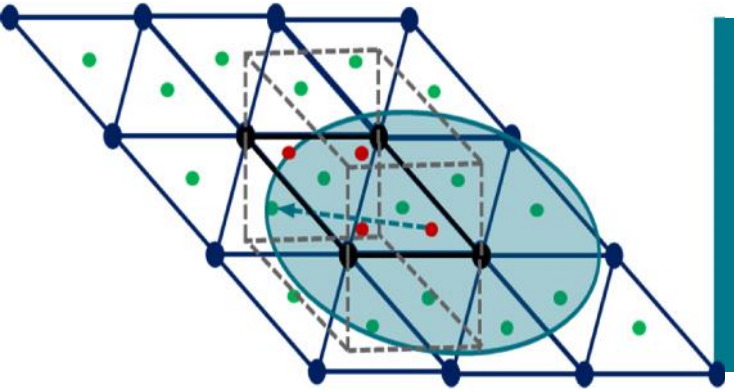
Nordic LS-DYNA User‘s Conference 2018



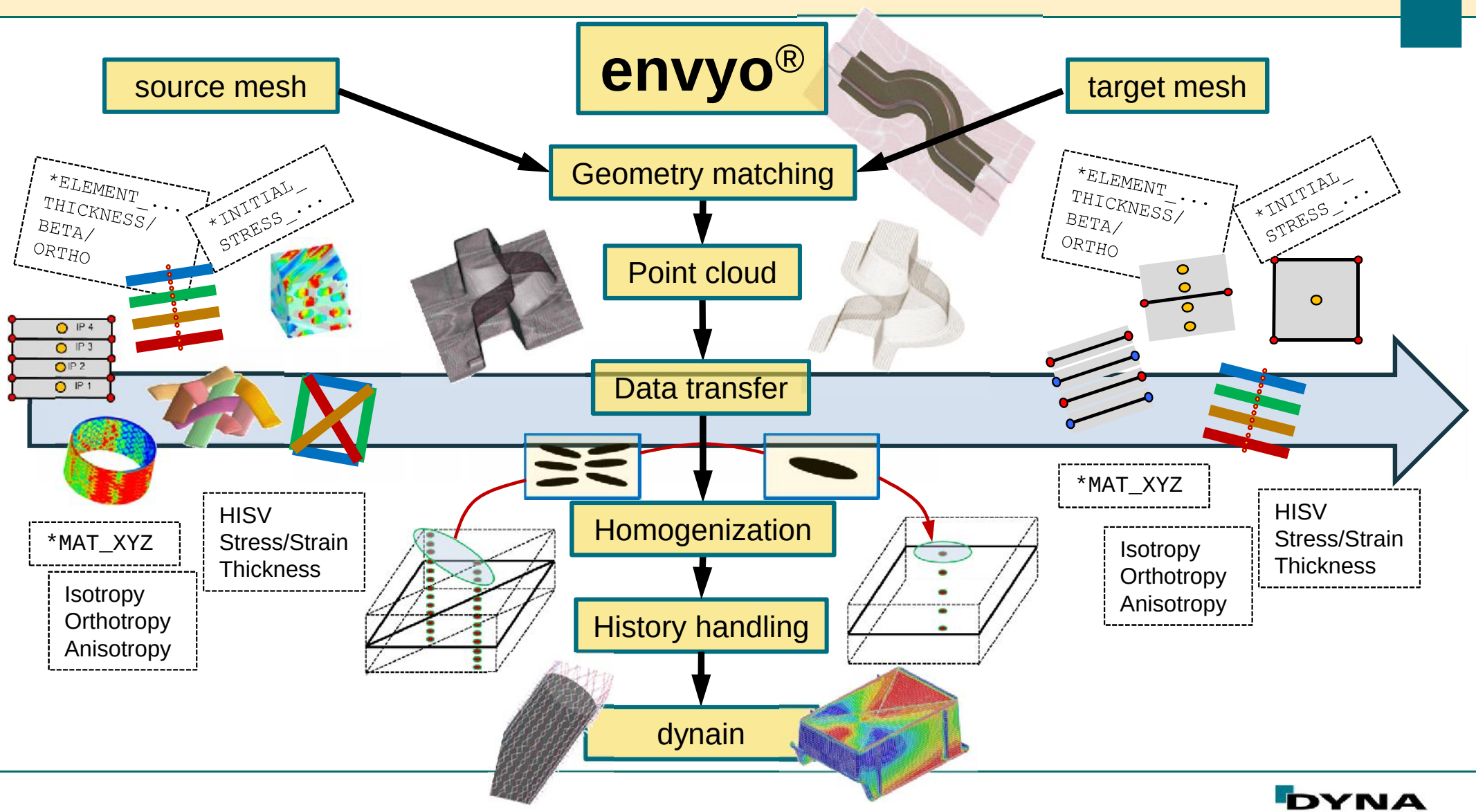
Coupling Process2Structural Analysis with envyo®

C. Liebold

10/2018 – Gothenburg, SWE

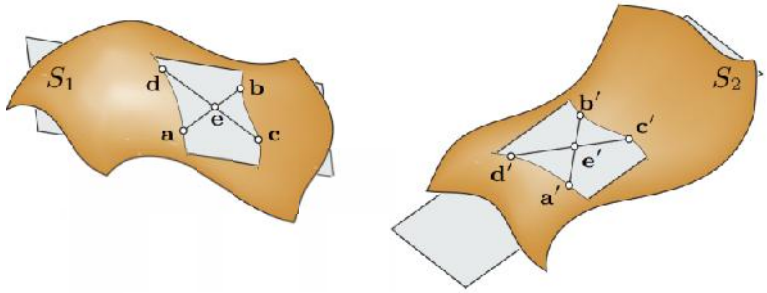
Agenda

- envyo® - requirements for mapping tool development
- Use cases
- Future Plans & Summary
- Questions & Answers


envyo®
source mesh
target mesh
Geometry matching
Point cloud
Data transfer
Homogenization
History handling
dynain
*ELEMENT_... THICKNESS/ BETA/ ORTHO
*INITIAL_ STRESS_...
IP 4
IP 3
IP 2
IP 1
*MAT_XYZ
Isotropy
Orthotropy
Anisotropy
HISV
Stress/Strain
Thickness
*ELEMENT_... THICKNESS/ BETA/ ORTHO
*INITIAL_ STRESS_...
*MAT_XYZ
Isotropy
Orthotropy
Anisotropy
HISV
Stress/Strain
Thickness

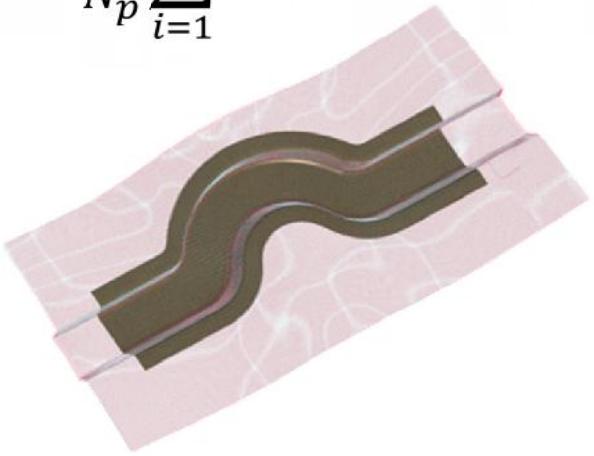
Geometry matching

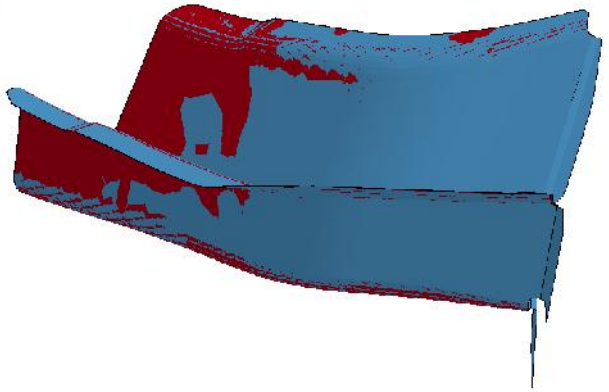
- Two automatic matching algorithms implemented:
  - 4-Point Congruent Sets [1]
  - Iterative Closest Point [2]



$$f(\vec{q}) = \frac{1}{N_p}\sum_{i=1}^{N_p} \|\overrightarrow{x_i} - R(\vec{q}_R)\vec{p}_i - \vec{q}_T\|$$

