Statistics on Structures 3.1

New features exploring new fields of application

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optiSLang & SoS: What is the difference ?
Stochastics: Degree of statistical information

deterministic numbers (e.g. Euro Code, DIN)	characteristic values, safety factors	safety for a single design, usually conservative
random parameters optiSLang	statistical description of single parameters random distribution functions, correlation	probability of failure quantile values sensitivity analysis
random field quantities optiSLang with SoS	spatially varying statistical description correlation between various points in space	realistic description of spatially distributed scatter

Optimisation: Complexity of description of variations

scalar parameters optiSLang	response of single parameters	constraint and objective functions sensitivity analysis meta models
signals optiSLang with SoS	temporally varying response correlation between various points in time	hot spots as constraint and objective functions sensitivity analysis meta models
field quantities optiSLang with SoS	spatially varying response correlation between various points in 3D space	hot spots as constraint and objective functions sensitivity analysis meta models

Random fields:
Typical quantities being random fields

- geometric perturbations
  - node coordinates
  - shell thickness
  - thickness of composite layers
- material properties
  - concrete: mortar, admixtures (gravel)
  - ceramics: porosity
  - contact friction
- damage
  - plastic strain, cracks
- loading
- state variables
  - stresses, strains
  - displacements

Software abilities for RDO (selection)

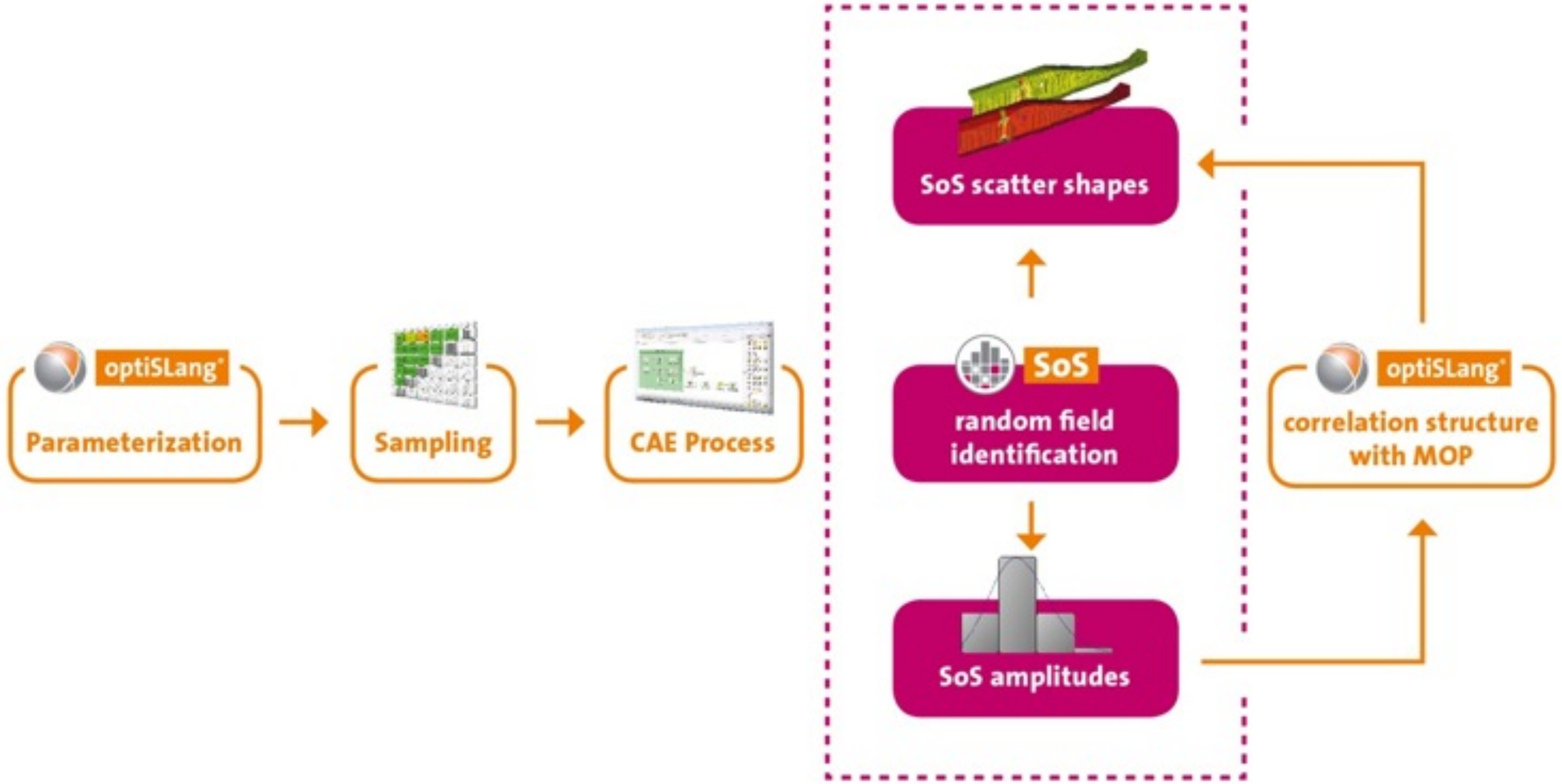
Robustness evaluation		
Generation of random samples	scalar	3D field
Compute robustness measures	scalar	3D field
Hot spot detection	no	3D field
Sensitivity analysis	scalar	3D field
Optimization		
Hot spot detection	no	3D field
Sensitivity analysis	scalar	3D field
Optimization on meta model (replace CAE process)	scalar	3D field

Typical application:
Robustness evaluation at hot spots

- Statistics on Structures:
  - Identify “hot spots”, i.e. potential failure locations
    - locations with large mean,
    - large variation or
    - extremal quantile values, etc.
- optiSLang:
  - Robustness evaluation at hot spots
  - Spatially local sensitivity analysis at hot spots to find responsible input parameters

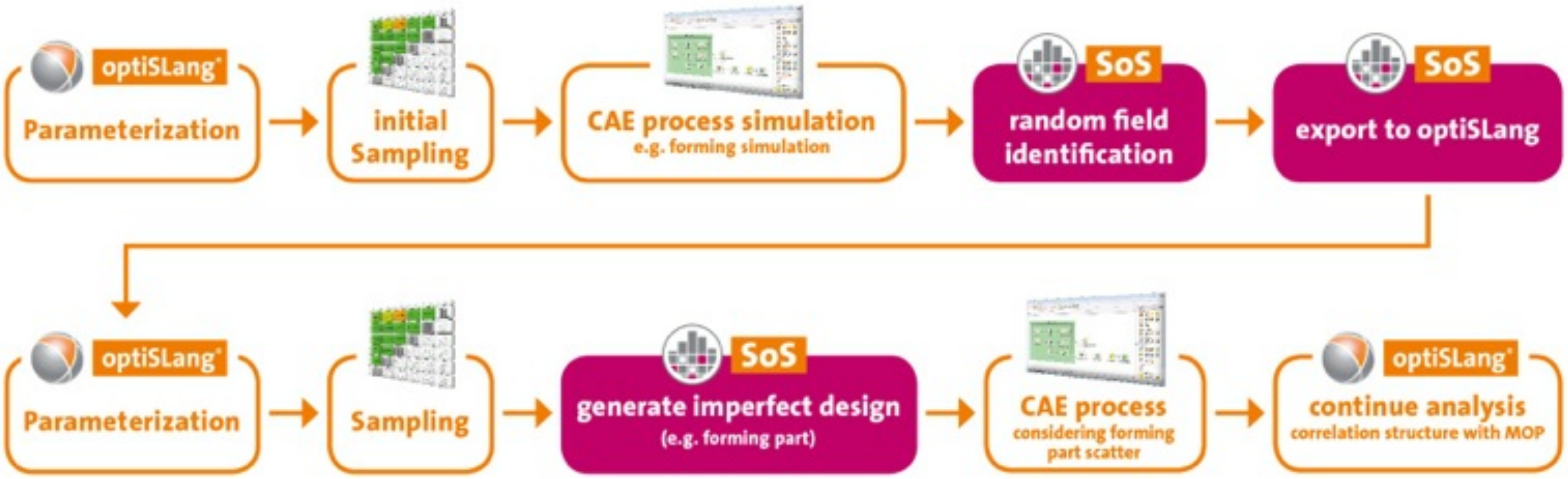
Typical application: Spatially global sensitivity analysis

- Random field decomposition:
  - Analyse sensitivity of amplitudes, visualise location of sensitivities through scatter shapes



Typical application: Generate random field samples

- Statistical estimation of random field model
- Consecutive CAE processes
  1. Forming step 1: Deep drawing
  2. Forming step 2
  3. ...



