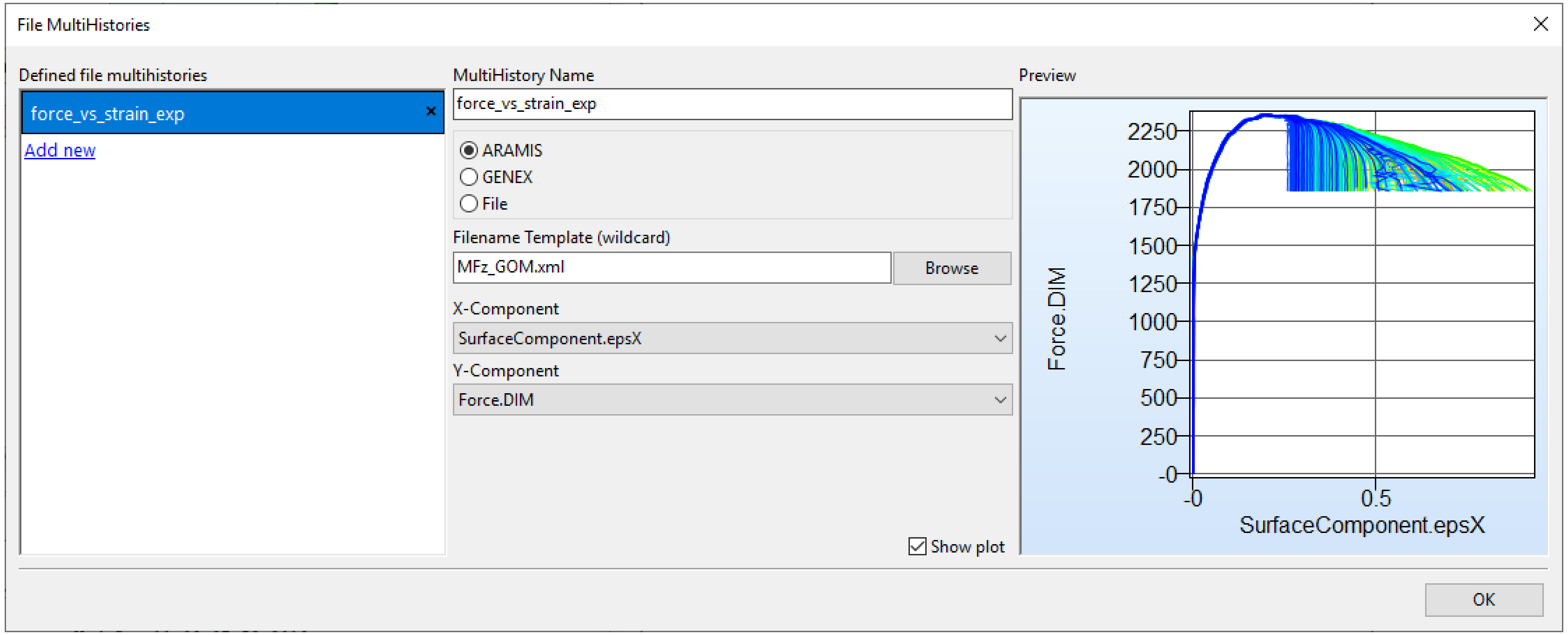
Multi-histories – test data formats

- Three ways of extracting multiple curves from full-field measurements exist:
  1. An interface to the optical measurement system ARAMIS (xml file).
  2. Extraction of curves from multiple text files using the LS-OPT tool GenEx (generic extractor).
  3. Curves are put in a single text file using the LS-PrePost fixed format.