- Mesh operations:
  - Scaling
  - Rotation
  - Transformation



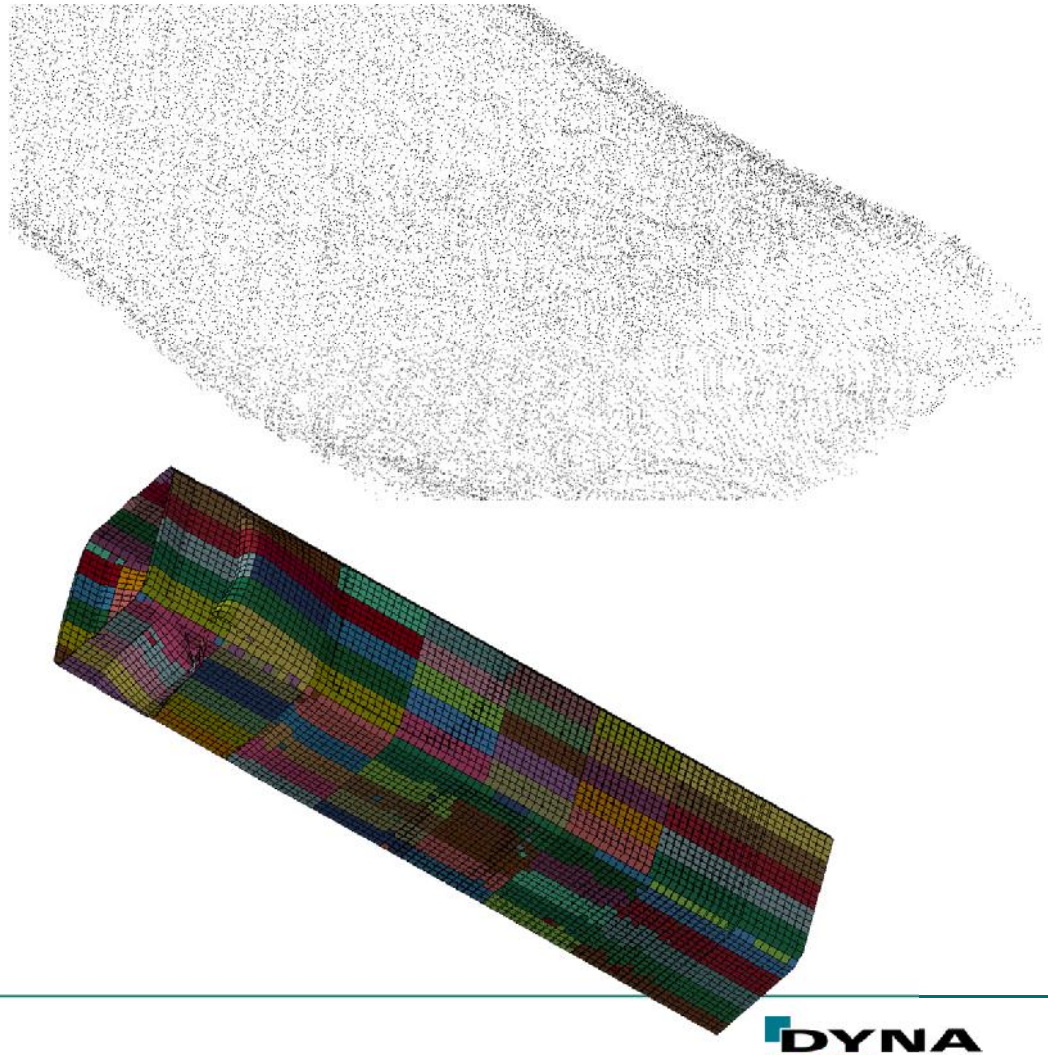


- Unit system conversion

[1] Aiger, D., Mitra, N., Cohen-Or, D.; 4-Point Congruent Sets for Robust Pairwise Surface Registration, ACM Transactions on Graphics 27 (3), 1-10.
[2] Besl, P., McKay, N..: A Method for Registration of 3-D Shapes, IEEE Transactions on Pattern analysis and Machine Inteligence, Vol. 14, No. 2, Feb. 1992.

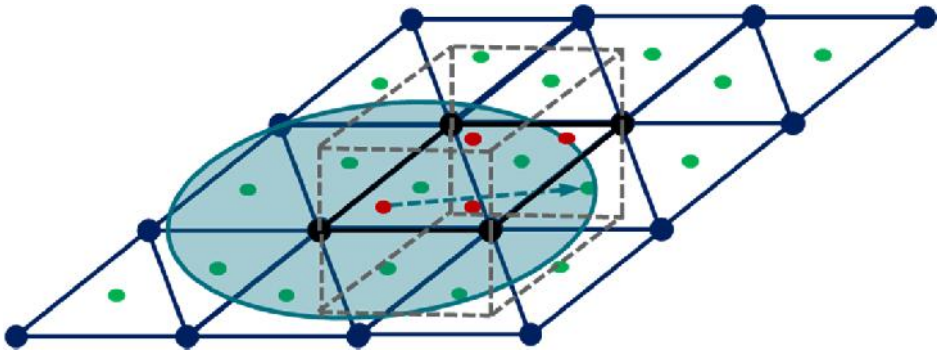
Point Cloud generation

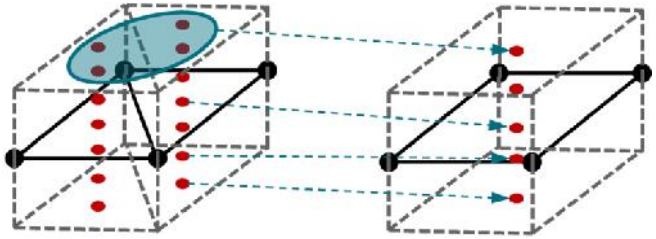
- Mapping based on point clouds
  - Element based (beam, (t)shell- and solid elements)
  - Integration point based (under- and fully integrated elements)
  - Node based
- Bucket sort algorithm for significant mapping speed-up



Data transfer

- Mapping based on a closest point search
- Investigations made for scalar value averaging and interpolation
- Investigations made for tensorial data averaging and interpolation
- **Maximum user control**





[3]

[3] Gahm, J.: Microstructural Feature-based Processing and Analysis of Diffusion Tensor MRI, PhD – thesis, University of California, Los Angeles, CA, USA, 2014.