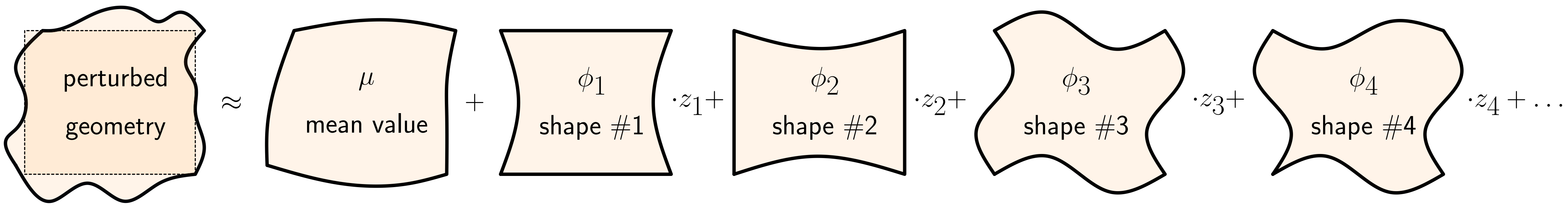
New Features

- **SoS 3.0**
  - new GUI
  - faster empirical random field model creation
  - no mesh coarsening
- **SoS 3.1 (December 2014)**
  - F-MOP (Field Meta model of Optimal Prognosis)
  - Extended finite element type library and visualisation
  - Non-matching meshes
  - Improved integration with optiSLang

Field Meta model of Optimal Prognosis (F-MOP)

F-MOP
Base: Random field model

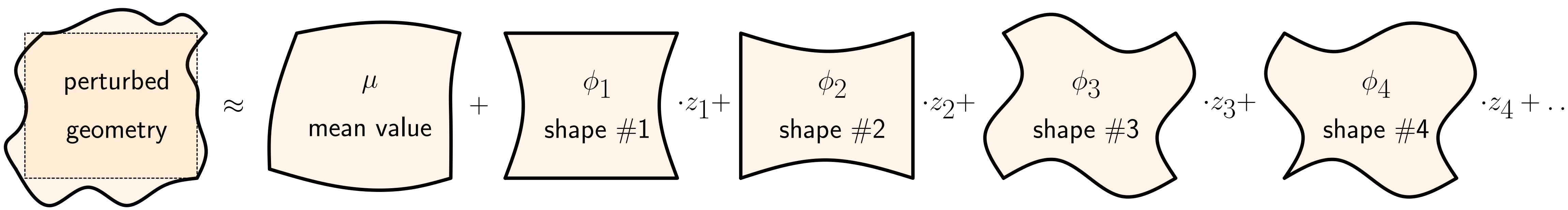
- Series expansion using deterministic "scatter shapes" and a small set of random numbers ("amplitudes")



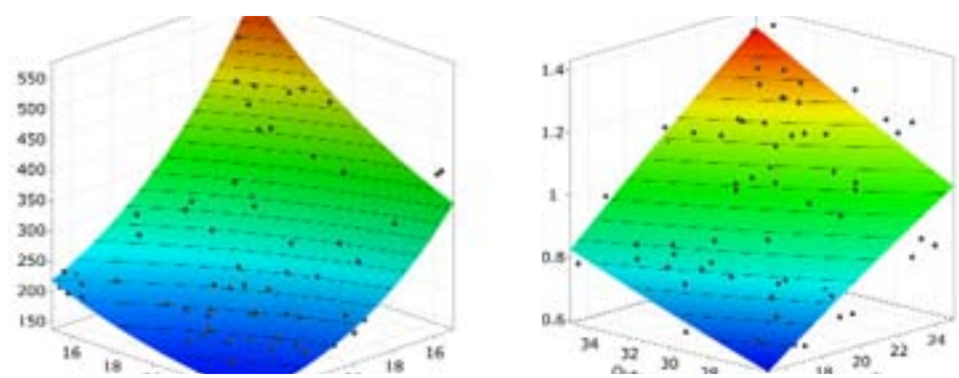
- optiSLang: simulation and analysis of amplitudes
- SoS: (de)composition of random fields from amplitudes and scatter shapes

F-MOP
Extension: Field meta model ("F-" = "Field-")

- 1st layer: Represent spatial variations of **field responses** in terms of scalar parameters



- 2nd layer: Represent these parameters in terms of the **inputs** by MOP



- Black box model (F-MOP):

Inputs → **F-MOP** → **Response field**

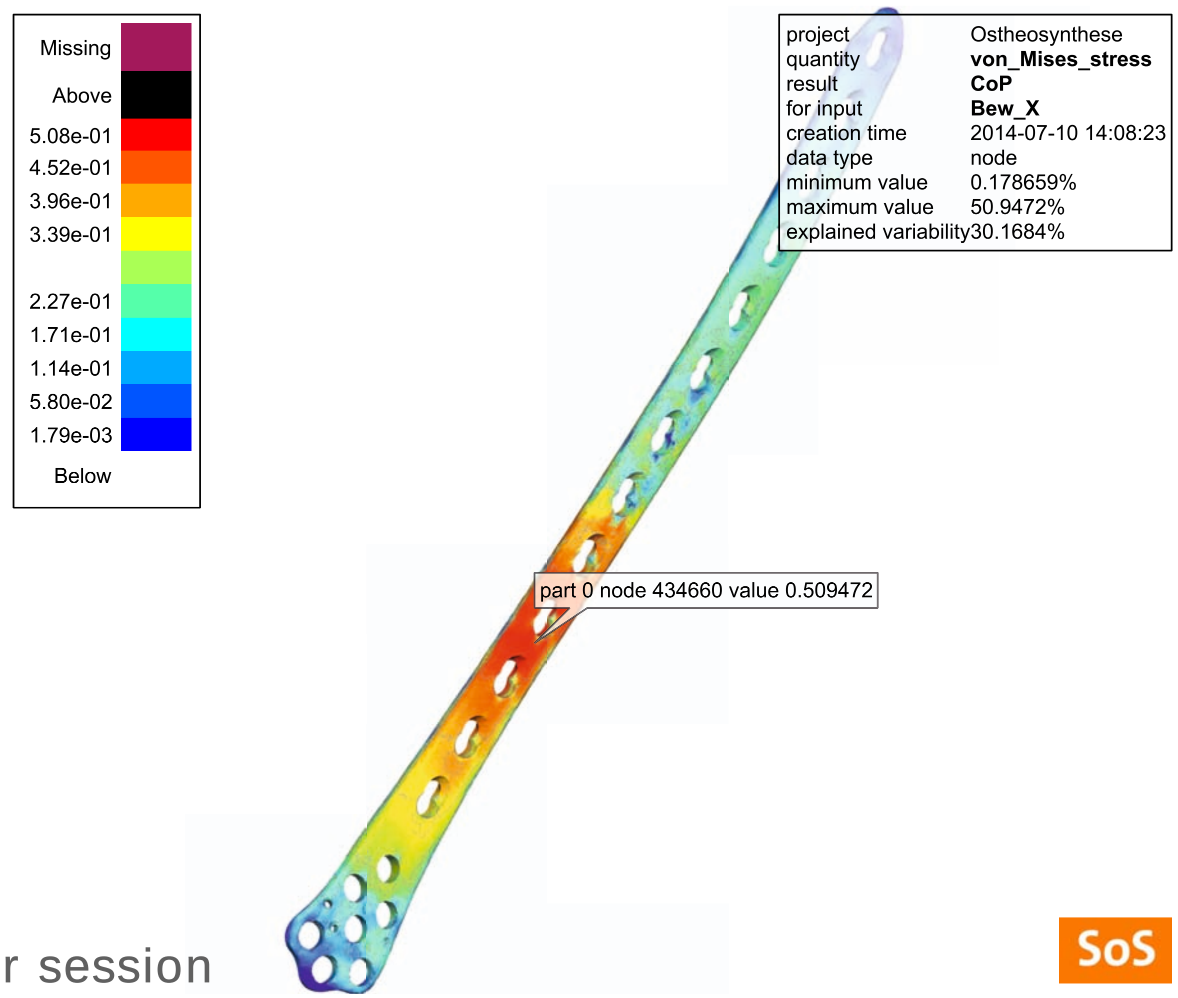
F-MOP: Spatially global sensitivity analysis
Field CoP

