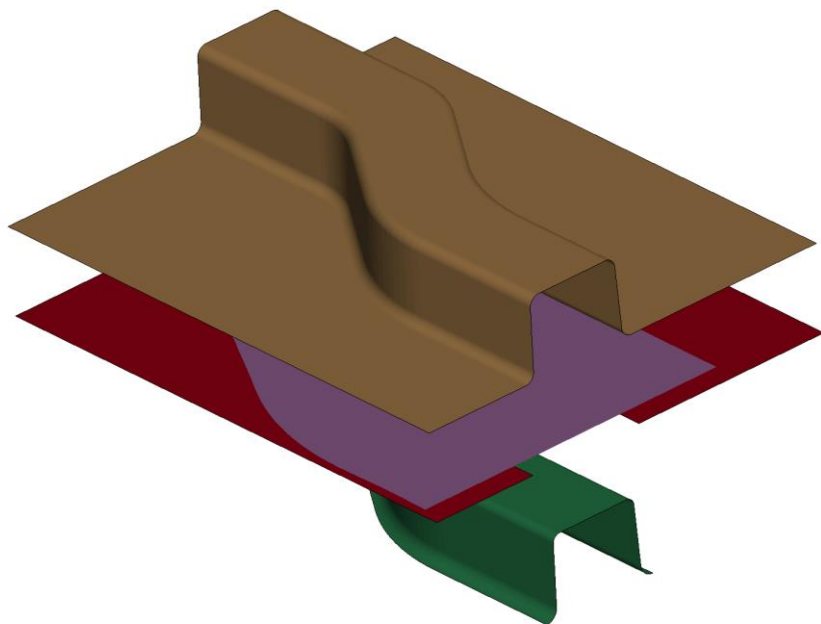


Systematic assessment of isogeometric sheet metal forming simulations based on trimmed, multi-patch NURBS models



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Systematic assessment of isogeometric sheet metal forming simulations based on trimmed, multi-patch NURBS models

sheet metal forming

- Plastic deformation of a Blank into a desired shape
- Highly nonlinear (Contact, Material, geometrically)
- Local features (sharp corners, double curved geometries, local plasticity)

IGA for sheet metal forming applications

- Superior behaviour of IGA compared to FEM
- Tighten the loop btw. CAD and CAE



Door inner [1]

Setup

Geometry: S-Rail, Numisheet

Benchmark 1996

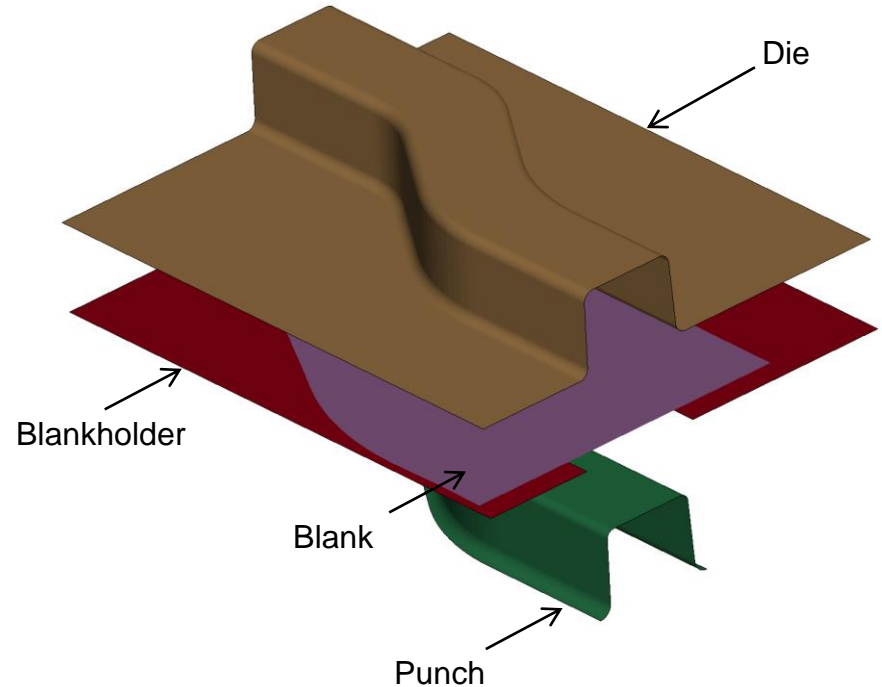
Solver: LS Dyna, explicit

Material: elasto-plastic model

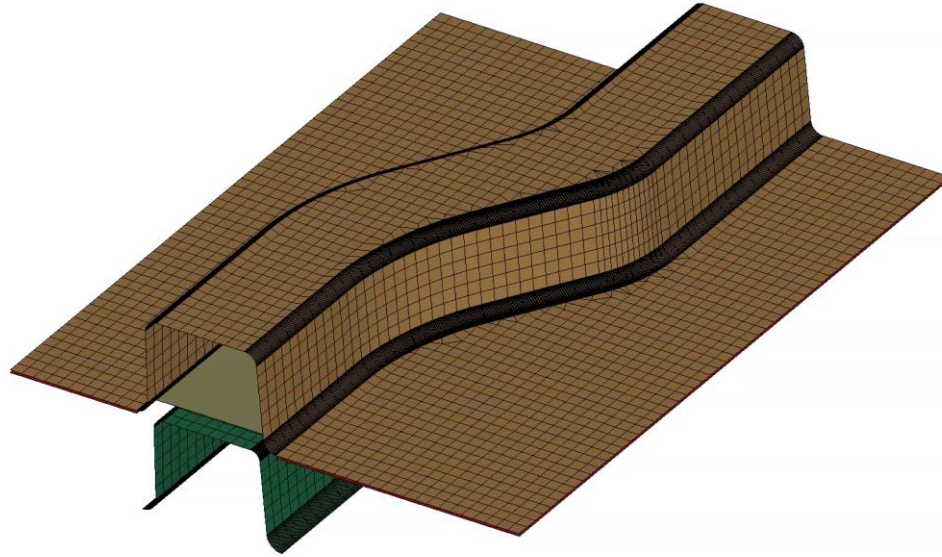
Shell model: Reissner-Mindlin

Tools: rigid bodies, t_{sim} : 9ms

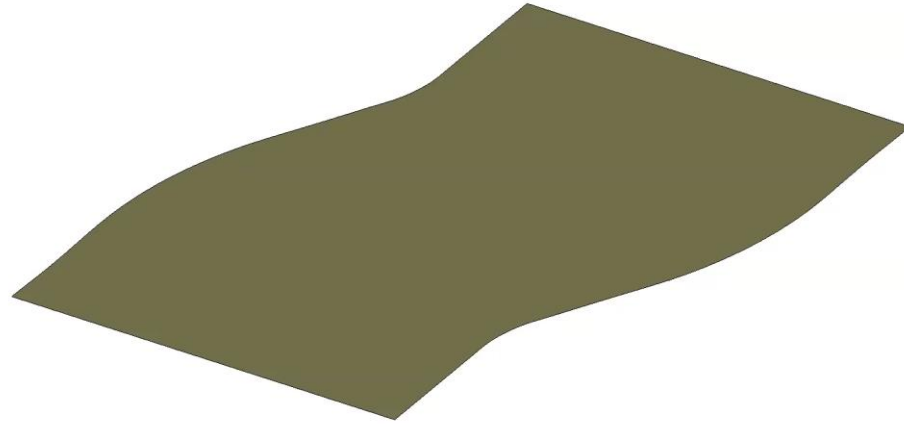
Hardware/ Setup: intel core i9,
nCPU=10, smp