Mapping of scalar values

- Shepard‘s function [4]:

$$f_4(P) = \begin{cases} \sum_{D_i \in C'} w_i \, (z_i + \Delta z_i) \Big/ \sum_{D_i \in C'} w_i & \text{if } d_i \neq 0 \text{ for all } D_i \\ z_i & \text{if } d_i = 0 \text{ for some } D_i \end{cases}$$

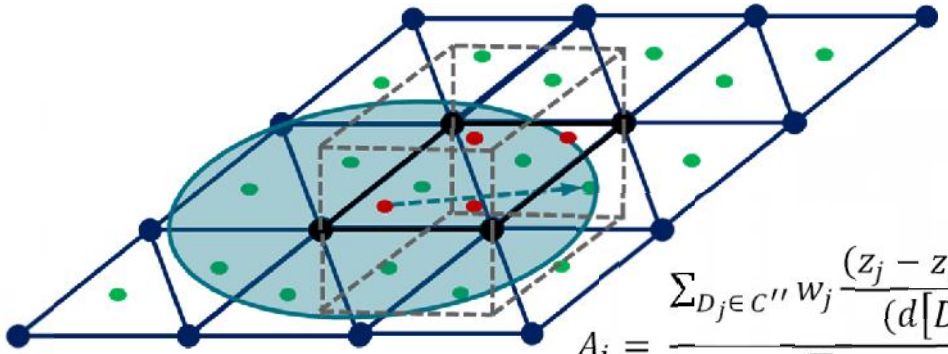
with:

$$\Delta z_i = [A_i(x - x_i) + B_i(y - y_i)]\left[\frac{\vartheta}{\vartheta + d_i}\right]$$

$$w_i = (s_i)^2 \, (1 + t_i)$$

$$s_i(d_i) = \begin{cases} \frac{1}{d_i} & \text{if } 0 < d_i \leq \frac{r'}{3} \\ \frac{27}{4\,r'}\left(\frac{d_i}{r} - 1\right)^2 & \text{if } \frac{r'}{3} < d_i \leq r' \\ 0 & \text{if } r' < d_i \end{cases}$$

$$t_i = \sum_{D_j \in C'} s_j [1 - \cos(D_i P D_j)] \Big/ \sum_{D_j \in C'} s_j$$



$$A_i = \frac{\sum_{D_j \in C''} w_j \frac{(z_j - z_i)(x_j - x_i)}{(d[D_j, D_i])^2}}{\sum_{D_j \in C''} w_j}$$

$$B_i = \frac{\sum_{D_j \in C''} w_j \frac{(z_j - z_i)(y_j - y_i)}{(d[D_j, D_i])^2}}{\sum_{D_j \in C''} w_j}$$

$$\vartheta = \frac{0.1 \, [\max(z_i) - \min[\![(z_i)]\!]]}{\left[\max\{A_i^2 + B_i^2\}\right]^{\frac{1}{2}}}$$

[4] Shepard, D.: A two-dimensional interpolation function for irregularly-spaced data, Proceedings, ACM National Conference, USA, 1968.

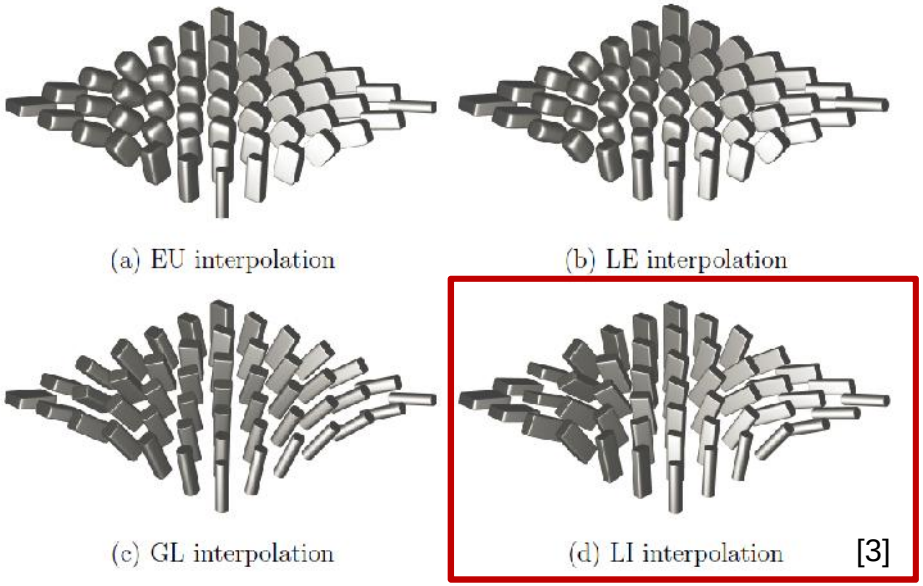
Mapping of tensorial values

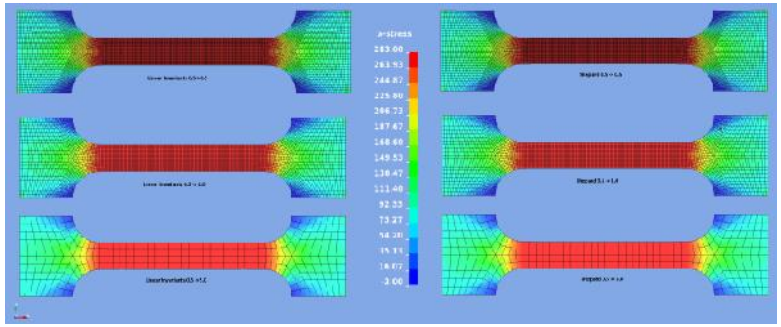
- Target is to conserve both, tensor shape and direction

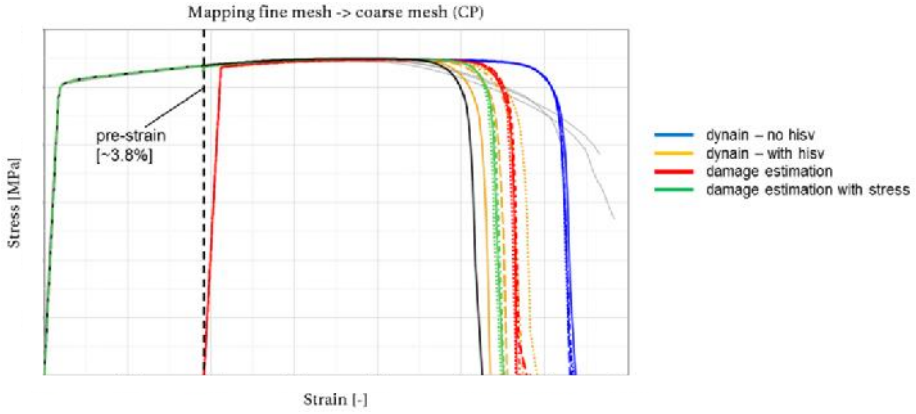
$$J(C_{LI}) = (1-t)J_j(A) + tJ_j(B)$$

$$C_{EU} = (1-t)A + tB$$

$$C_{LI} = R_{EU}\Lambda_{LI}R_{EU}^{T}$$







[3] Gahm, J.: Microstructural Feature-based Processing and Analysis of Diffusion Tensor MRI, PhD – thesis, University of California, Los Angeles, CA, USA, 2014.

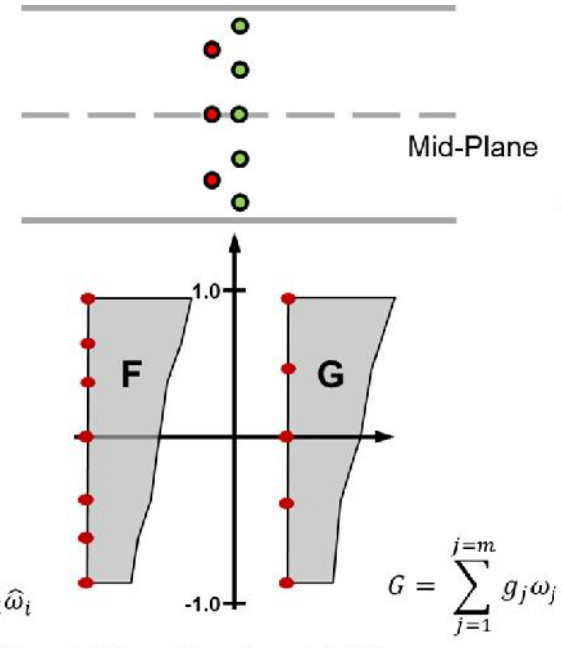
Through thickness interpolation

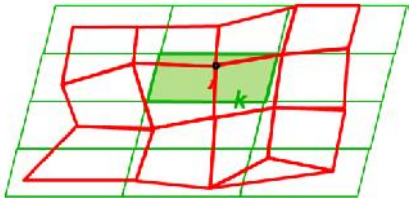
- Conservation of energy [4]:

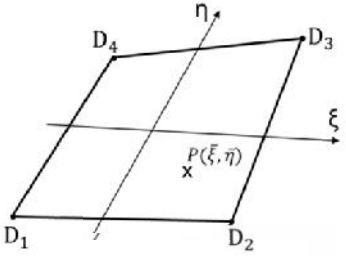
$$G = \sum_{j=1}^{j=m} g_j \omega_j = F = \boldsymbol{\omega}^{\boldsymbol{T}} \boldsymbol{g}$$

$$\frac{\partial Q}{\partial g_j} = g_j + \sum_{\substack{k=1 \\ k \neq \alpha}}^{k=m} g_k \frac{\omega_k \omega_j}{{\omega_\alpha}^2} - c_j = 0$$

with $c_j = \dot{g}_j + F \frac{\omega_j}{{\omega_\alpha}^2} - \frac{\omega_j}{\omega_\alpha} \dot{g}_\alpha$







$$F = \sum_{i=1}^{i=N_{IP}} f_i \hat{\omega}_i \qquad G = \sum_{j=1}^{j=m} g_j \omega_j$$

N_{IP} - number of through-thickness integration points (IP)
f_i - values at each integration point (e.g. plast. strain)
$\hat{\omega}_i$ - weights, corresponding to quadrature rule

$$\boldsymbol{D_P} = \left[\sum_{i=1}^{n_{nodes}} N_i D_i \right]_{(\bar{\xi},\bar{\eta})}$$

[4] Wolf, K., Scholl, U., Post, P., Peetz, J.-V., D'Ottavio, M., Wallmersperger, T., Waedt, M., Kröplin, B.: *Verbesserung der Prognosefähigkeit der Crashsimulation aus höherfesten Mehrphasenstählen durch Berücksichtigung von Ergebnissen vorangestellter Umformsimulationen.* Forschungsreihe Automobiltechnik e.V., FAT Schriftenreihe 198, Frankfurt, Mai 2005.

Mapping approaches

Read FE Data and Do Bucket Sort

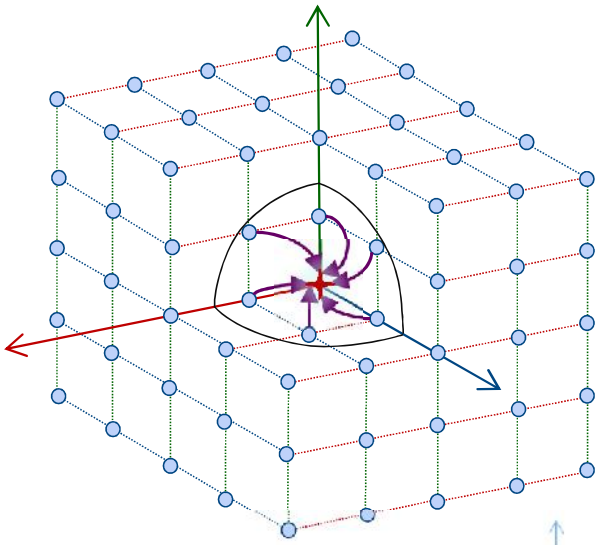
Search Through Elements and IPs

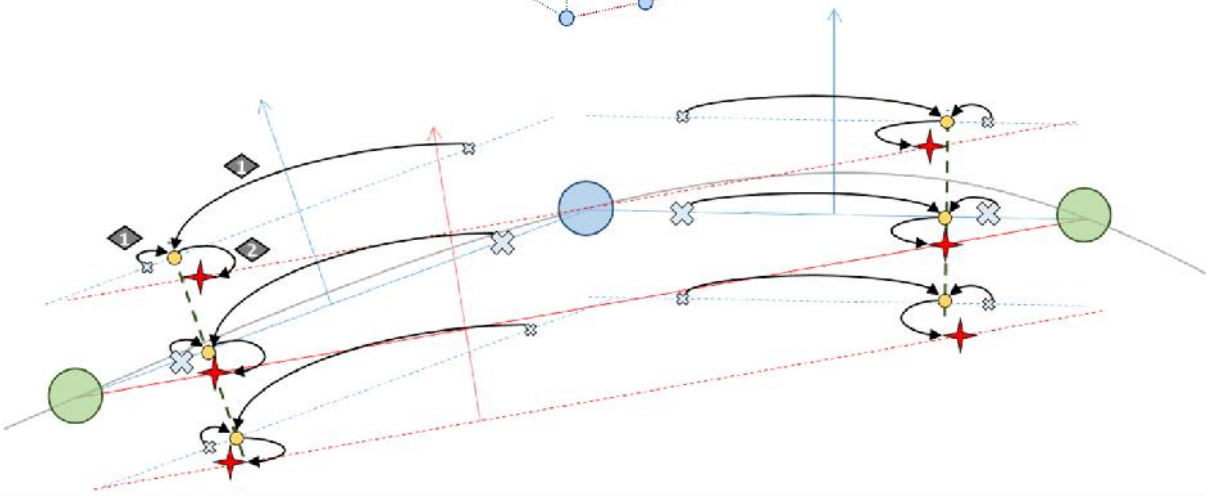
Do Mapping

Point Cloud Approach

FE Approach

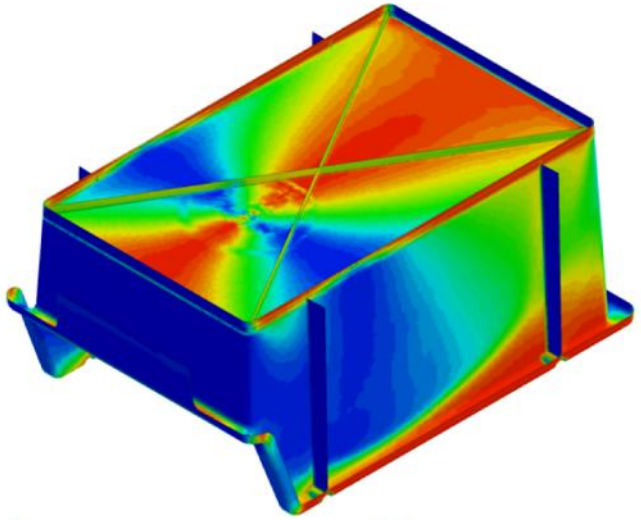
Write FE Data for Structural Analysis

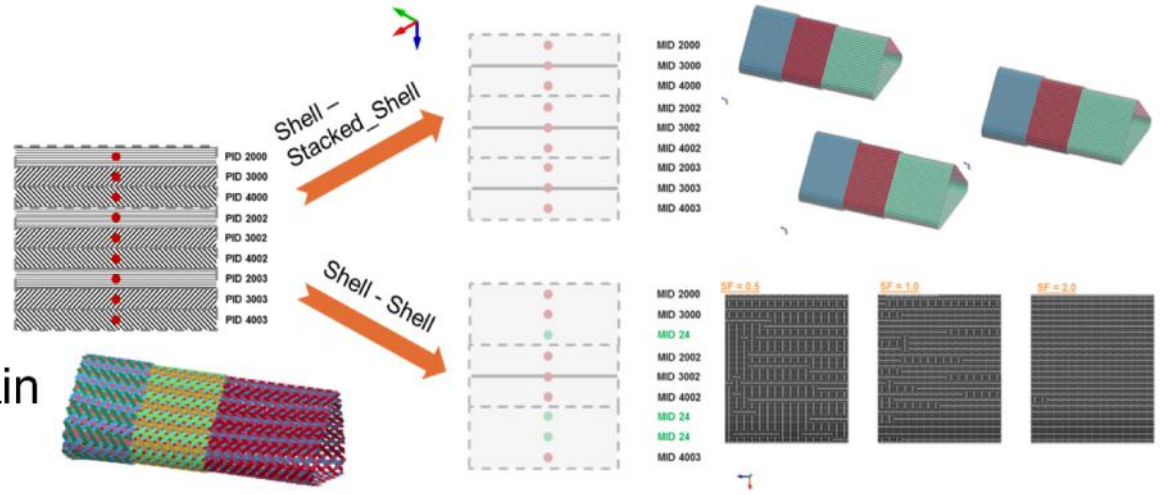




Homogenization / History handling

- Adjust mapped data for intended LS-DYNA analysis
  - Calculate β_i for composite elements such as: *ELEMENT_SHELL_COMPOSITE / *ELEMENT_SOLID_ORTHO
  - move positions of specific history variables when changing the material model
  - Assign specific material or part IDs to designated areas
  - Calculate material properties for certain material models (*MAT_157)