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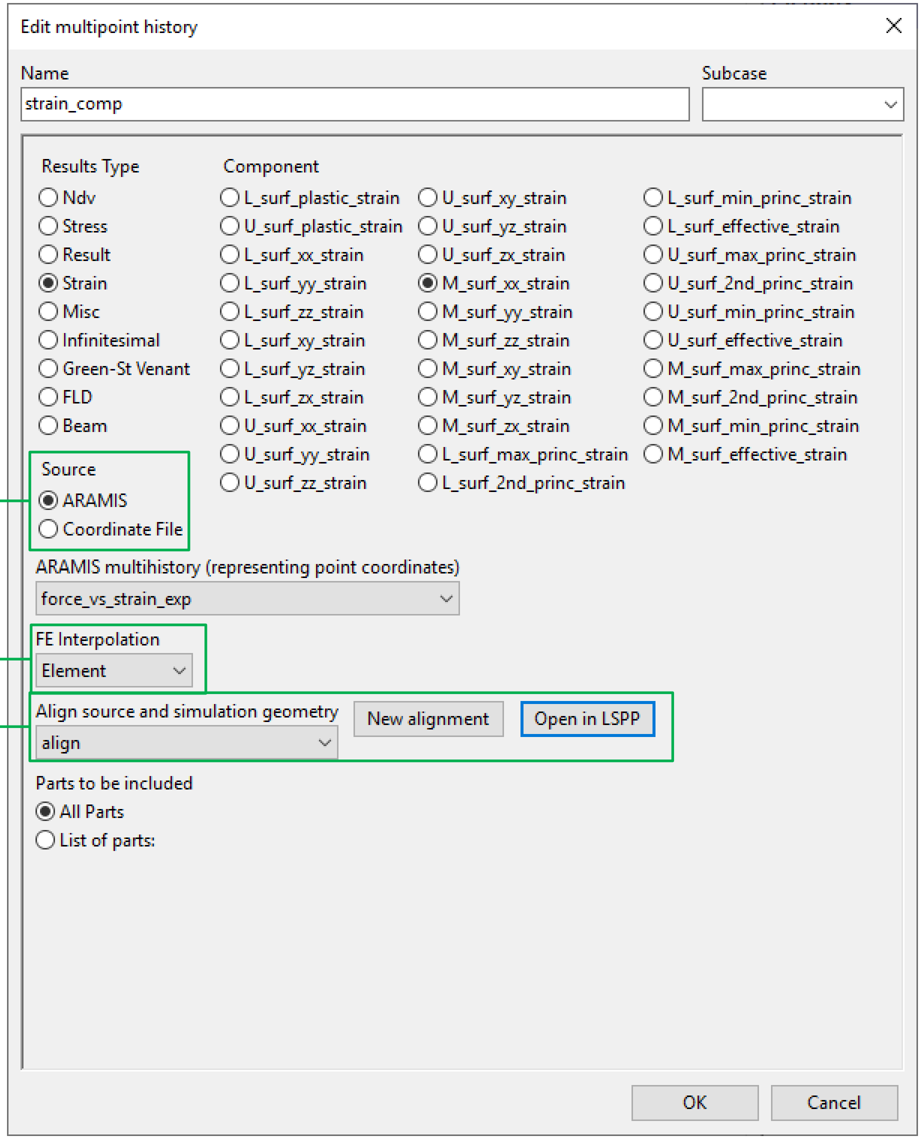
Multi-histories – simulations

- Multi-histories are extracted from the d3plot database.
- The history can be extracted from both shells and solids.
- The locations at which histories are extracted can come from:
  - the tracked points from an ARAMIS system
  - own coordinates (*NODE format)
- The histories can be:
  - bilinearly interpolated within the element
  - evaluated or averaged at node locations
    - with this selection, two methods to filter the amount of points in the test data becomes available
- Alignment needs to be defined to correlate test data and simulations.