LS-DYNA keyword deck by LS-PrePost
Time = 0



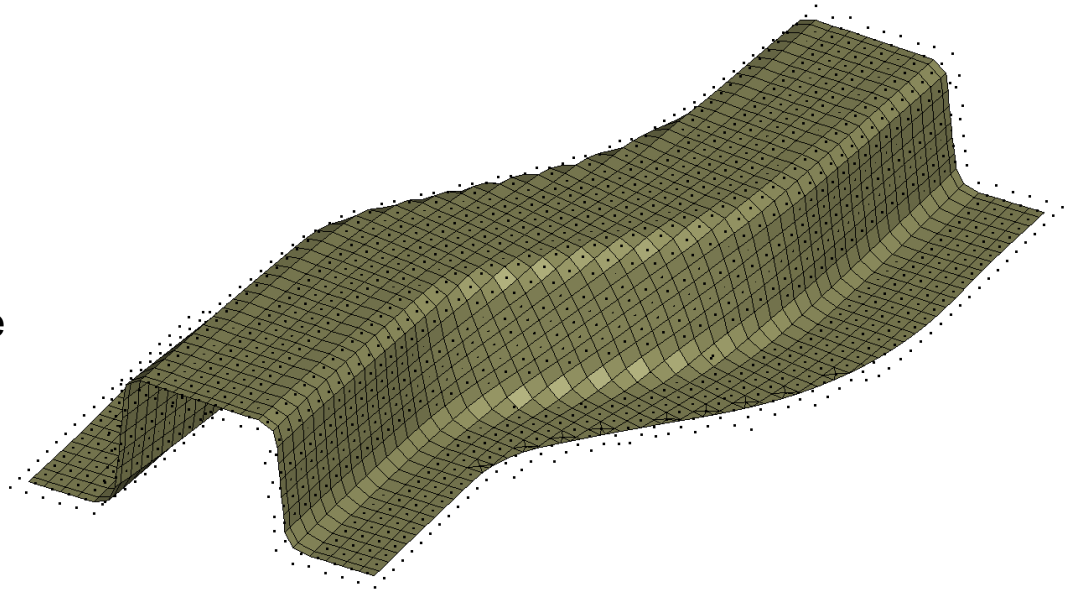
LS-DYNA keyword deck by LS-PrePost
Time = 0



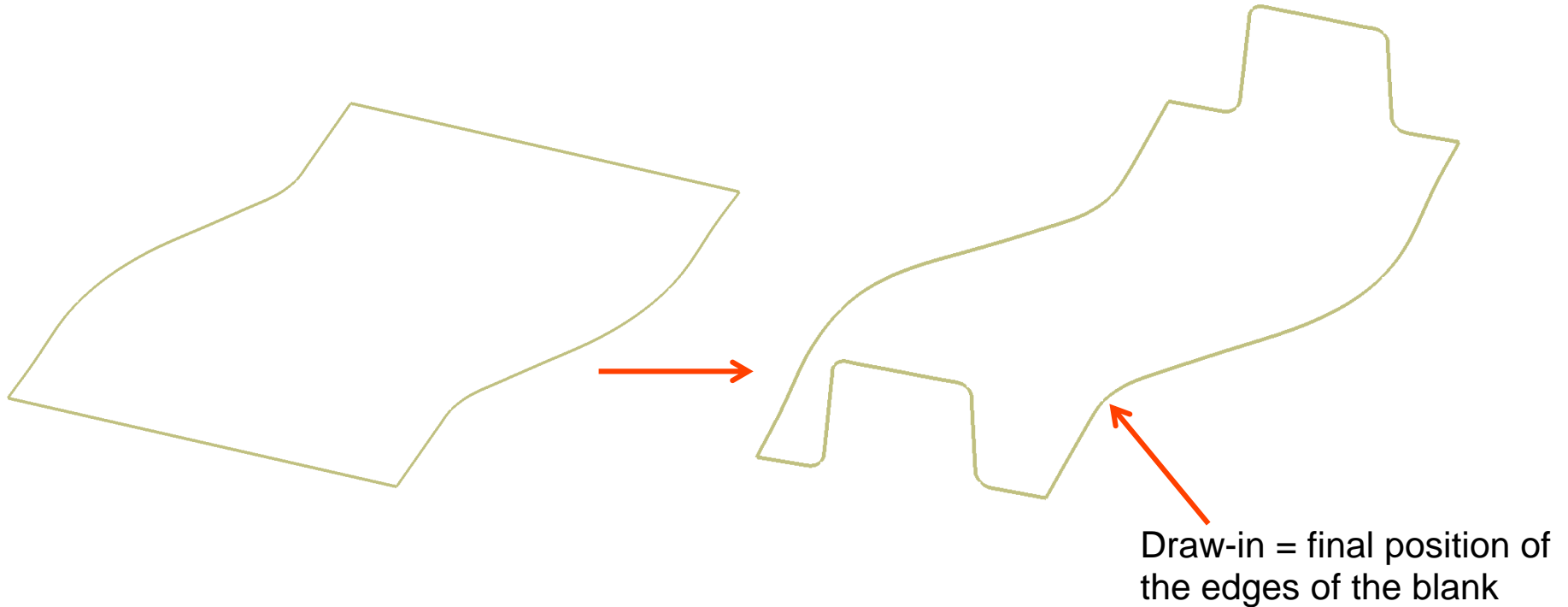
Systematic assessment of Isogeometric sheet metal forming simulations based on trimmed, multi-patch NURBS models

Focus on:

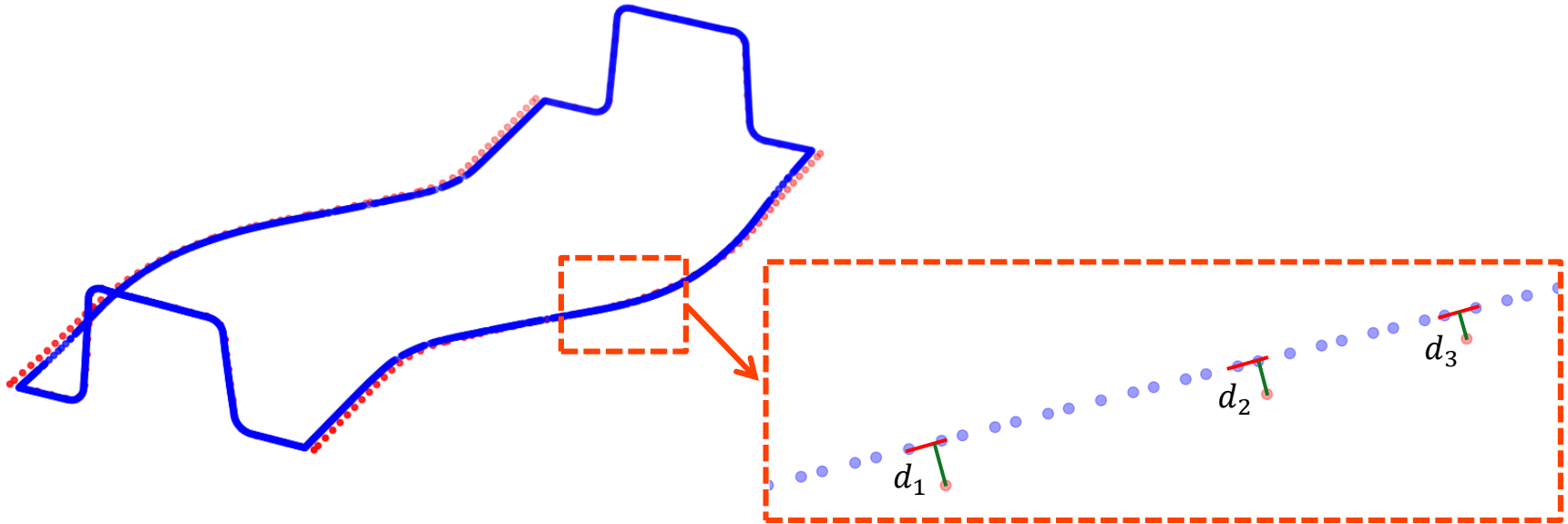
- Contact
- Integration rule
- timestep size
- Absolute CPU time



Definition of a measurement to quantify the quality of the results for FE and IGA

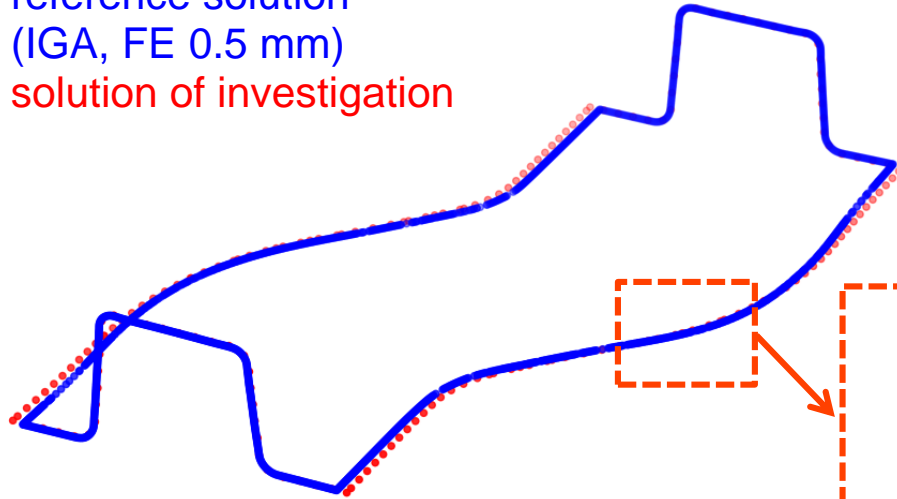


Definition of a measurement to quantify the quality of the results for FE and IGA



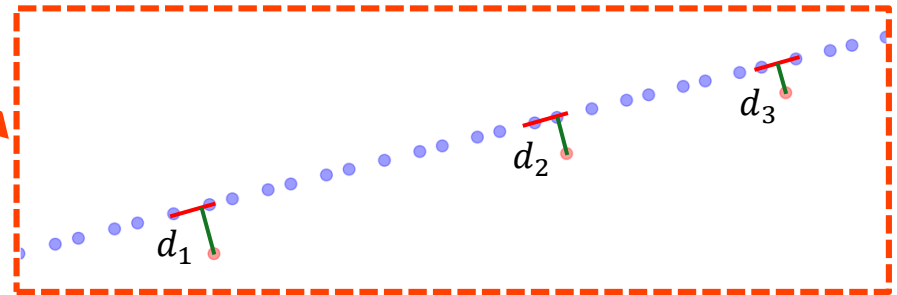
Definition of a measurement to quantify the quality of the results for FE and IGA

reference solution
(IGA, FE 0.5 mm)
solution of investigation

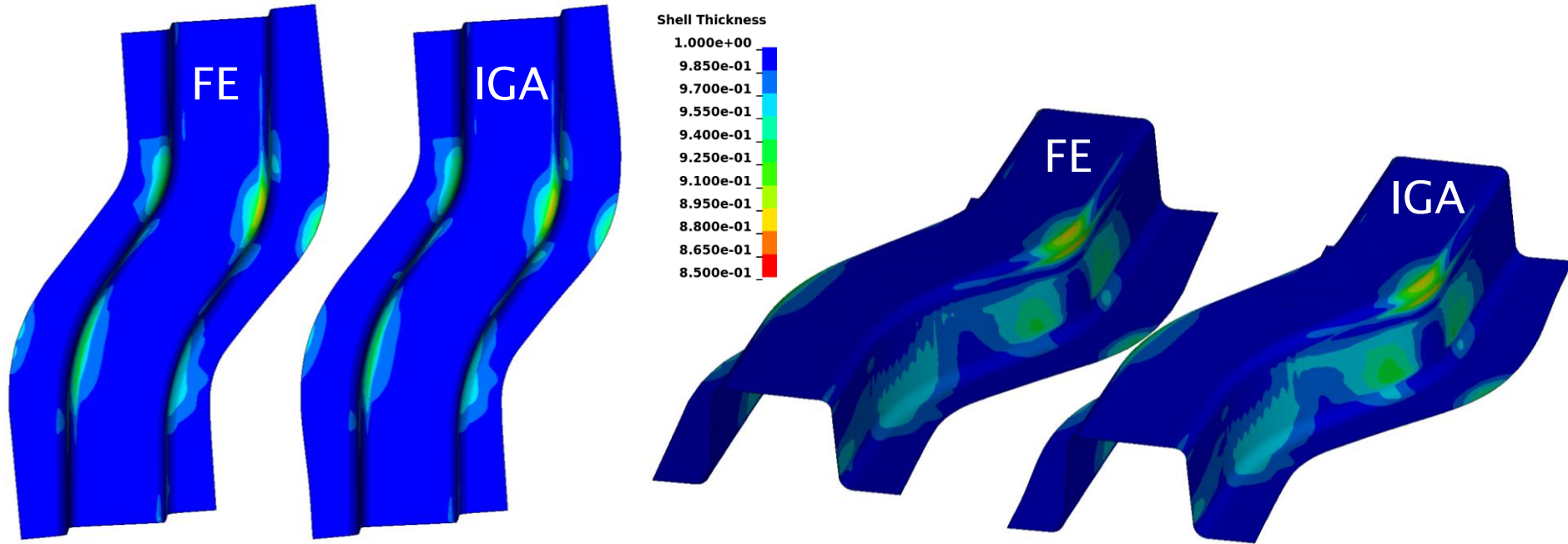


Error measurement:

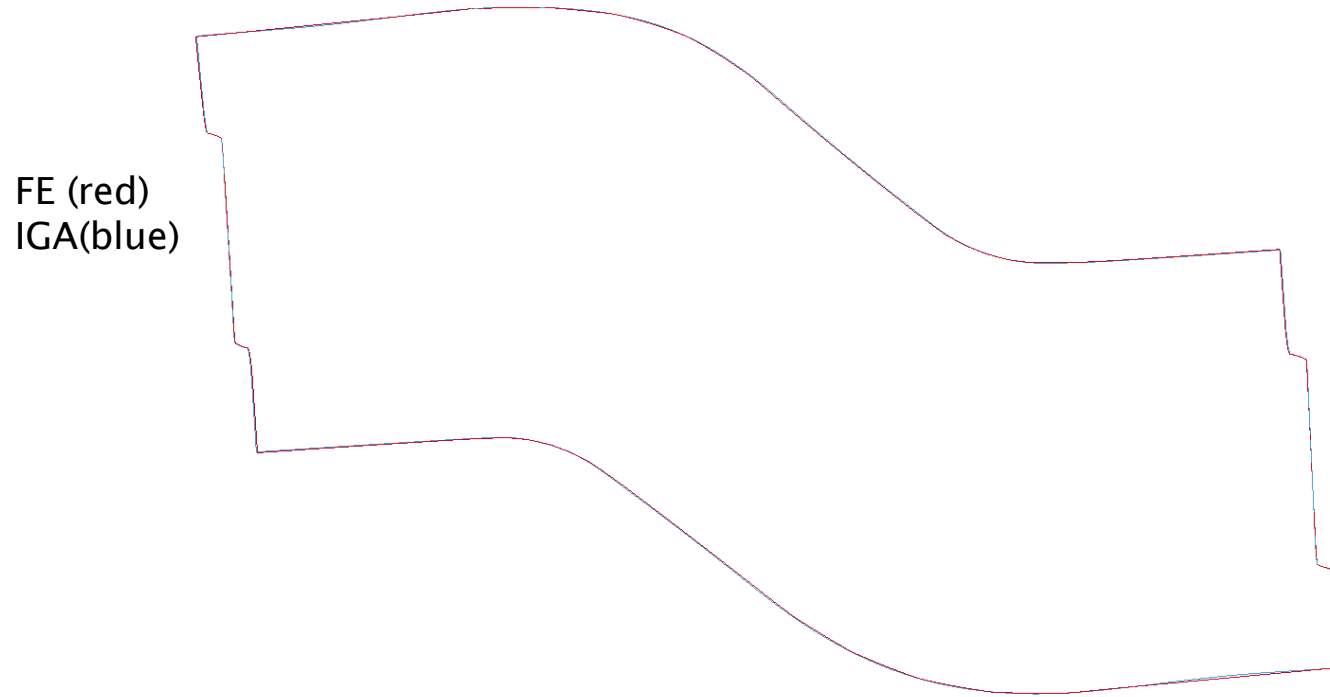
$$e = \frac{1}{L_R} \oint \left\| (C_R(\xi) - C_S(\xi)) \frac{dx}{d\xi} \right\|_2 d\xi \approx \frac{1}{n} \sum_{i=1}^n d_i$$








Comparison FE/IGA – shell thickness of reference solutions



Comparison FE/IGA – draw-in of reference solutions

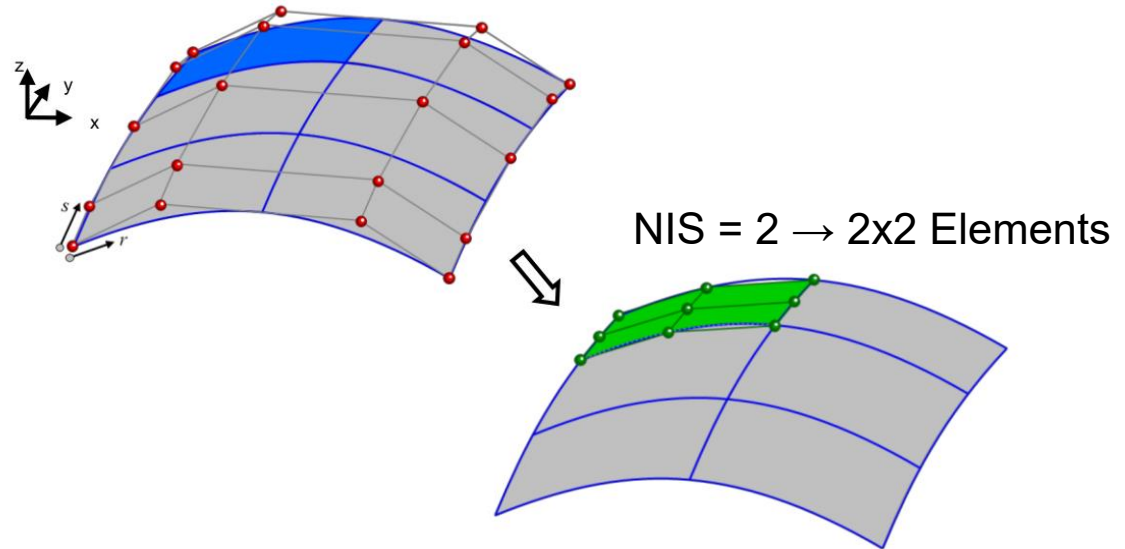


Focus on Contact

-  Control Points
-  Control mesh
-  IGA Element
-  Interpolation Node
-  Lagrangian Interpolation mesh