Agenda

- envyo® - requirements for mapping tool development
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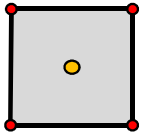
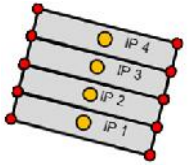
dynain – file for a lot of conceivable applications

- BEAM – SHELL
- BEAM – ALE_MESH

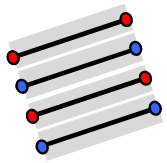
- SHELL – SHELL
- SHELL – TSHELL
- SHELL – STACKED_SHELL
- SHELL – SOLID
- SHELL – SOLID (GENERATION)

- SOLID – SHELL
- SOLID – SOLID

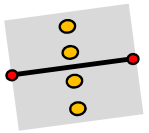




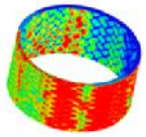
- ABAQUS2DYNA



- PCL - SHELL

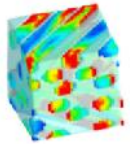


- MOLDEX3D – SOLID
- MOLDEX3D_MUCELL - SOLID
- MOLDFLOW – SHELL
- MOLDFLOW – SOLID



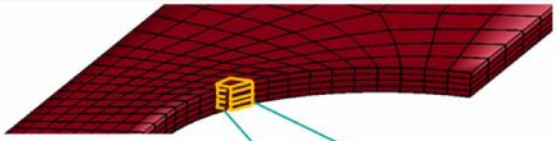
- GCODE-PATH

- HDF5 - Support



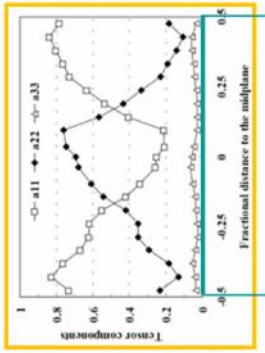
Process Chain for SFRP in LS-DYNA

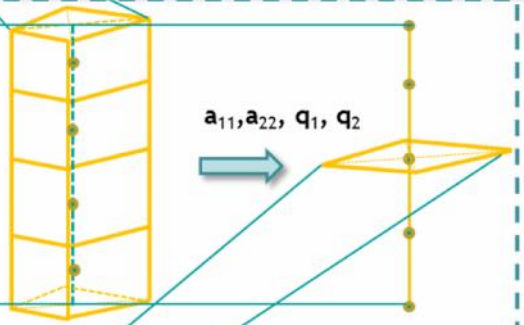
- **Process simulation:**
  fiber orientation / fiber content



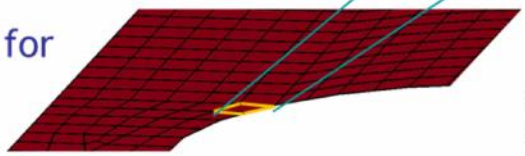
molding discretization

- **Mapping of fiber orientation tensor**
  (main values und main directions)
  - fiber content





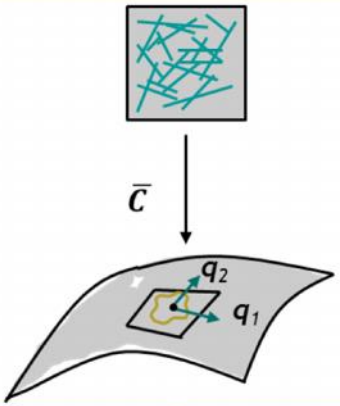
- Data mapping and homogenization for
  *MAT_002, *MAT_157, *MAT_215

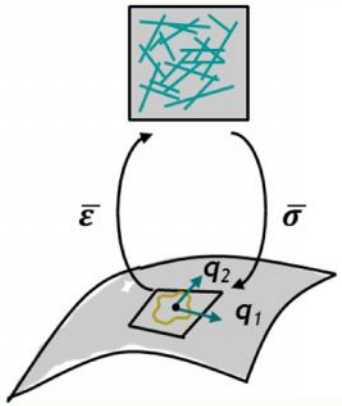


structural analysis discretization

- Structural analysis using homogenized anisotropic material model (*MAT_157)
- Structural analysis with homogenization in the material model (*MAT_215)

Overview on proposed material models





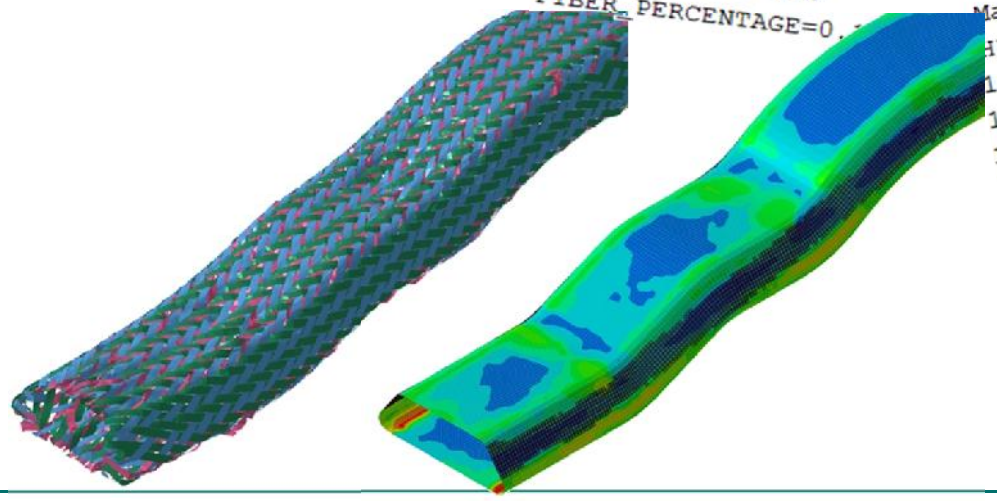
homogenized elastic		homogenized elastic - macroscopic visco-plastic	homogenized elastic-visco-plastic with fiber-/matrix-failure
fiber orientation and homogenization with **Envyo**	fiber orientation with **Envyo** homogenization with ***MAT_215**	fiber orientation and elastic homogenization with **Envyo** (from R8.1)	fiber orientation with **Envyo** homogenization with ***MAT_215** (planned from R9)
***MAT_157**	***MAT_215**	***MAT_157** (*MAT_ANISOTROPIC_ELASTIC_PLASTIC)	***MAT_215** (*MAT_4A_MICROMEC)

SHELL – SHELL mapping capabilities

- Various options for shell – shell mapping
  - Switch of history variables
  - Handling of history variables
    - Scalar values
    - Tensorial values
  - RVE – detection
  - Stress mapping
  - Strain mapping
  - Thickness mapping

```
ROTATING_YARNS 3000 4000
REINFORCING_YARNS 2000
UD 1
BIAX_30 30
BIAX_40 40
BIAX_50 50
BIAX_60 60
TRIAX_30 300
TRIAX_40 400
TRIAX_50 500
TRIAX_60 600
$#-------------
TargetThickness=3.0
ResinMatID=24
SEARCH_RADIUS=1.0
FIBER_PERCENTAGE=0.
```