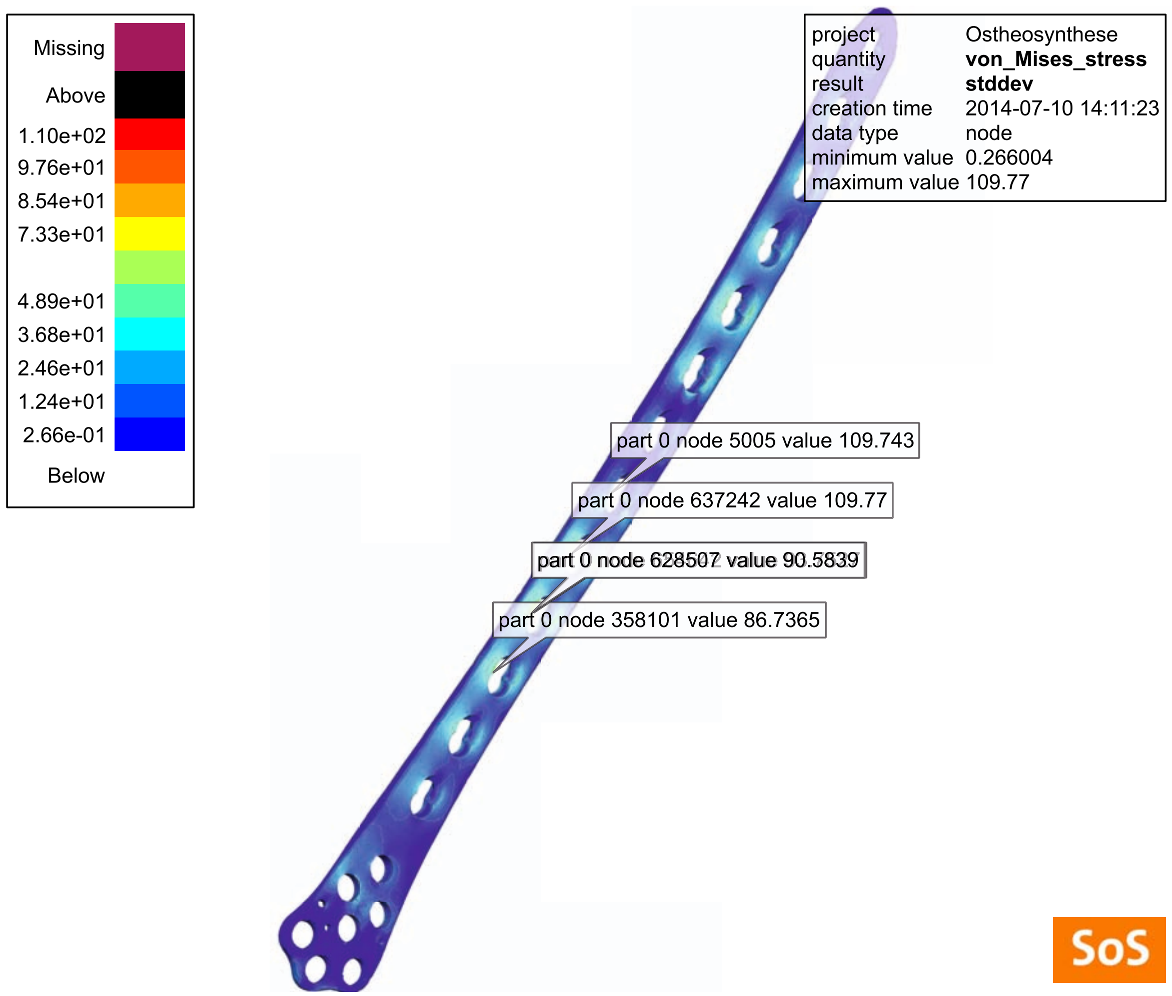
- Field Coefficient of Optimal Prognosis (F-CoP):
  - A global F-CoP value: integral value of the CoP for the entire field
  - F-CoP plot: CoP at the respective position
- F-CoP of whole model:
  - Explainable variation at specific position
- F-CoP for individual input parameters:
  - Explainable variation at specific position through respective parameter

- **Identifies and orders important input parameters**
- **Simplifies presentation and interpretation !**

F-MOP: Example
F-CoP of stress field in a biomedical simulation

- ANSYS Workbench, tetra10 elements, incompatible meshes
- Varying position of maxima of von Mises stress
- Most important input parameter: Bew_X, global F-CoP = 30% (0 … 51%)





See poster session

New finite element type library and visualisation

Finite element types

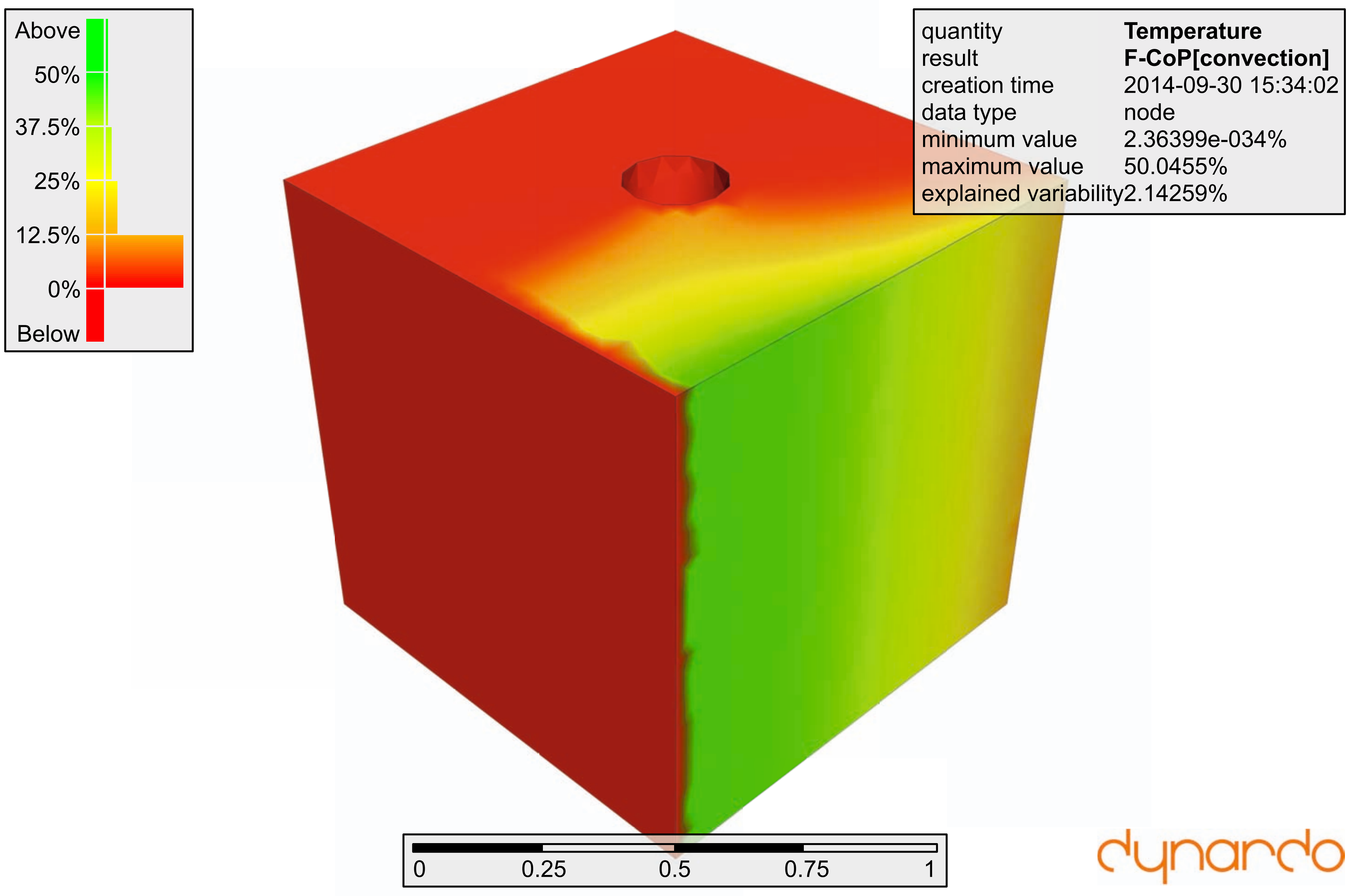
- Old: Shell elements (target application: metal forming)
- **New: 3D Continuum elements**

- FEM element types:

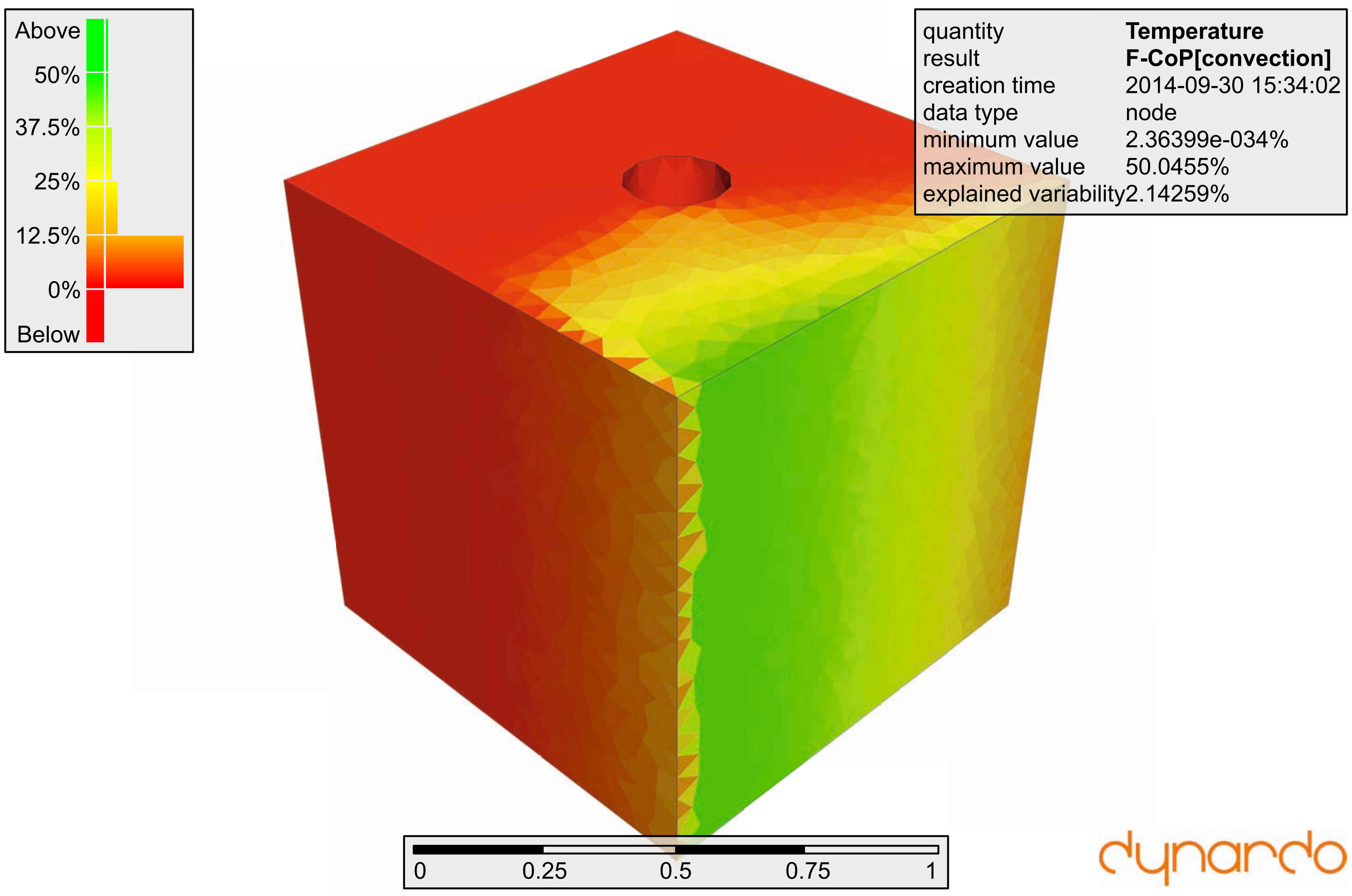
triangular shells	3n, 6n
quadrilateral shells	4n, 8n
tetrahedra	4n, 10n
pentahedra	6n, 15n
hexahedra	8n, 20n

- Further mesh types: 1d grid (signals), 2d grid (pictures), 3d grid (voxel data)

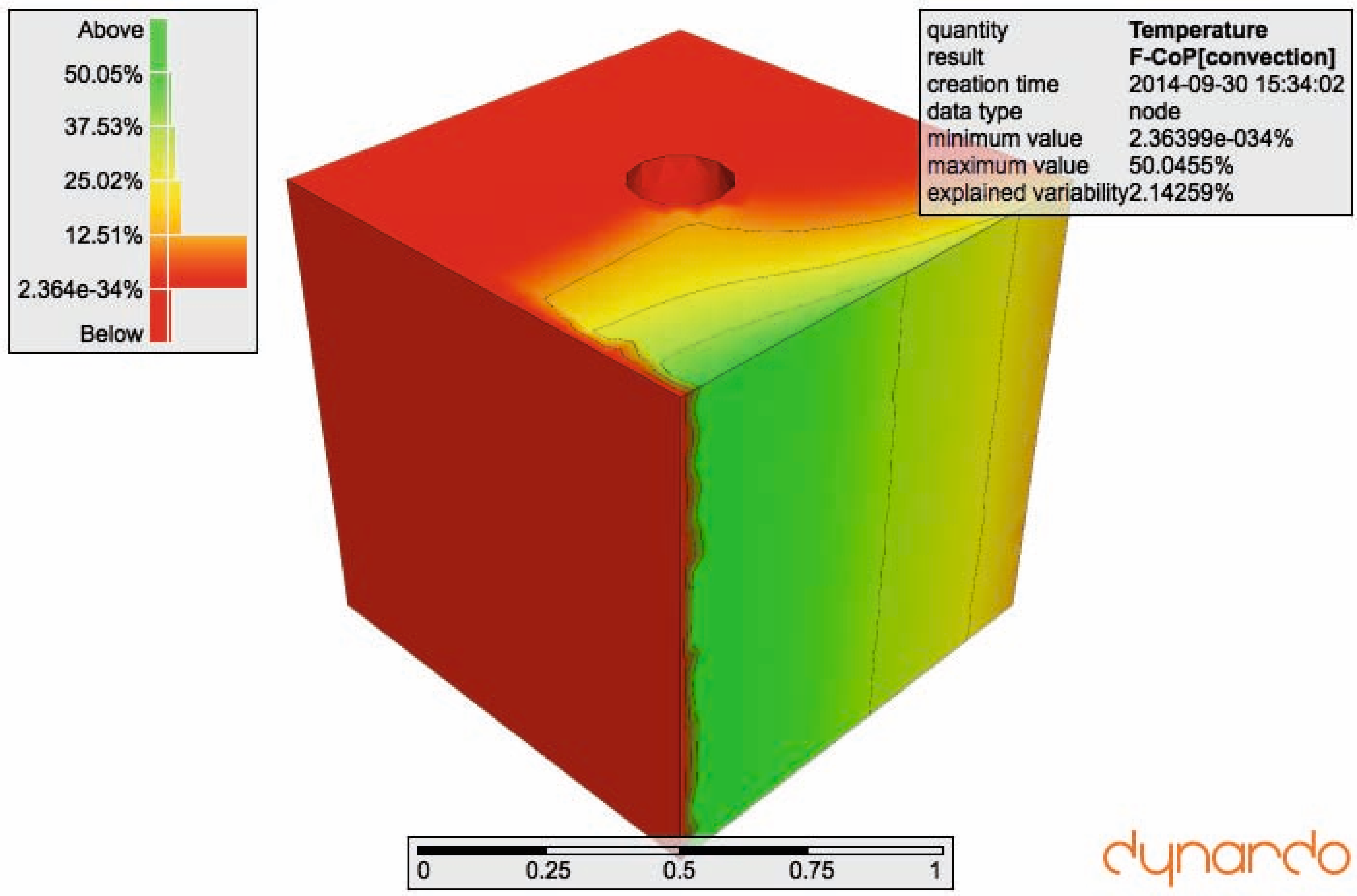
Visualisation of continuum elements
Example: Smooth data interpolation