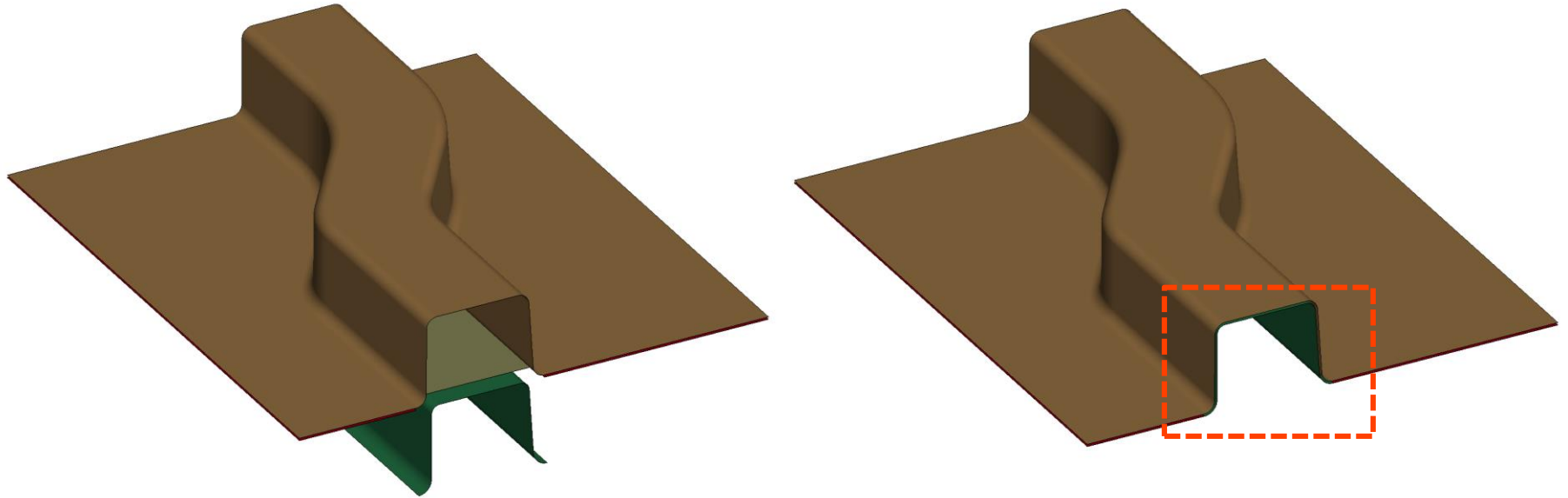
Interpolation mesh is used for:

- contact procedure
- postprocessing



From: LS-DYNA Compact: Introduction to Isogeometric Analysis with LS-DYNA, 2022

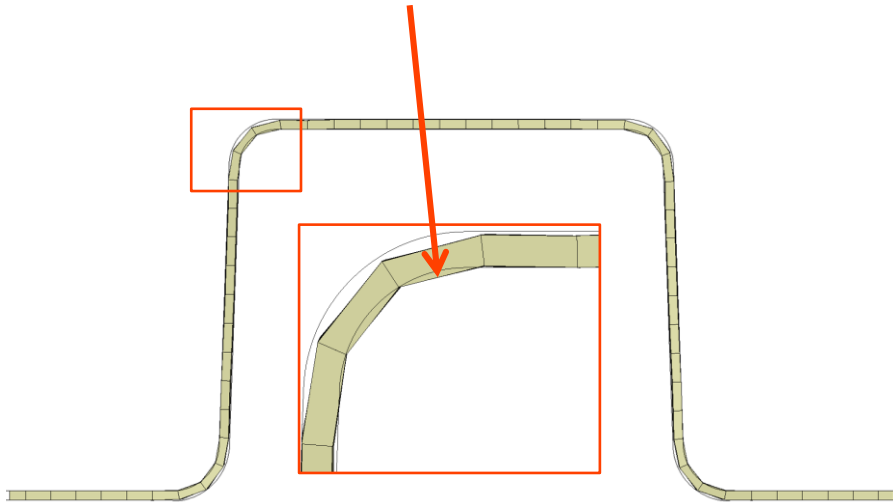
Focus on Contact



Focus on Contact

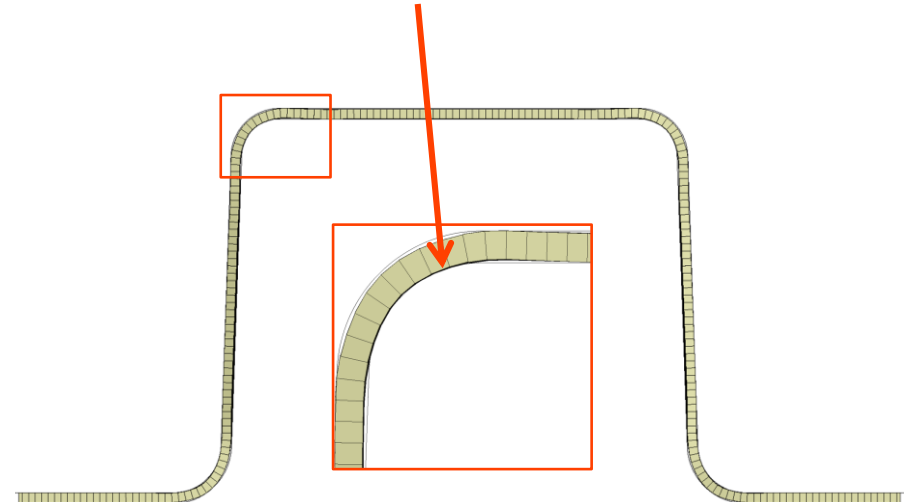
$p=2$, Elsize=5mm, NIS=1

Large penetrations

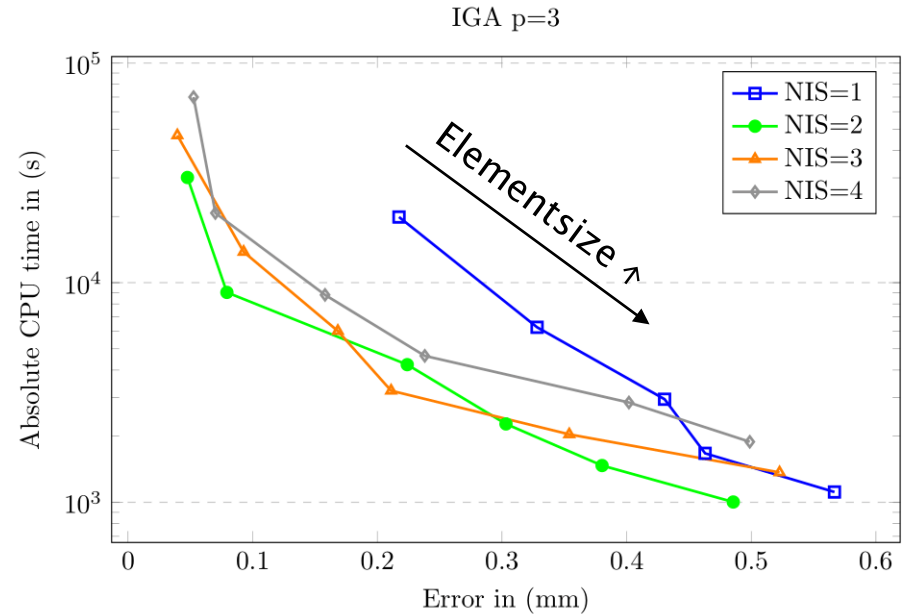
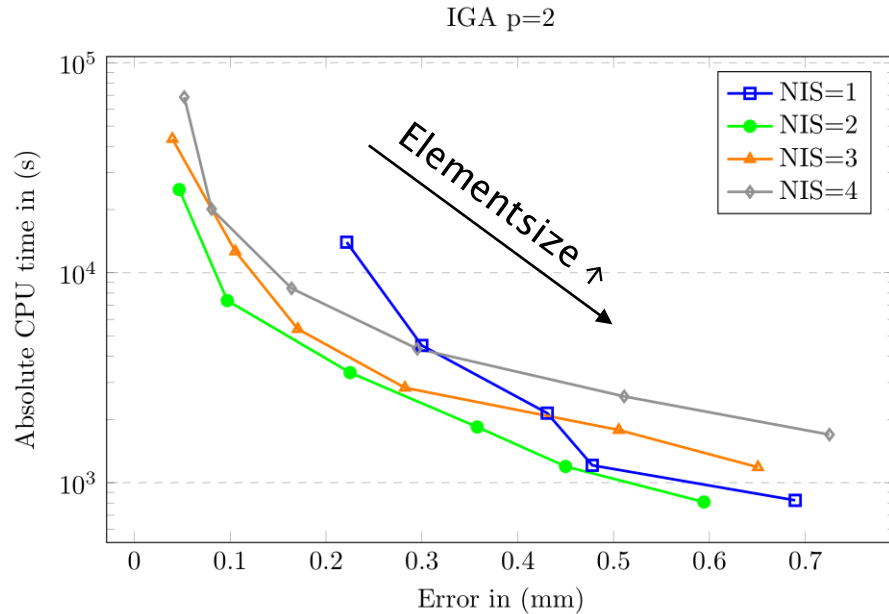