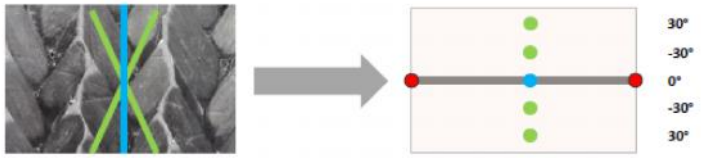
```
$#-------------------------
$# Source - PIDs
$#-------------------------
NumSourcePIDs=1
SourcePid#1=5
$#-------------
NPLANEs=4
NTHICK=5
IntegrationRule=Gauss
MapStrain=NO
MapStress=YES
InitialStress=0.0
MapThickness=YES
HISV_HANDLING=YES
13 0 0 10
17 0 0 14
18 0 0 6
MAX_NUM_HISV=18
$#-------------------------
$# END-OF-FILE
$#-------------------------
```



Braided Composites [5]

Reference approach

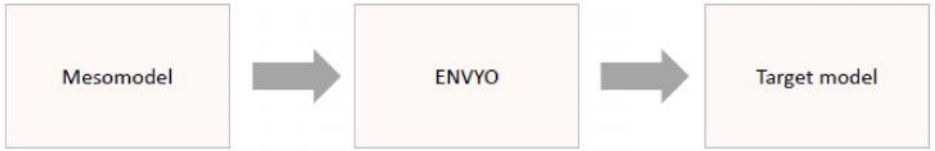
Modelling with UD-plies

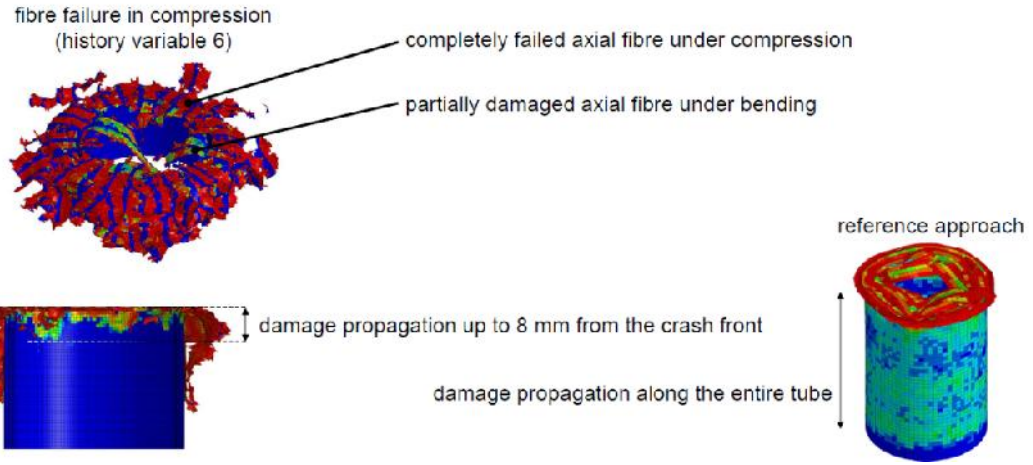


Mapping approach

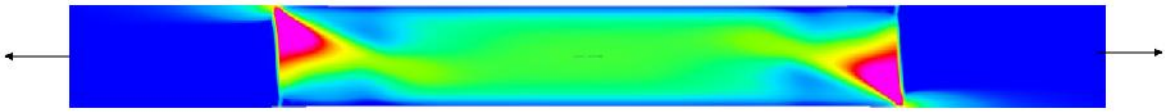
1. Generation of a realistic FE-Model on the mesoscale
2. Transfer of yarn orientations on a target mesh

DLR

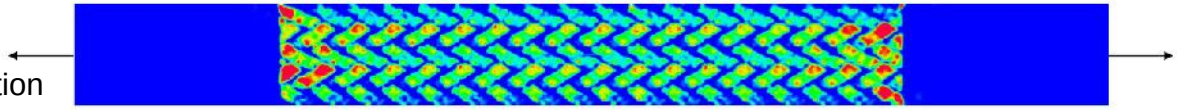




State of the art reference simulation



Simulation with the new mapping approach

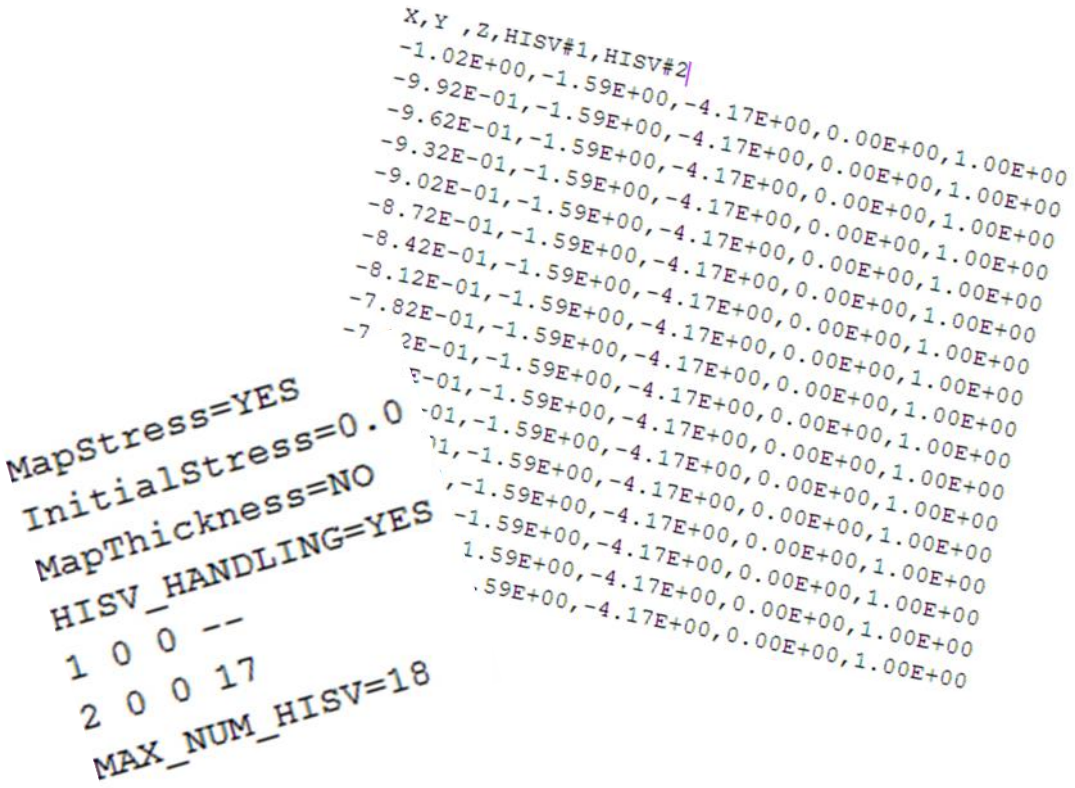


[5] Vinot, V., Liebold, C., Holzapfel, M.: Investigation of Energy Absorption in Textile Composites with the Mapping Tool ENVYO, ENVYO and Composites Information Day, Stuttgart, GER, 2018.