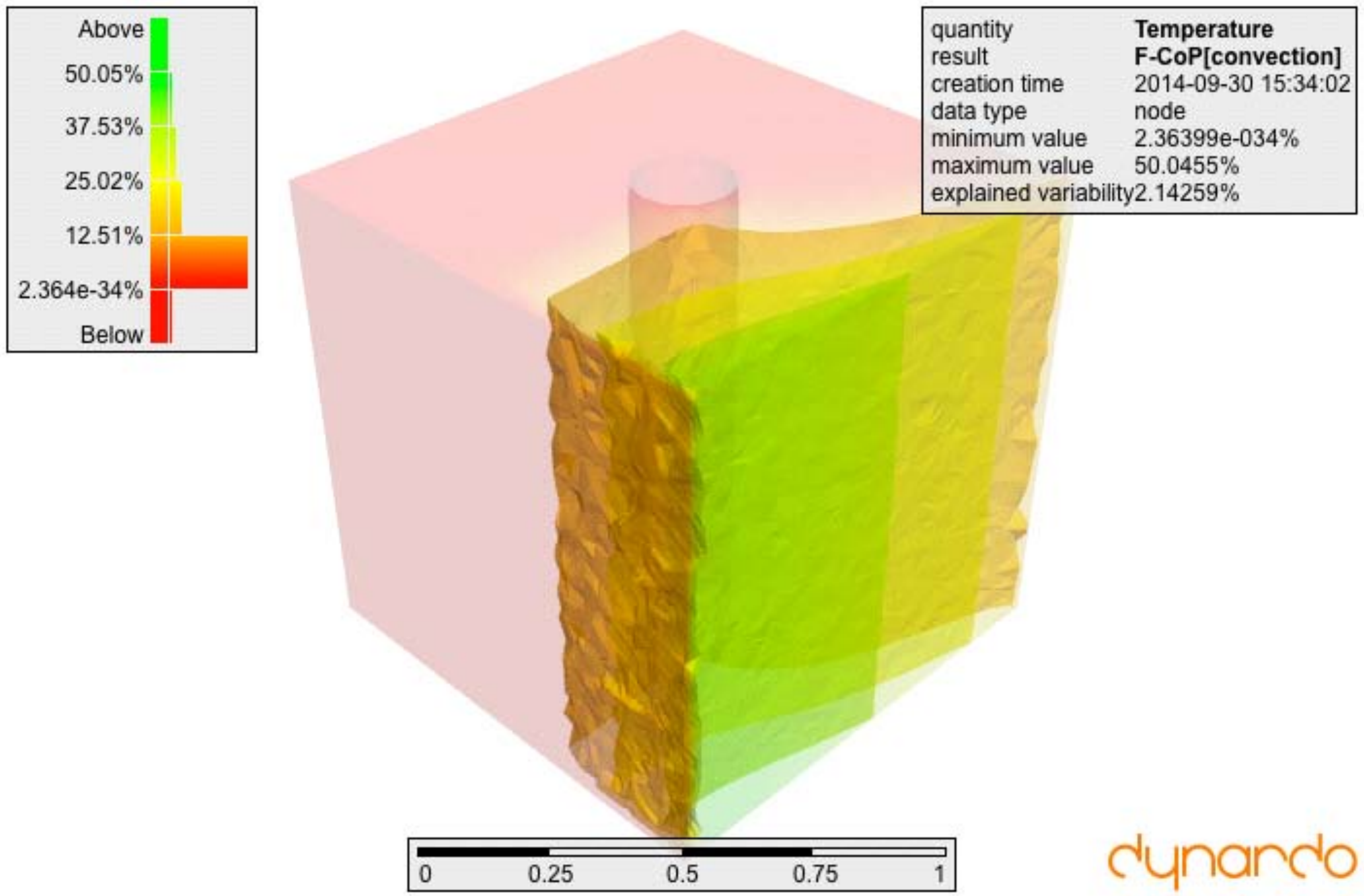
Visualisation of continuum elements
Example: Element wise coloring



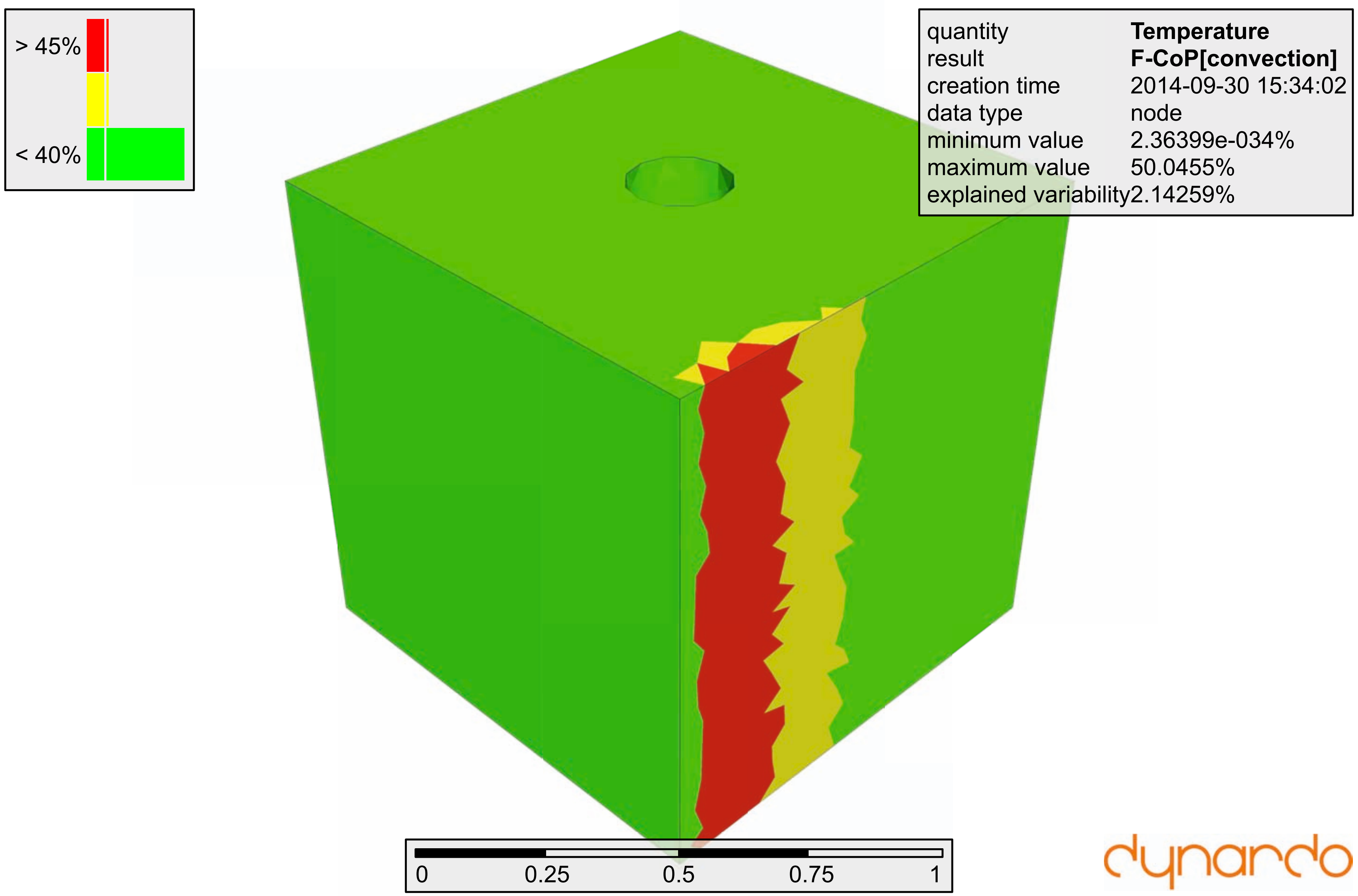
Visualisation of continuum elements
Example: Isolines



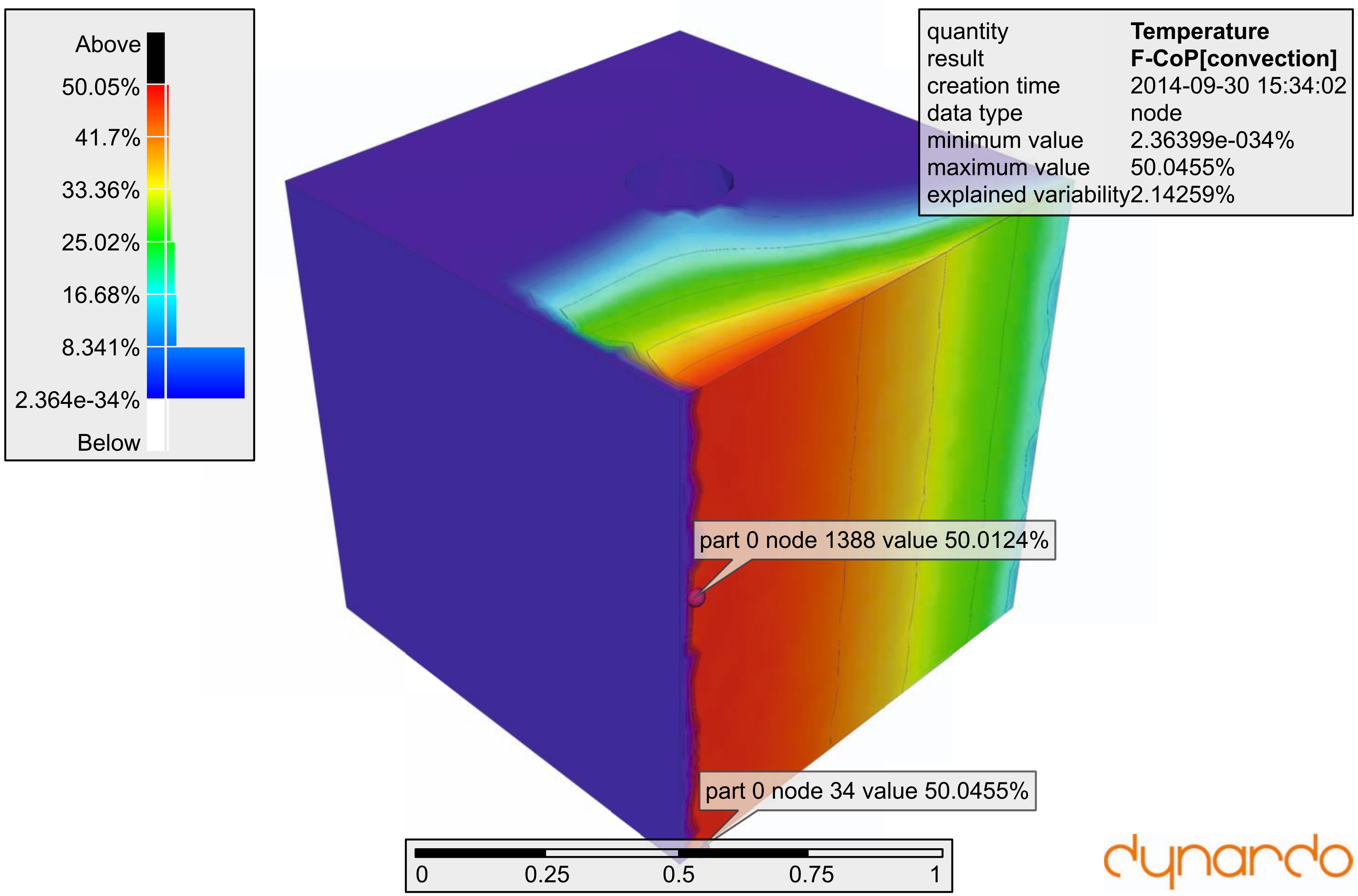
Visualisation of continuum elements
Example: Isosurfaces and transparency