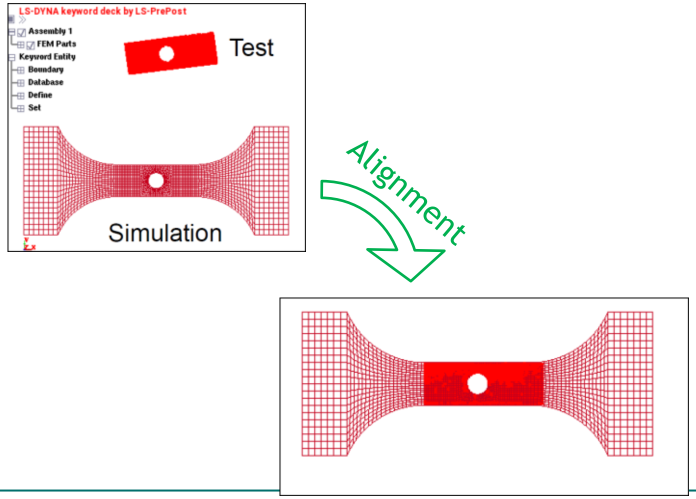


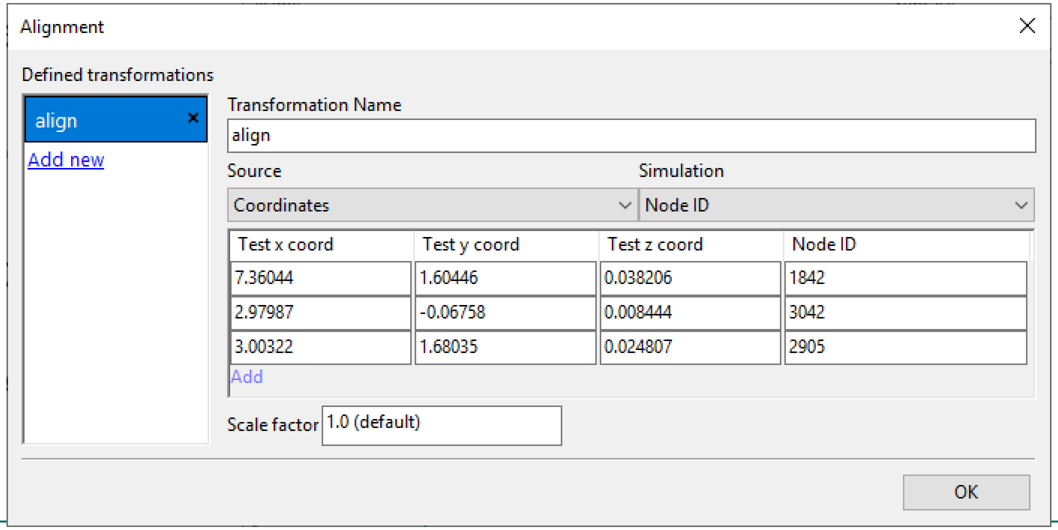
Alignment

- Test and simulation geometries are typically in different coordinate systems.
- A transformation is defined through three test points and three simulation points, either by ARAMIS points, nodes or coordinates.
- The transformation is carried out through a least squares fit to the defined transformation.

$$\min_{T} \| \hat{s} \boldsymbol{X}_{Test} T - \boldsymbol{X}_{FE} \|$$

- The alignment can be previewed in LS-PrePost.