$p=2$, Elsize=5mm, NIS=4

Smaller penetrations



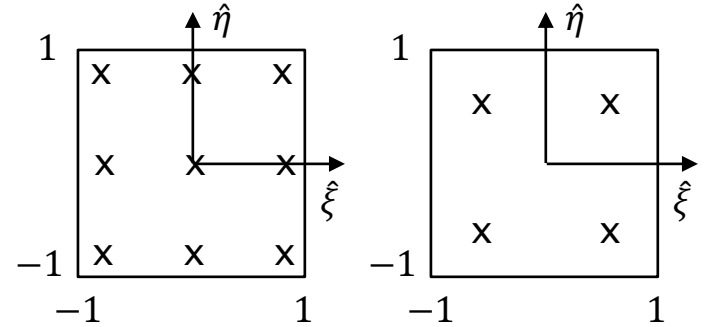
Tradeoff between CPU time and error in draw-in



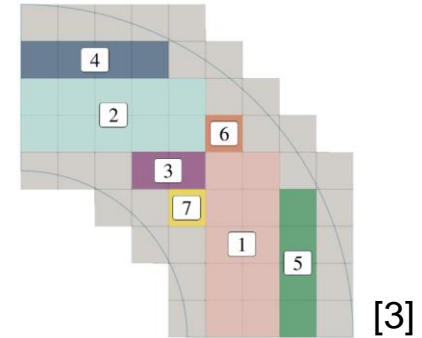
→ low costs and high accuracy for NIS=2

Focus on Integration rule

- full Gauss $(p+1)^2$ Integrationpoints per Element
- reduced Gauss (red. GL): p^2 Integrationpoints per Element
- full optimal Gauss (full opt. G)
- reduced optimal Gauss (red. opt. G)
- double reduced optimal Gauss (double red. opt. G) [2]



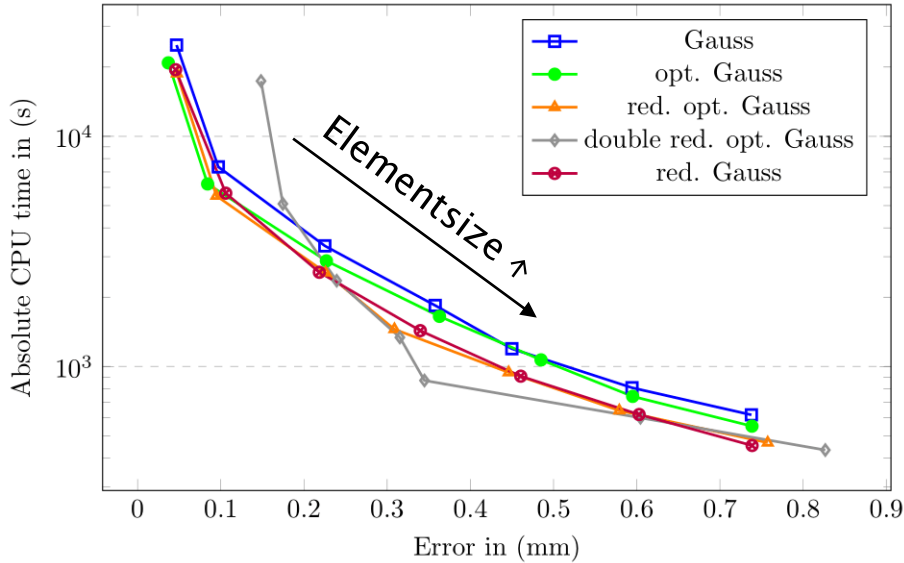
→ element-based rule



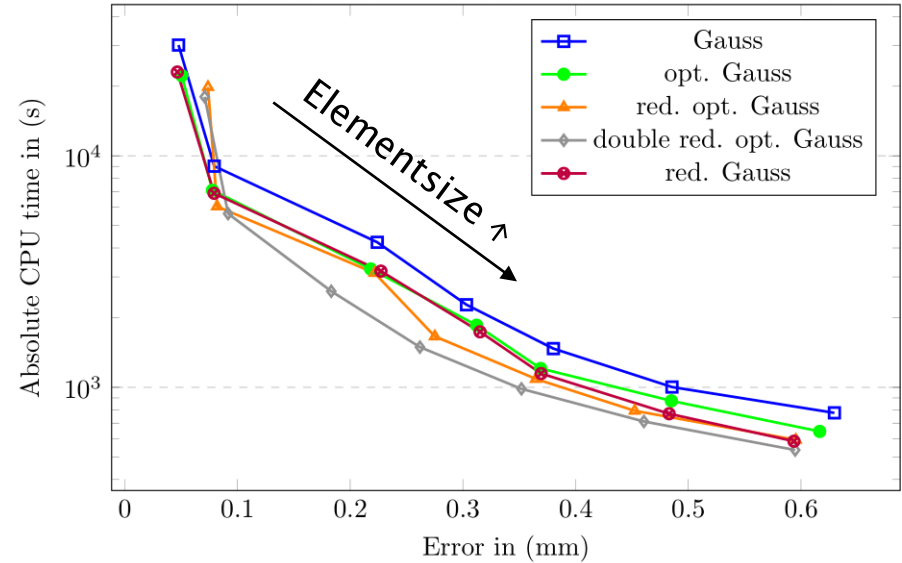
→ macroelement-based rule for uniform knotvectors