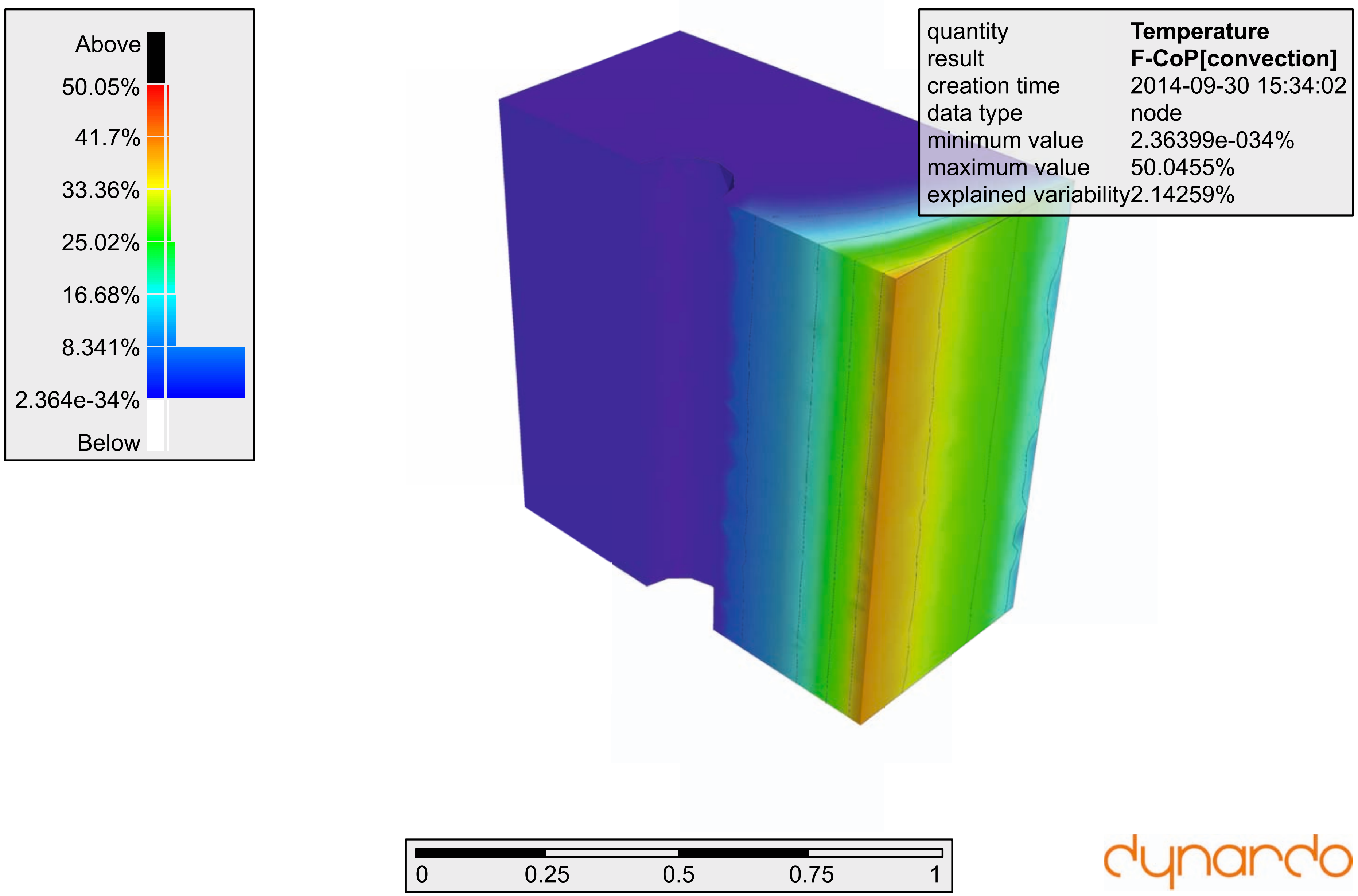
Visualisation of continuum elements
Example: Highlight critical areas



Visualisation of continuum elements
Example: Identify maxima



Visualisation of continuum elements
Example: Cutting plane

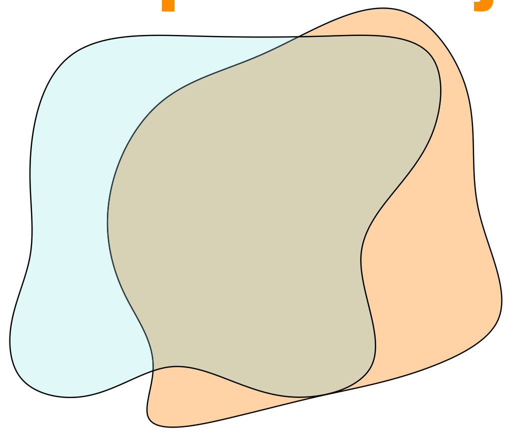


Mapping of data among non-matching meshes

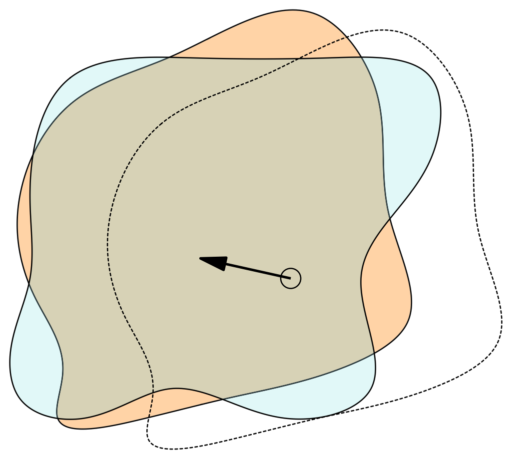
Incompatible meshes
Why ?

- SoS needs a unique mesh that serves as reference to store and compute statistical data (Important: mesh topology, i.e. node and element numbers)
- Design meshes may differ from reference mesh topology due to:
  - Eroded elements: Erase elements (and nodes) during analysis
  - Varying position of production sheets (robustness DoE)
  - Varying position of reference mesh (e.g. from CAD) and design meshes (e.g. measurements)
  - Variations in geometry -> remeshing
  - Adaptive mesh refinement (and coarsening)
- **Observed effects:**
  - different coordinate systems
  - slightly deformed
  - non-matching meshes