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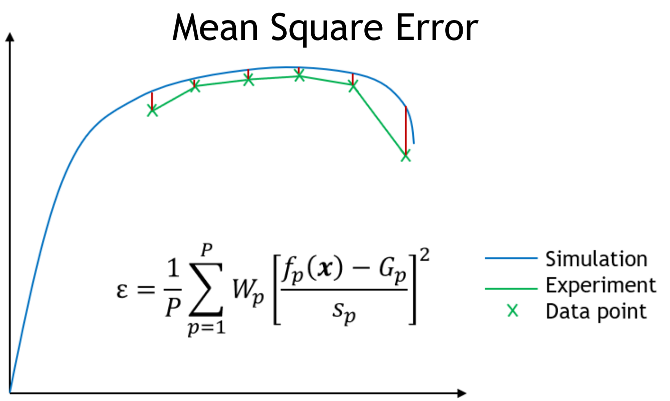
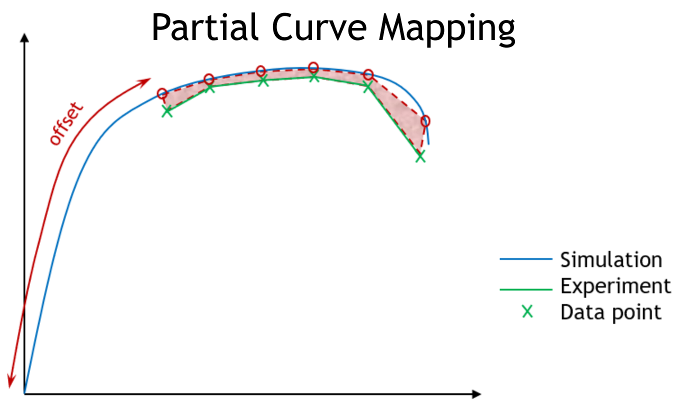
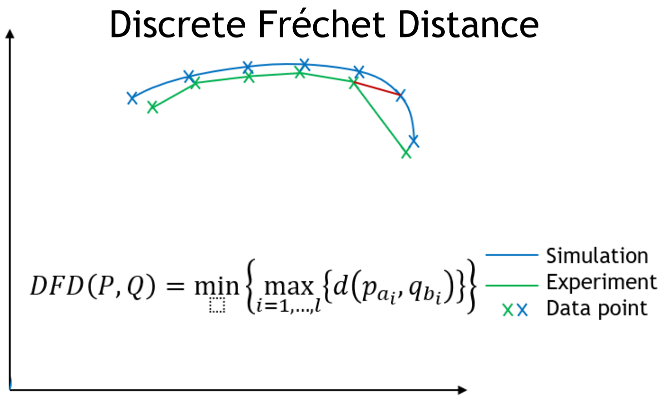
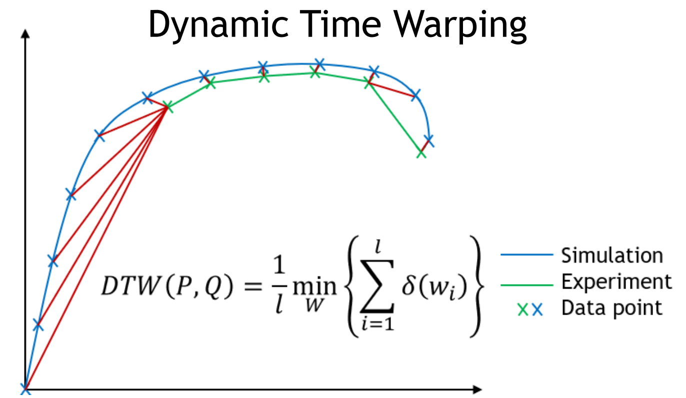
Measuring the error between test and simulation

- The FFC curve matching interface currently provides four ways of calculating the error between test and simulations results, a.k.a. the similarity measure.