DYNA MORE

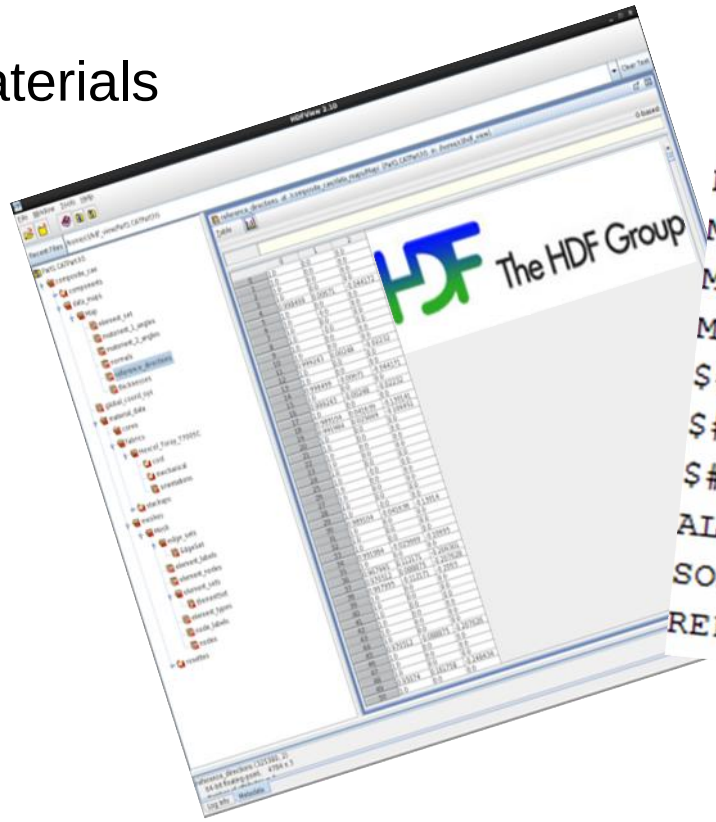
Point Cloud - Shell

- The most general mapping case
  - Reading arbitray csv data:
    - X, Y, Z, HISV#1, HISV#2,…
  - Points can be element centers, integration points, CT scan data,…



MOLDEX3D_MUCELL - SOLID

- Consider locally varying densities from foam filling analysis.
- User provides various materials models for part clustering
- HDF5 link necessary




```
SG_3.0 30
SG_4.25 40
SG_12.0 50
SG_6.0 60
$#-------------------------
$# Target - PIDs
$#-------------------------
ETYP=2
MapStress=NO
MapWeldline=NO
MapMainDir=NO
$#-------------------------
$# Mapping-Options
$#-------------------------
ALGORITHM=ClosestPoint
SORT=BUCKET
REPEAT=YES
```

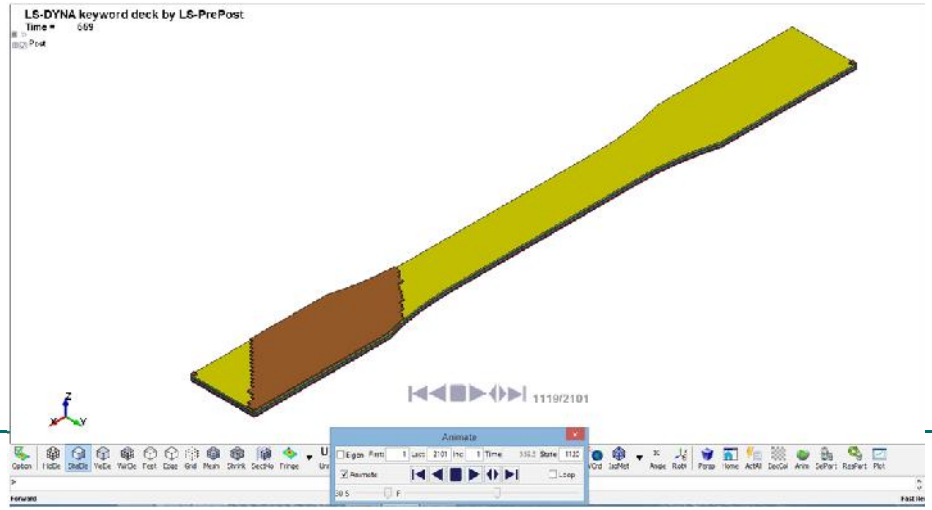
Agenda

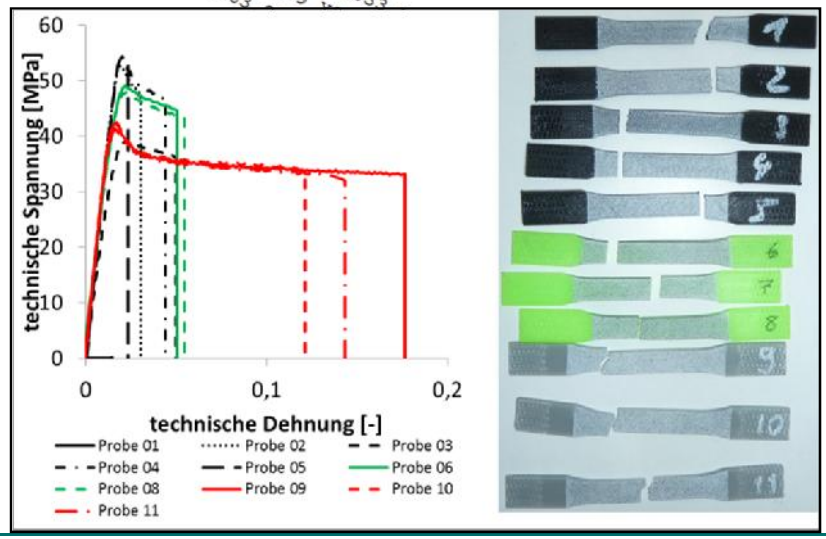
- envyo® - requirements for mapping tool development
- Use cases
- Future Plans & Summary
- Questions & Answers

GCODE – PATH – Preprocessing AM - Analysis

- Considering the manufacturing process of 3D – printed parts, reading gcode data and preparing the path of the printer source
- Next step includes mapping of warpage onto the target mesh
- Enhance computed source paths

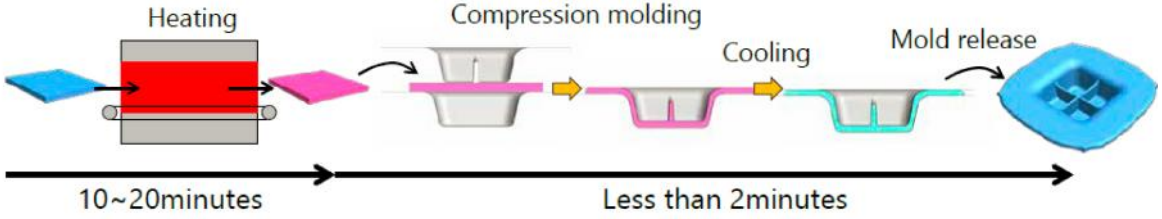
```
G21 ;metric values
G90 ;absolute positioning
M82 ;set extruder to absolute mode
M107 ;start with the fan off
G28 X0 Y0 ;move X/Y to min endstops
G28 Z0 ;move Z to min endstops
G1 Z15.0 F9000 ;move the platform down 15mm
G92 E0 ;zero the extruded length
G1 F200 E6 ;extrude 6 mm of feed stock
G92 E0 ;zero the extruded length again
G1 F9000
;Put printing message on LCD screen
M117 Printing...
;LAYER_COUNT:8
;LAYER:0
M107
G1 F1500 E-6.5
G0 F3600 X12.7 Y93.2 Z.4
;TYPE:WALL-OUTER
G1 F1500 E0
G1 F1800 X52.833
G1 X58.009
G1 X63
```