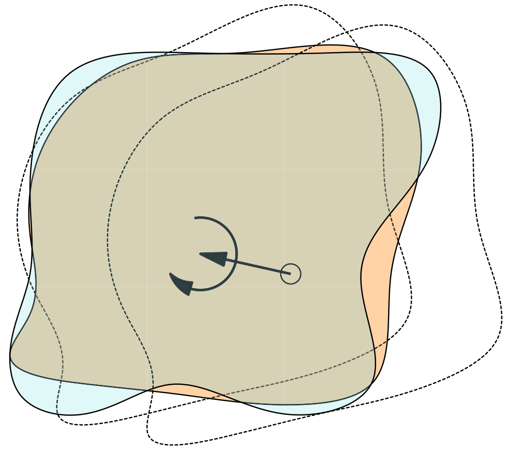
Incompatible meshes
Step 1: Adjust coordinate system for each design



no correction



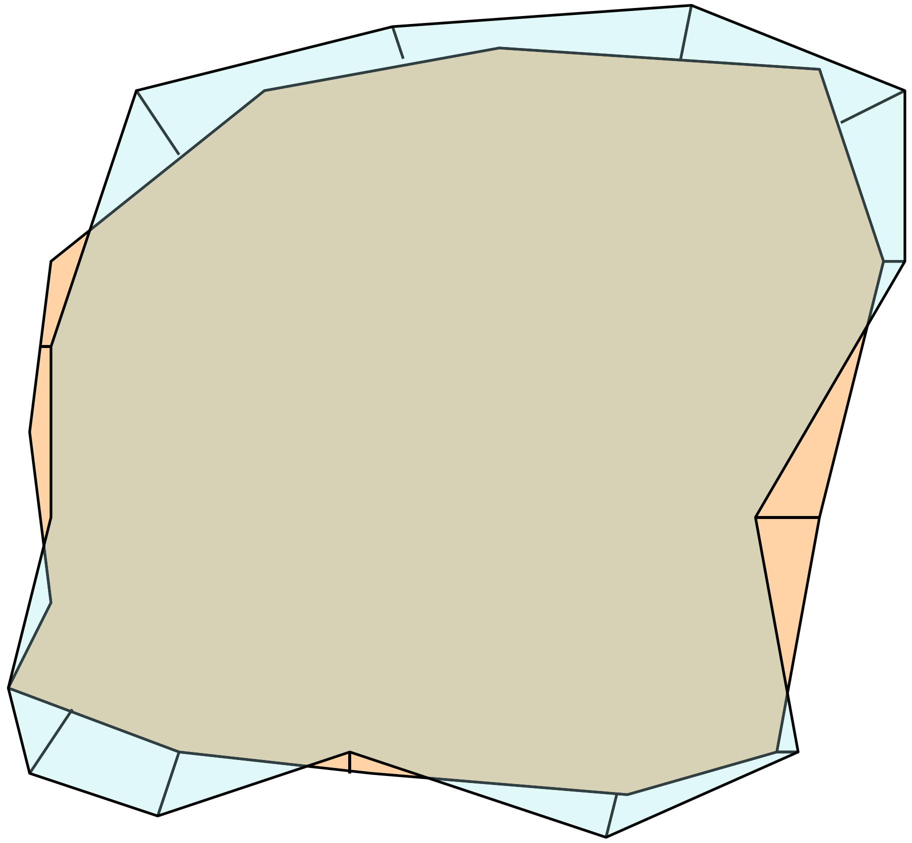
Translate
design mesh to position of reference mesh



Translate and rotate
design mesh to position of reference mesh

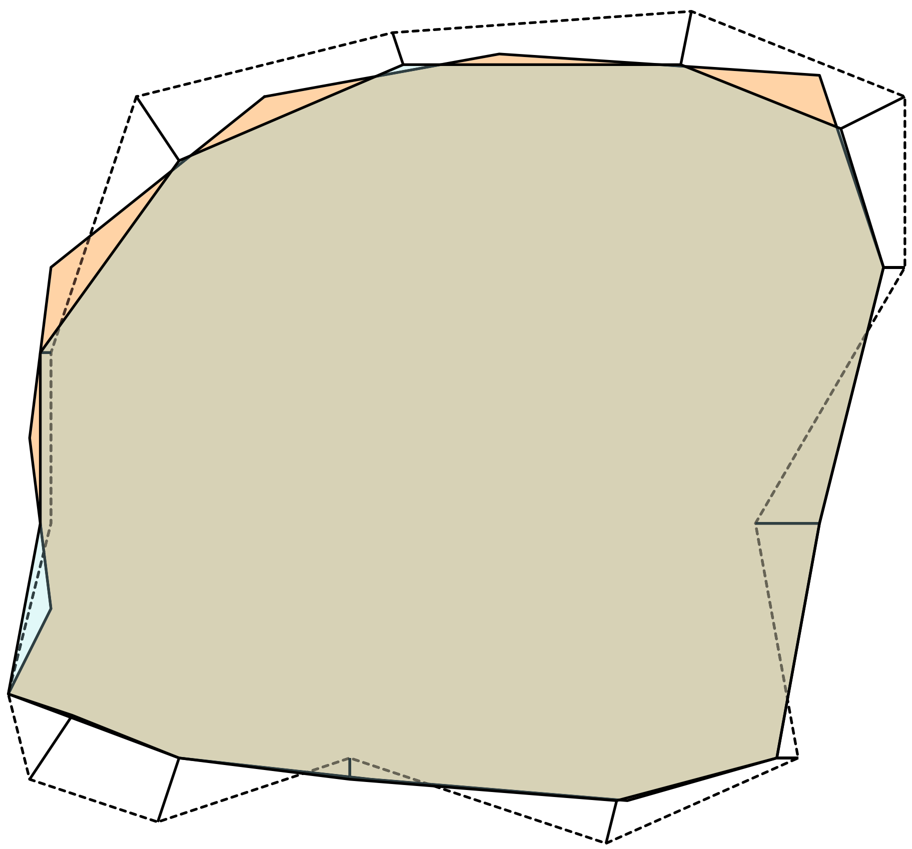
Incompatible meshes
Step 2: Find closest point projection

- Project boundary points of the reference mesh onto the boundary of the design mesh



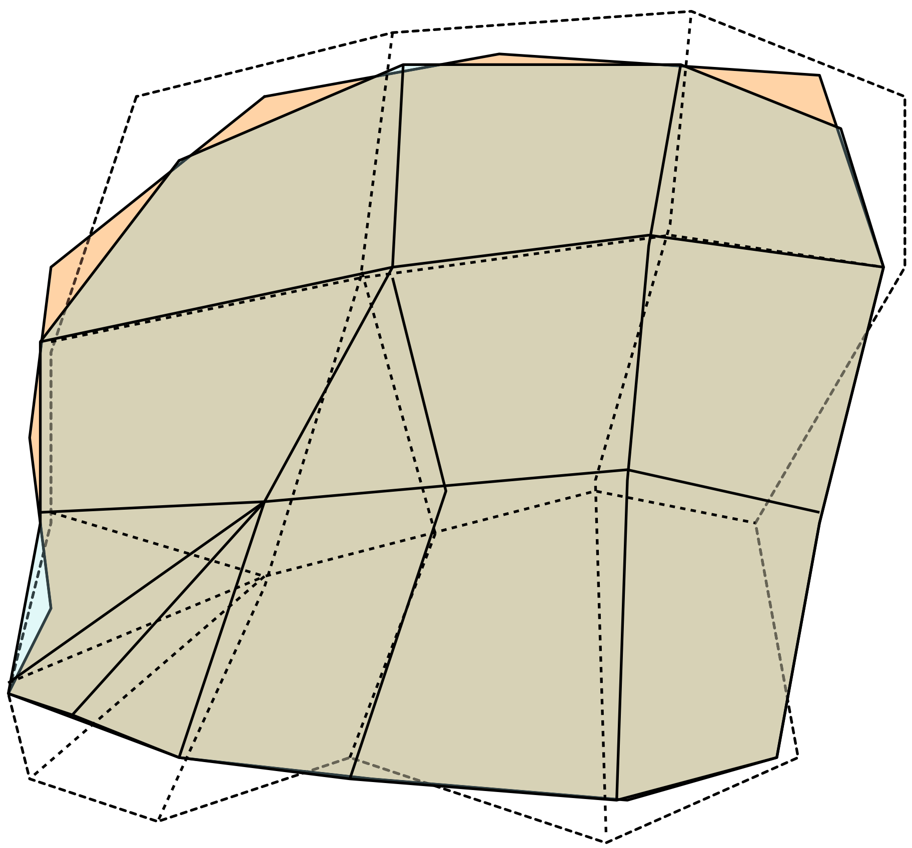
Incompatible meshes
Step 3: Deformed reference mesh

- Objective: Represent the geometry of the design mesh using the reference mesh topology
- Create a deformed boundary of the reference mesh



Incompatible meshes
Step 4: Adjust interior nodes

- Apply displacements to the interior nodes of the reference mesh in order to represent the changed shape of boundary