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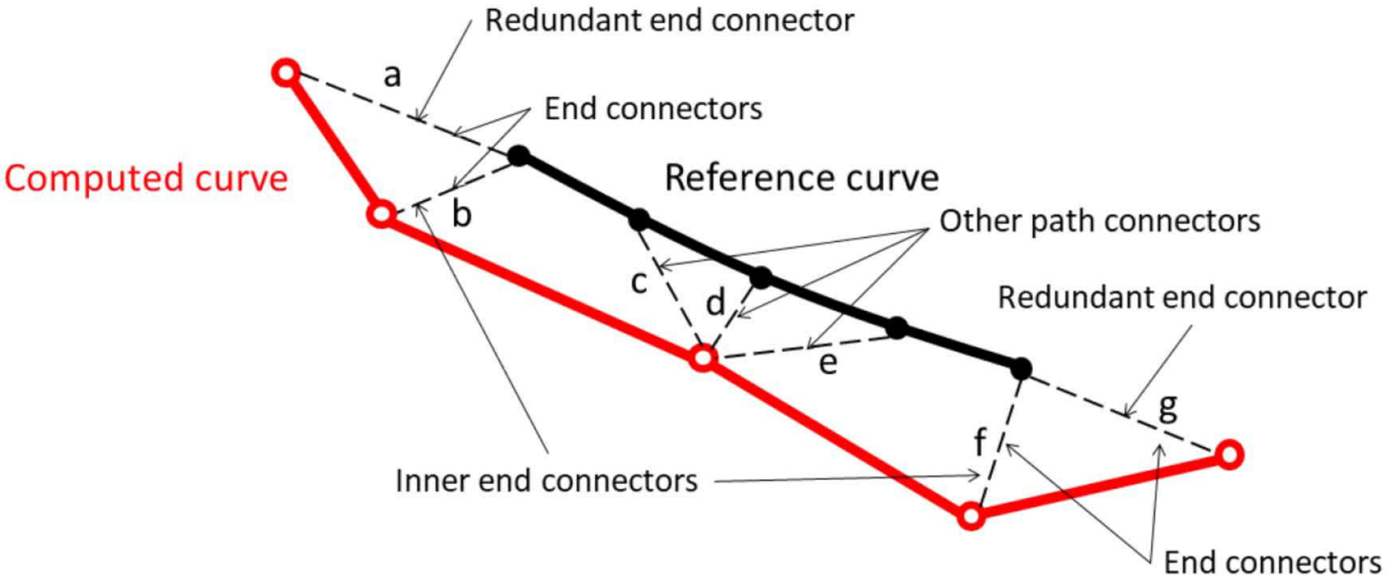
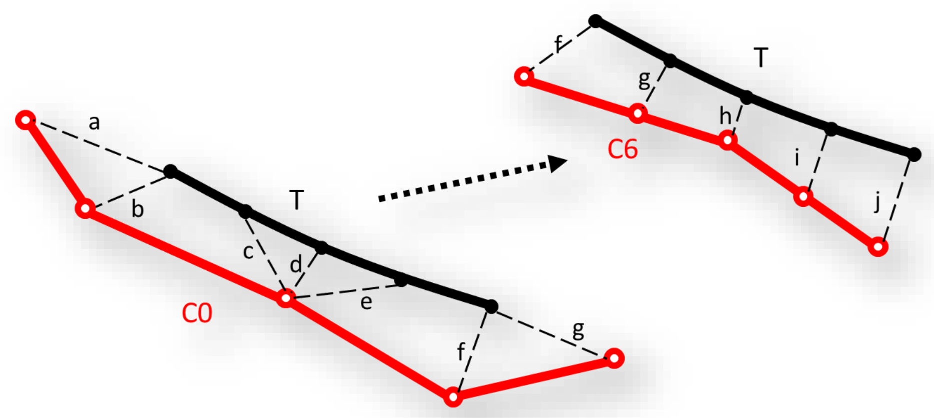
Partial Dynamic Time Warping, DTW-p

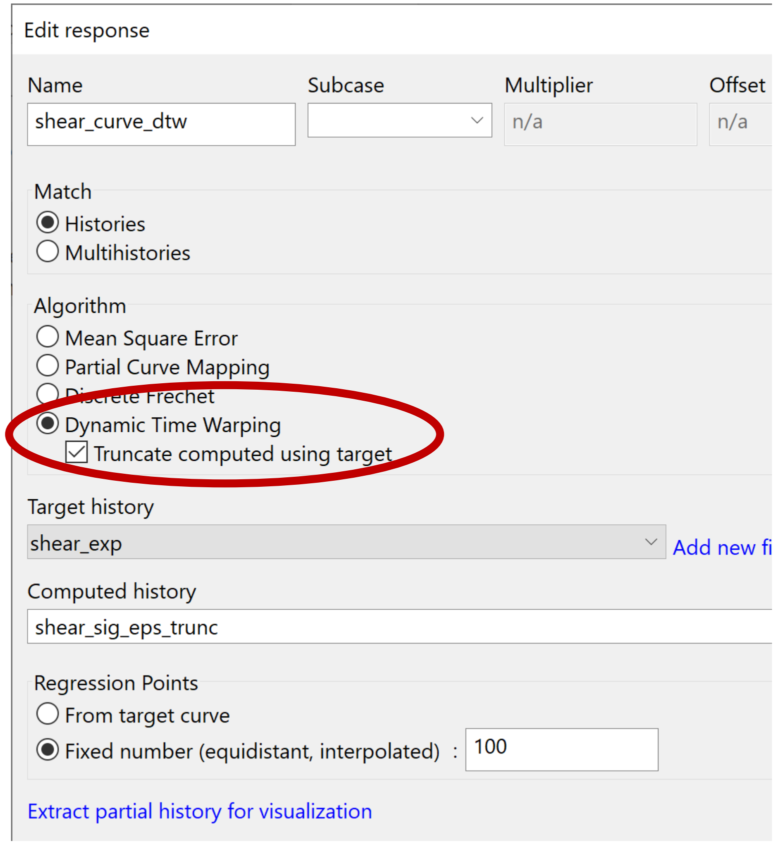
- DTW-p automatically truncates curves so that errors related to trailing ends of curves does not dominate the error measure.