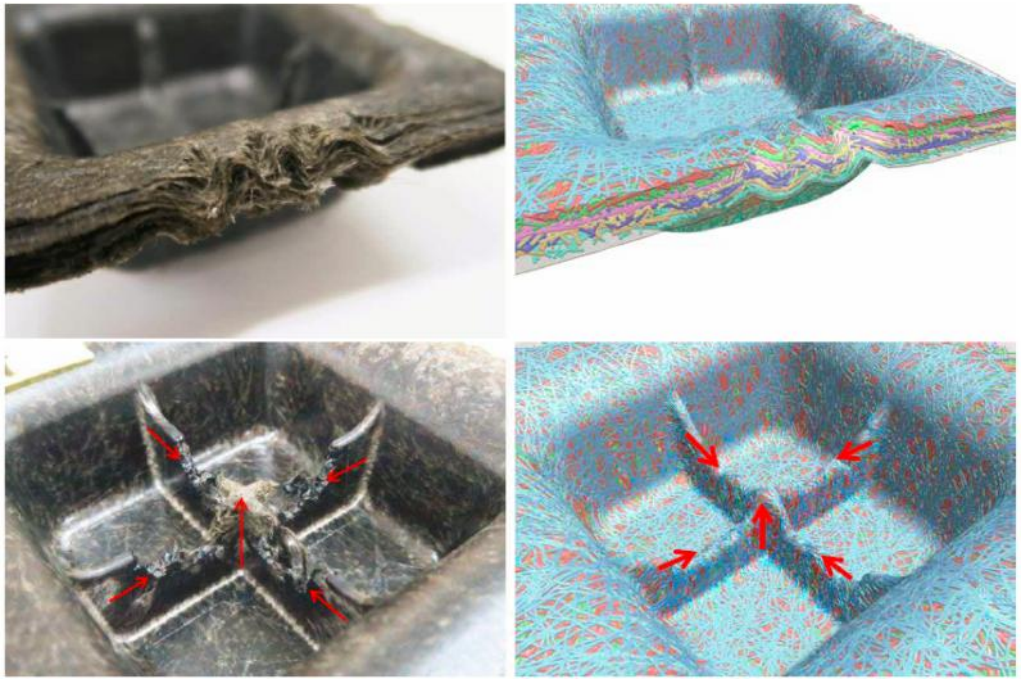




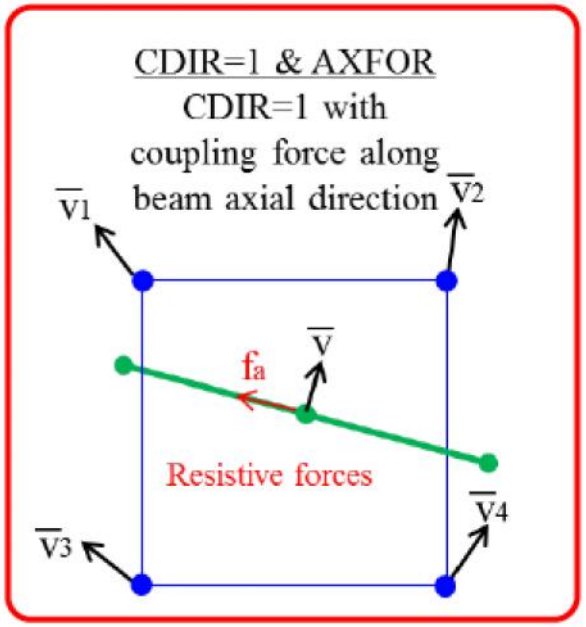
SMC [7]

- Apply homogenization techniques to beam element driven forming analysis.





JSOL



[7] Nishi, M., Hayashi, S, Wang, S.: Composites Manufacturing Process Modeling with Introduction to J-Composites, ENVYO and Composites Information Day, Stuttgart, GER, 2018.

DYNA MORE

Gray-scale data mapping

- Transfer images into gray-scale format and export as pgm (portable graymap)
- Read pgm ascii – and implement one (or more) user values for assigning various material IDs
- Identify material directions using the gray-scale analysis method

FSI – data mapping

- Read pressure data and use it for further structural analysis

Output format standardization (ITEA-VMAP)

- Various use cases are defined
- Transfer of temperature dependent data:

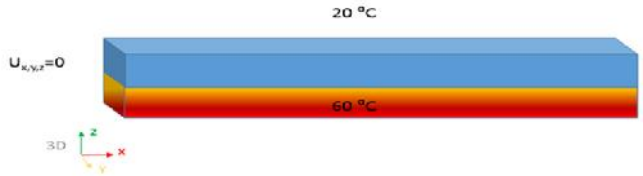


Figure 9. Depiction of the 3D Beam and the heat source underneath. The left sided is fixed.

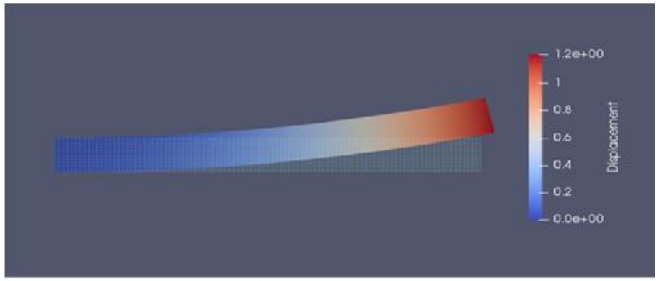
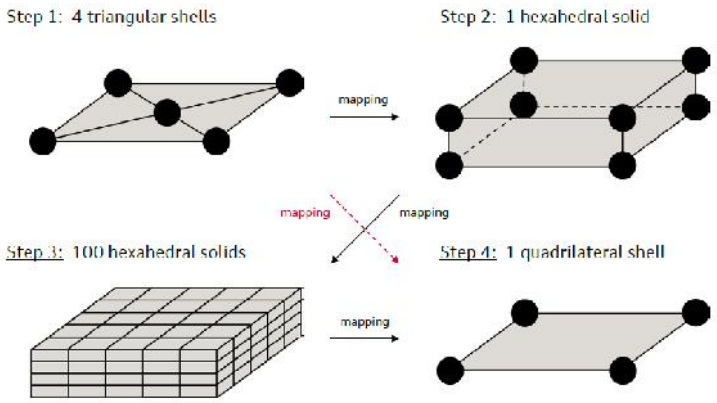


Figure 8. Deformation of the beam

- Standard composite test case:
  - Draping
  - (Infiltration)
  - (Curing)
  - Structural



Summary

- envyo® is available for both, windows and linux operating systems.
- Test versions can be requested @ DYNAmore, preferrably with a small application example.
- After a successful testing period it is thought to distribute envyo® commercially. Details will follow in due time.
- Participation in the ITEA-VMAP project to define a common result mapping standard.

Remark:

- The quality and the capability of the program are highly dependent on its usage. Feedback is highly appreciated!

Acknowledgement

- The mapping tool ENVYO® is and has been developed in the following research projects:
  - TPult
  - Swim-RTM
  - ARENA2036
  - ITEA-VMAP

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PTKA Projektträger Karlsruhe
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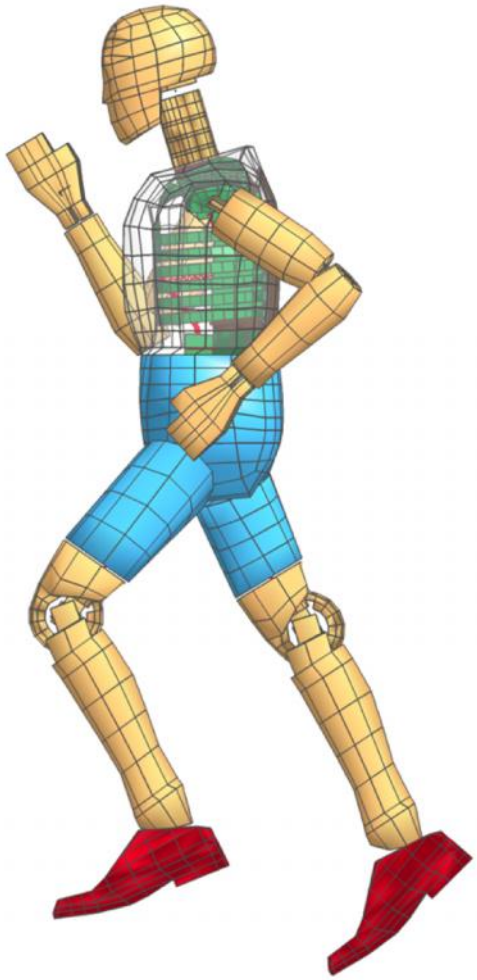
ITEA 3

VMAP



FIN

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