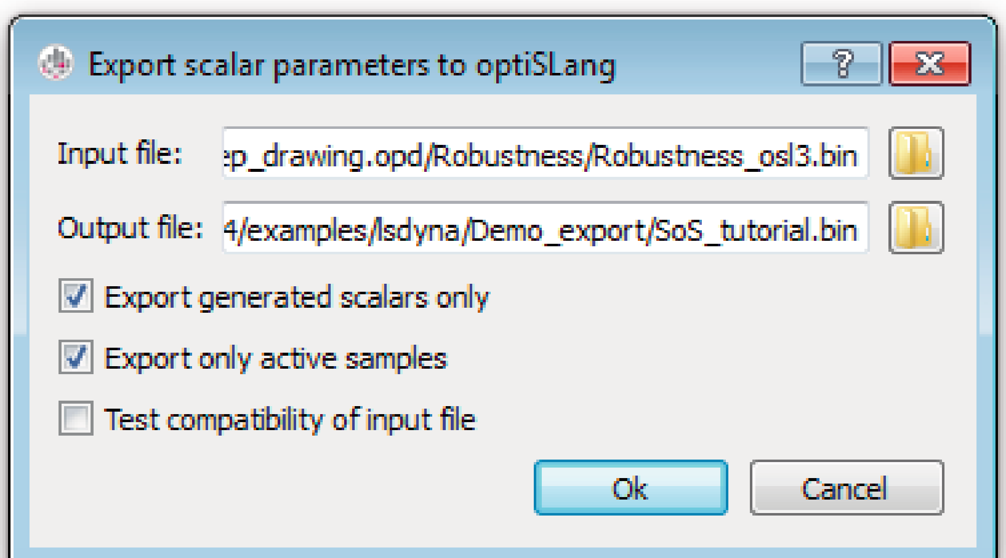


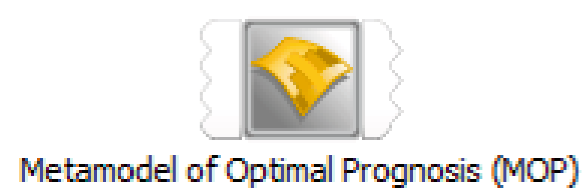
Step 5: Map data between both meshes (coor deviations, strain, stress)

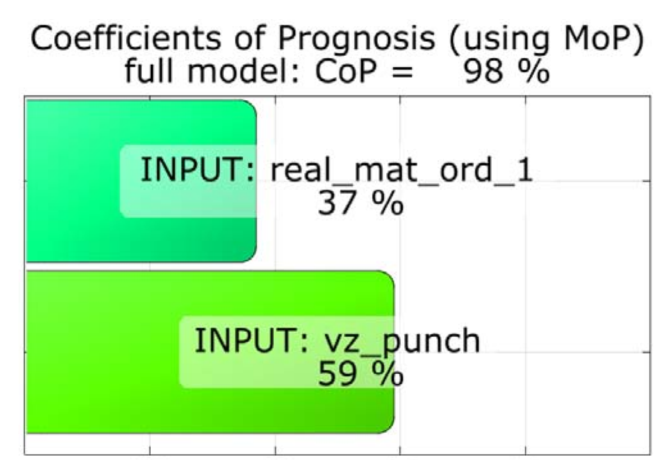
Integration of SoS and optiSLang

Integration SoS & optiSLang
Support for optiSLang Bin files

- Import samples of input parameters (scalars and vectors) as scalar quantities into SoS
- Export samples of amplitudes and of hot spots as responses to optiSLang
- Direct use of exported bin files for use in MOP (sensitivity analysis at hot spots)



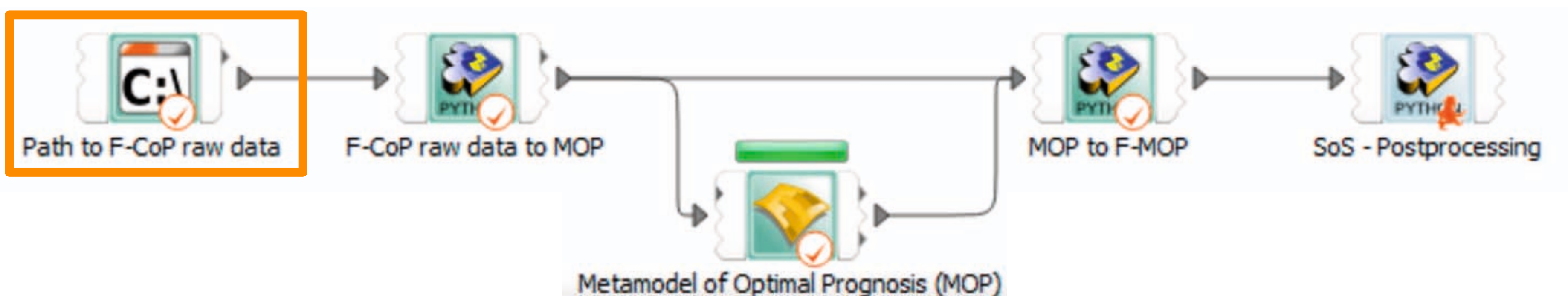


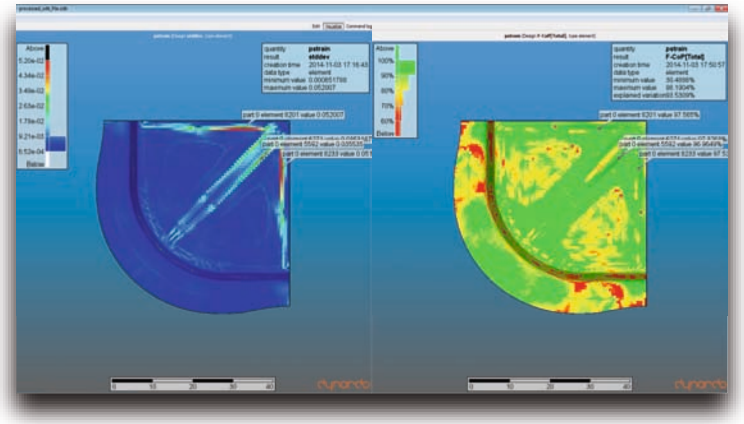


Integration SoS & optiSLang F-MOP

- SoS: Export data in pre-defined format for F-MOP
- optiSLang example project
  - Create F-MOP
  - Open SoS post processing

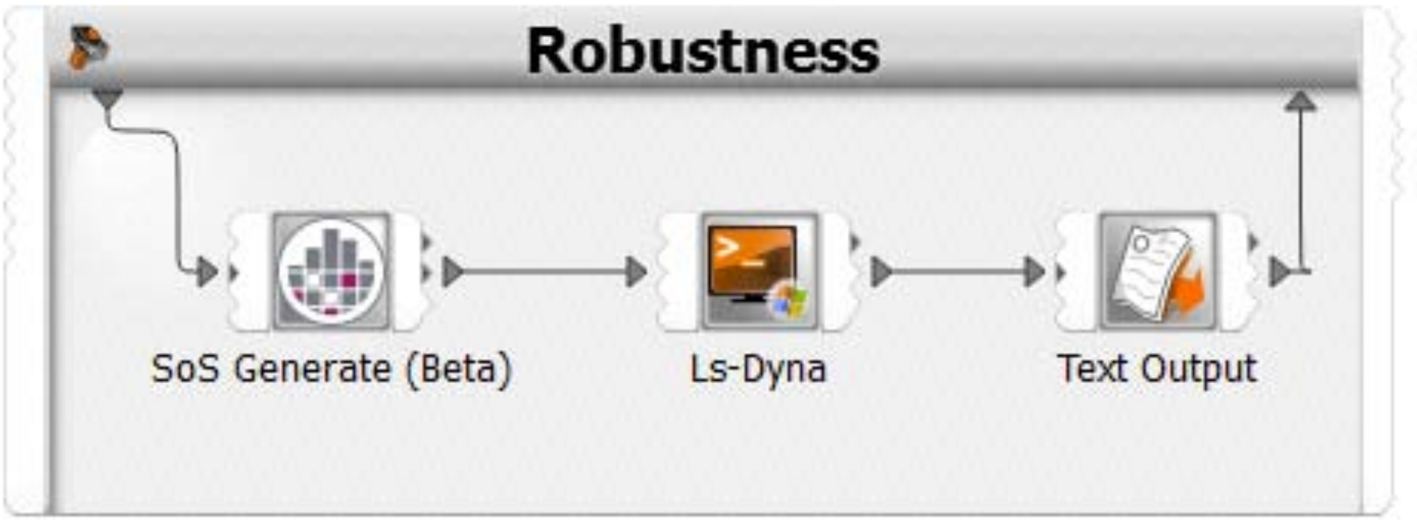
	pstrain
F-CoP[Total]	93.5309 %
F-CoP[blank_thickness_1]	9.04117 %
F-CoP[real_mat_abs_1]	2.42726 %
F-CoP[real_mat_ord_1]	23.2564 %
F-CoP[rho]	1.55072 %
F-CoP[vz_punch]	55.2845 %
F-CoP[yield_stress]	1.22439 %





Integration SoS & optiSLang
Generate random field samples

- SoS: Export data in pre-defined format for random field simulation
- optiSLang Beta modules: “SoS Generate”
  - Defines random field parameters and sets statistical properties
  - Copies for each design CAE input files to design directory
  - Calls SoS in batch mode: modify the copied files



Summary

- **SoS should be used if**
  - position of maxima/minima is changing
  - spatially distributed effects are to be considered
- SoS can be applied to a **wide range of applications** within the fields of robustness analysis and optimisation
- **SoS extends optiSLang by**
  - Hot spot detection
  - Spatially local sensitivity analysis
  - Spatially global sensitivity analysis
  - Generation of random field samples
- Visualisation is the simplest way to **provide confidence** in statistical results

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Further questions and support:

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