Partial Dynamic Time Warping, DTW-p

- Partial Dynamic Time Warping is available from LS-OPT 7.





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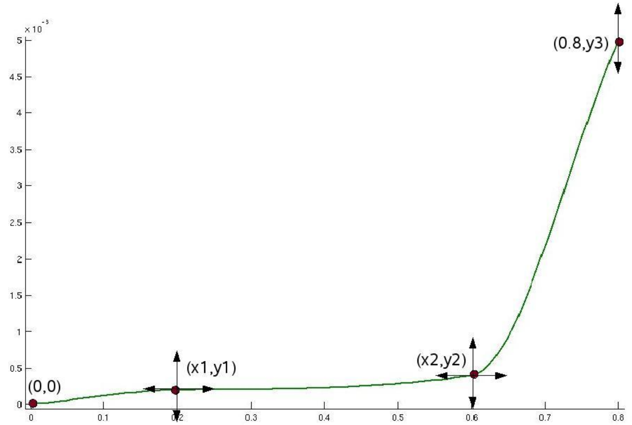
Parameterisation of simulation input

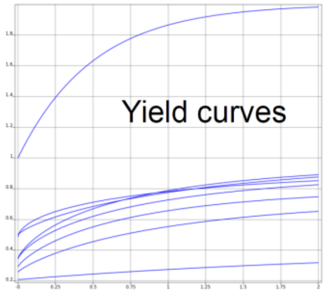
- It is very common that material models require a curve as input, e.g. to describe:
  - Hardening
  - Strain rate dependency
  - Failure
  - …
- These curves need to be parameterized in some way for the optimizer to be able to find the optimal shape of the curve.
- Given a parameterised curve, an input curve is usually generated through a preprocessor script that reads the values of the current curve variables.

Examples of parameterised curves

- Spline function
  - www.lsoptsupport.com/howtos/splines
  - Perl script that generates a curve based on the location of four points (5 variables).
  - Free to download and modify.