Tradeoff between CPU time and error in draw-in

IGA $p=2$



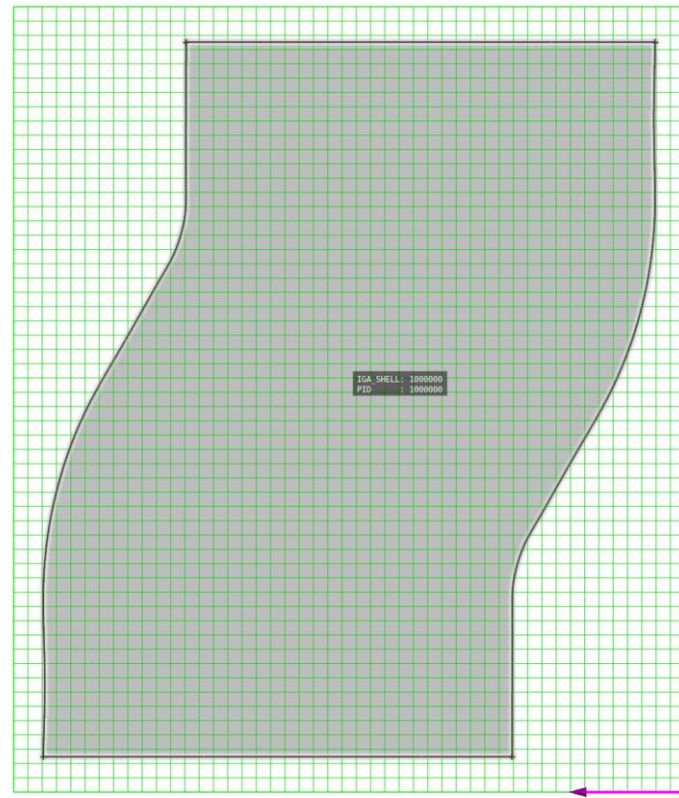
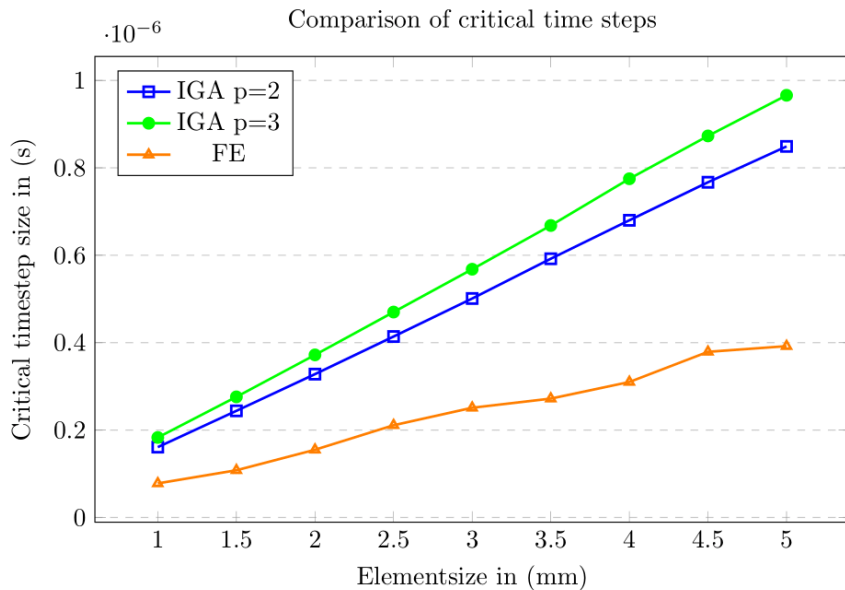
IGA $p=3$



→ low costs and high accuracy for red. Gauss/ red. opt. Gauss for $p=2$ and double red. Opt. Gauss for $p=3$

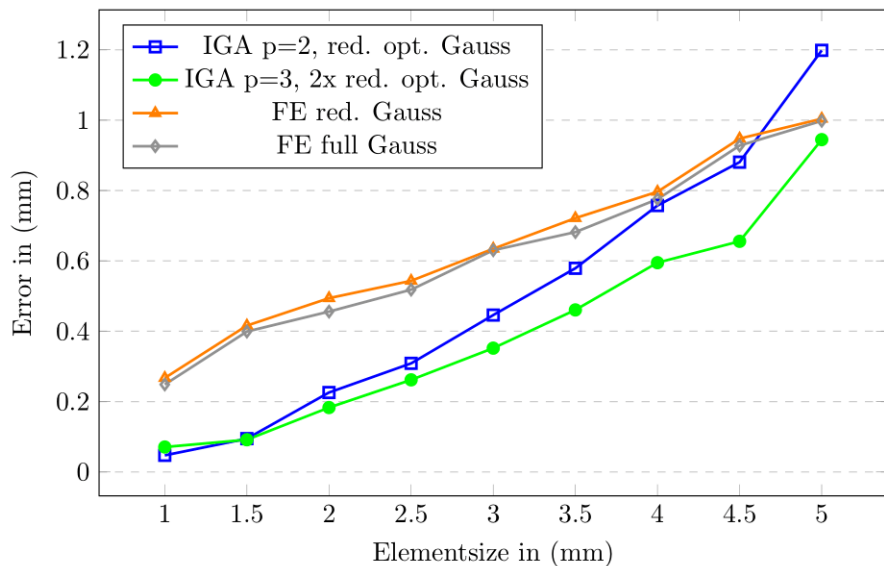
Comparison of IGA and FE

High Continuity +
Trimming of p-1 first and last rows and columns
→ Higher timestep [4]