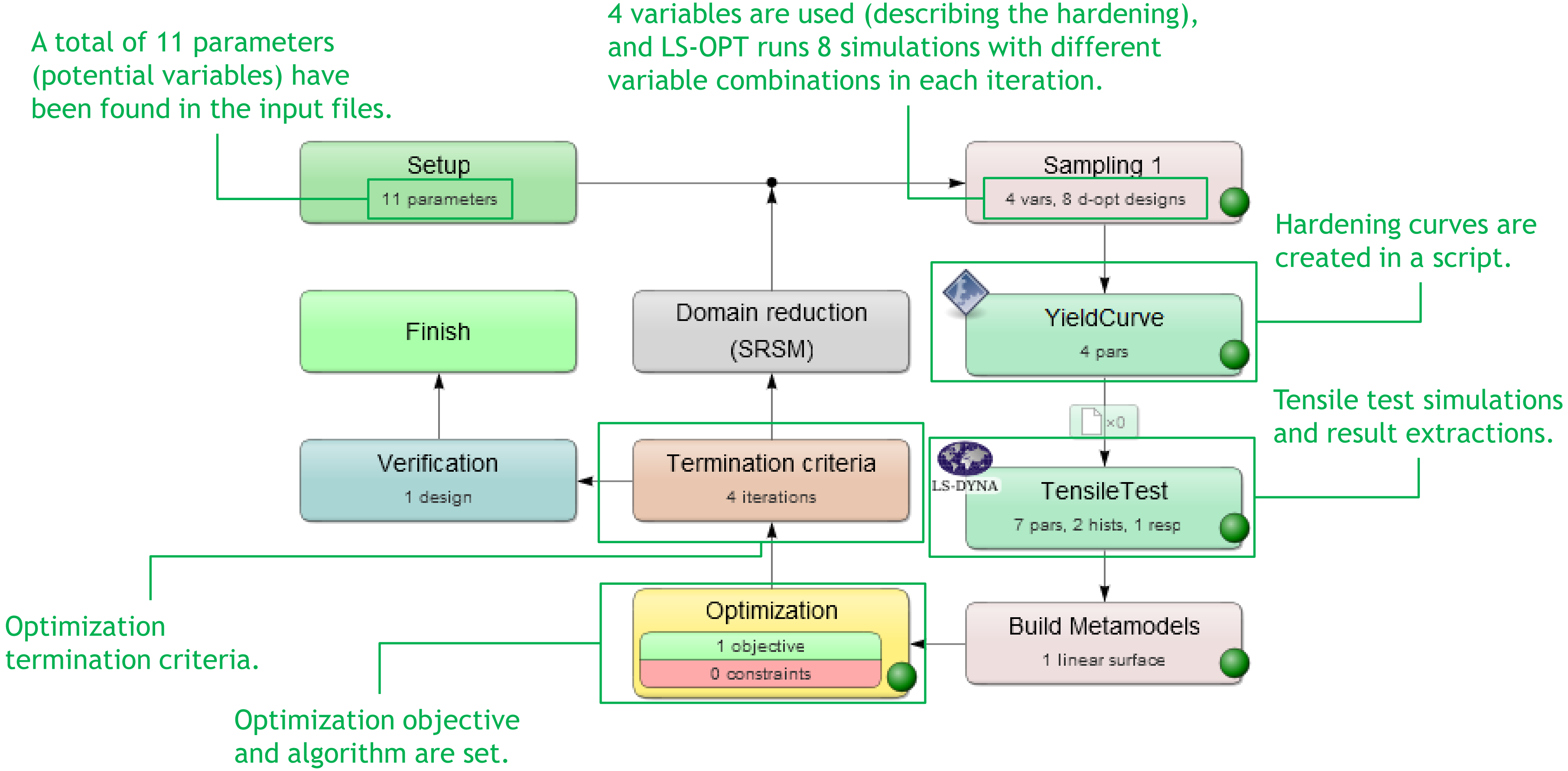


- Modified Hocket-Sherby hardening
  - FFC example in tutorial package, www.lsoptsupport.com/documents/tutorials/ls-opt
  - Python script that generates a hardening curve (4 variables).
  - $f(\varepsilon_p) = D + B\left(1 - e^{-C\varepsilon_p^N}\right)$
  - Free to download and modify.



Set-up of FFC in LS-OPT

Step-by-step video of set-up in LS-OPT. https://youtu.be/mOWoqcKtTt4



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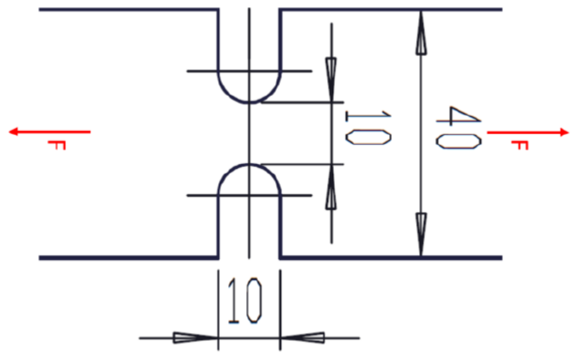
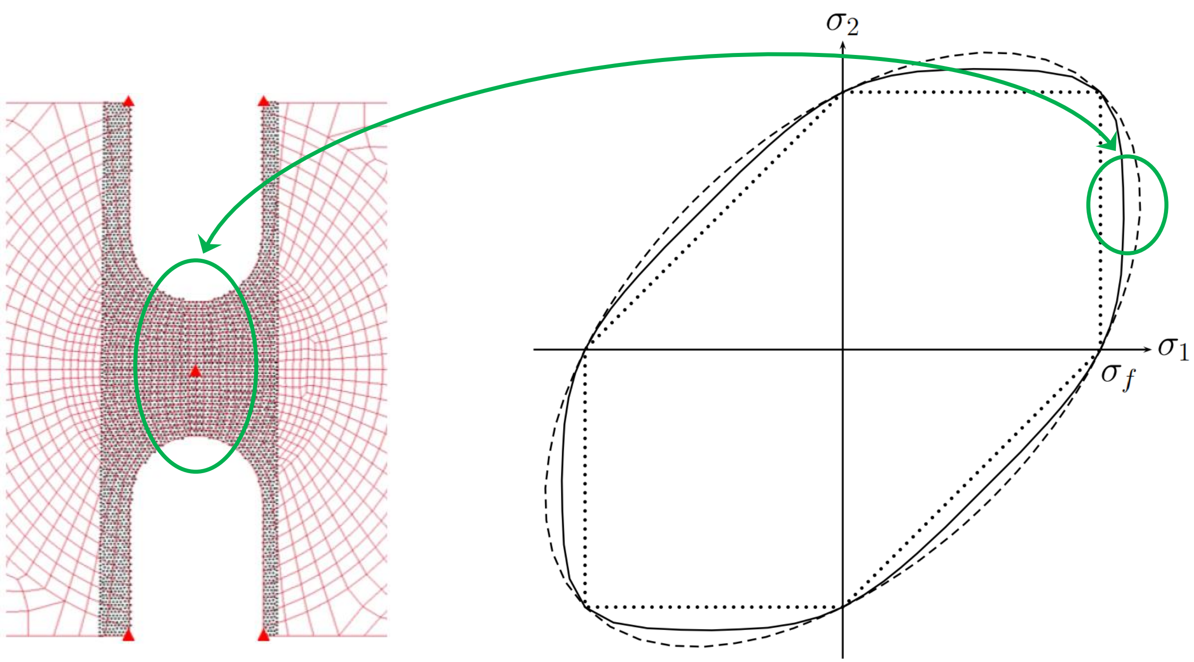
Example of other sample geometries