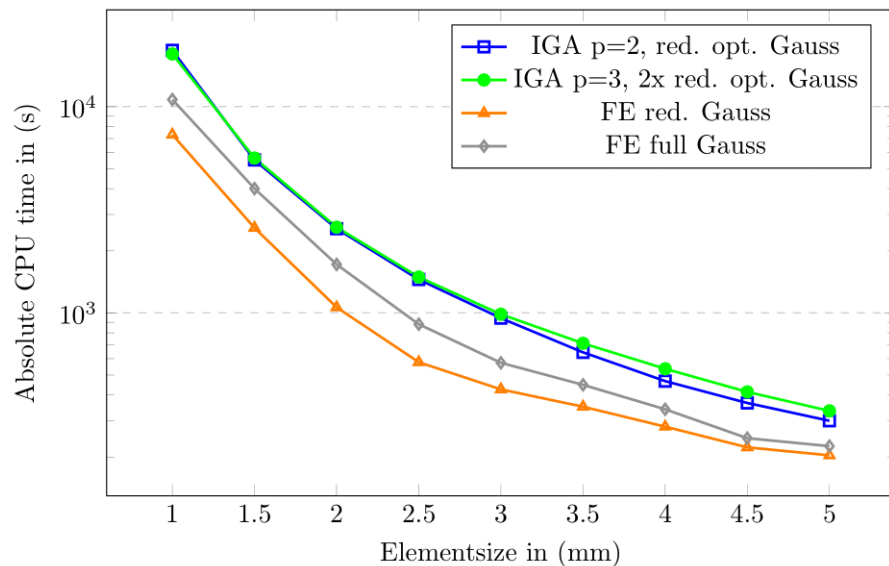
Comparison of IGA and FE

Comparison of accuracy



→ IGA more accurate

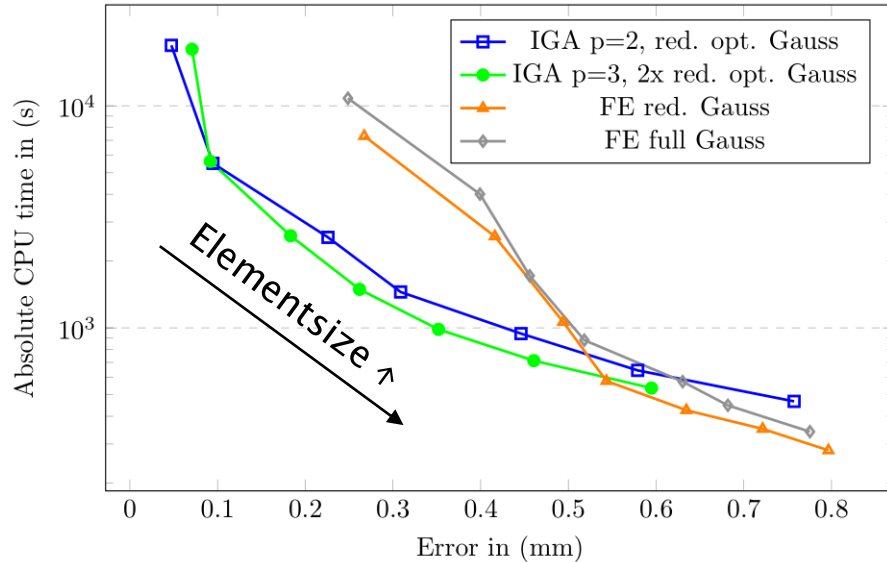
Comparison of computational costs



→ IGA more expensive

Comparison of IGA and FE

Tradeoff between computational costs and accuracy



→ higher accuracy for the same element size for IGA

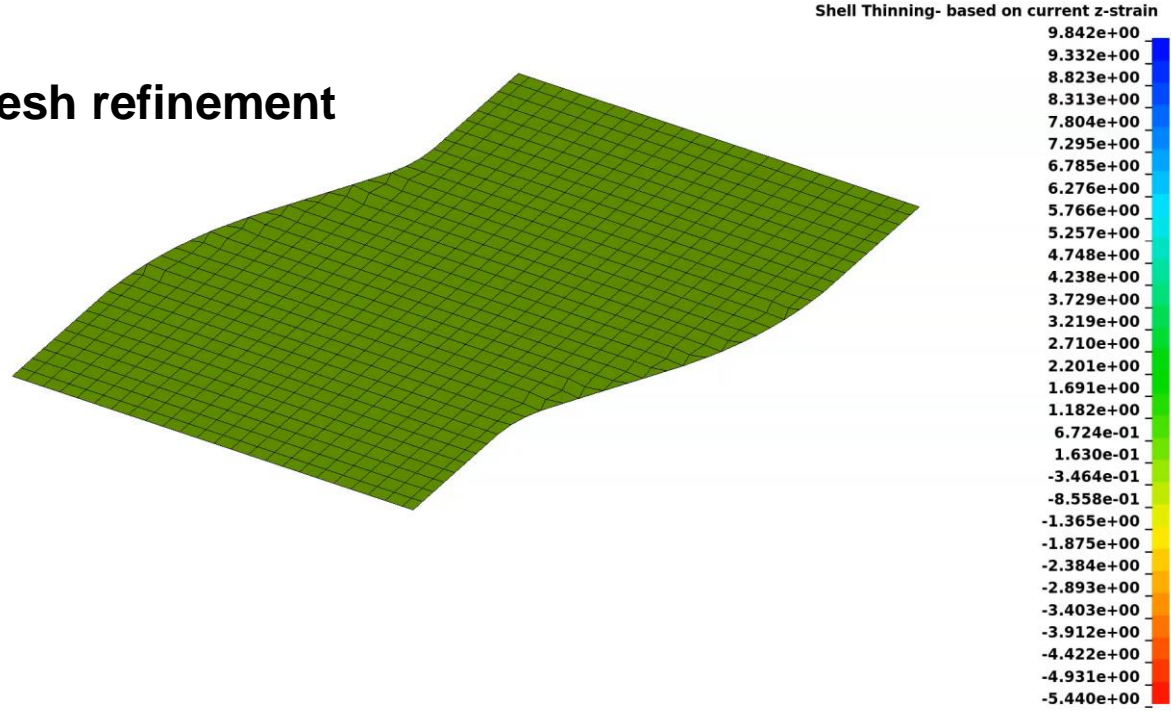


→ higher CPU time for IGA than for FE for the same element size



→ superior behaviour for IGA

Adaptive mesh refinement



Future work

- Standard tensor product structure doesn't allow for a real local refinement by inserting meshlines
- potential remedy: LR-Splines, HB-Splines, THB-Splines [5,6,7]
- Next steps: systematic assessment of:
 - suitability of different local spline formulations for sheet metal forming
 - different refinement strategies and error measurements
 - factors influencing the error, e.g curvature, contact...
- Future goal: Development of an adaptive Mesh refinement/ coarsening strategy for isogeometric shell elements

References

- [1] Wagner M., Lineare und nichtlineare FEM, 2022
- [2] René R. Hiemstra, Francesco Calabrò, Dominik Schillinger, Thomas J.R. Hughes, Optimal and reduced quadrature rules for tensor product and hierarchically refined splines in isogeometric analysis, Computer Methods in Applied Mechanics and Engineering, 2017
- [3] Manuel Meßmer, Tobias Teschemacher, Lukas F. Leidinger, Roland Wüchner, Kai-Uwe Bletzinger, Efficient CAD-integrated isogeometric analysis of trimmed solids, Computer Methods in Applied Mechanics and Engineering, 2022
- [4] Explicit Isogeometric B-Rep Analysis for Nonlinear Dynamic Crash Simulations, Lukas F. Leidinger, Technische Universität München, PhD Thesis, 2020
- [5] Kjetil André Johannessen, Trond Kvamsdal, Tor Dokken, Isogeometric analysis using LR B-splines, Computer Methods in Applied Mechanics and Engineering, Volume 269, 2014
- [6] Luca Coradello, Pablo Antolin, Rafael Vázquez, Annalisa Buffa, Adaptive isogeometric analysis on two-dimensional trimmed domains based on a hierarchical approach, Computer Methods in Applied Mechanics and Engineering, Volume 364, 2020.
- [7] P. Hennig, M. Ambati, L. De Lorenzis, M. Kästner, Projection and transfer operators in adaptive isogeometric analysis with hierarchical B-splines, Computer Methods in Applied Mechanics and Engineering, 2018