- Holger Hippke et al., *A full-field optimization approach for iterative definition of yielding for non-quadratic and free shape yield models in plane strain*, IOP Conf. Ser.: Mater. Sci. Eng. 967 012084, 2020.





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Further reading

- Parameter identification: Step-by-step video of set-up in LS-OPT. https://youtu.be/mOWoqcKtTt4
- FFC: Step-by-step video of set-up in LS-OPT. https://www.youtube.com/watch?v=hQJ9rM3blXU

- Nielen Stander et al., *Application of Digital Image Correlation to Material Parameter Identification using LS-OPT®*, 11th European LS-DYNA Conference 2017, Salzburg, May 9-11, 2017.
- Christian Ilg et al., *Application of a Full-Field Calibration Concept for Parameter Identification of HS-Steel with LS-OPT®*, 15th International LS-DYNA® Users Conference, Detroit, June 10-12, 2018.
- Katarina Witowski et al., *Modified Dynamic Time Warping for Utilizing Partial Curve Data to Calibrate Material Models*, 16th International LS-DYNA® Users Conference, Virtual Event, June 10-11, 2020.
- Holger Hippke et al., *A full-field optimization approach for iterative definition of yielding for non-quadratic and free shape yield models in plane strain*, IOP Conf. Ser.: Mater. Sci. Eng. 967 012084, 2020.

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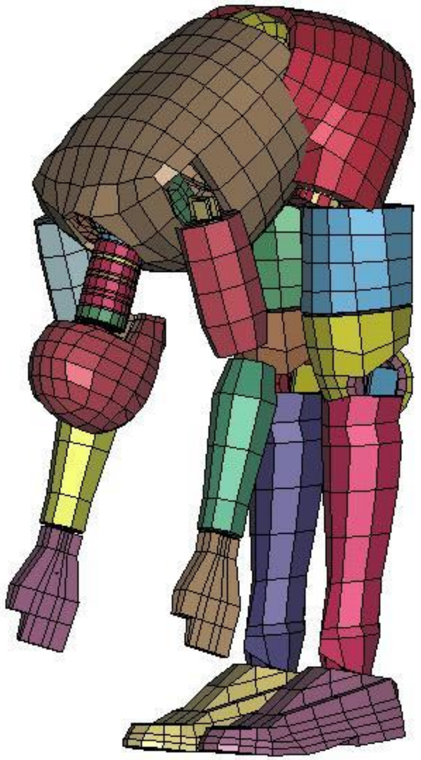

Thank you!

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Your LS-DYNA distributor and more

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