Crack Propagation in Crash
A new approach without local remeshing

Karlheinz Kunter
Lead Researcher
Department Human-Centered Systems and Road Safety

VIRTUAL VEHICLE Research Center
www.v2c2.at

Content

- Motivation
- Crack propagation algorithm
- Prototypical implementation
- Conclusion and Outlook

Coauthors:

Dr. Thomas Heubrandtner, Kompetenzzentrum - Das virtuelle Fahrzeug Forschungsgesellschaft mbH

Michael Koplenig, Kompetenzzentrum - Das virtuelle Fahrzeug Forschungsgesellschaft mbH

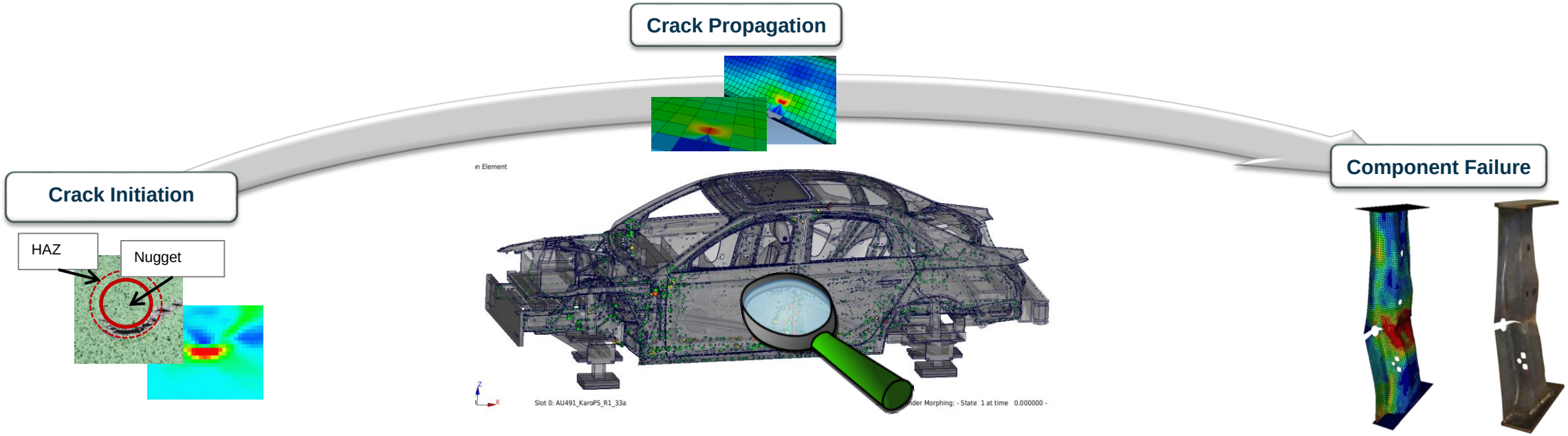
Bernhard Fellner, MAGNA STEYR FAHRZEUGTECHNIK AG & CO KG

Jean-Daniel Martinez, AUDI AG

Motivation

Statement of the problem

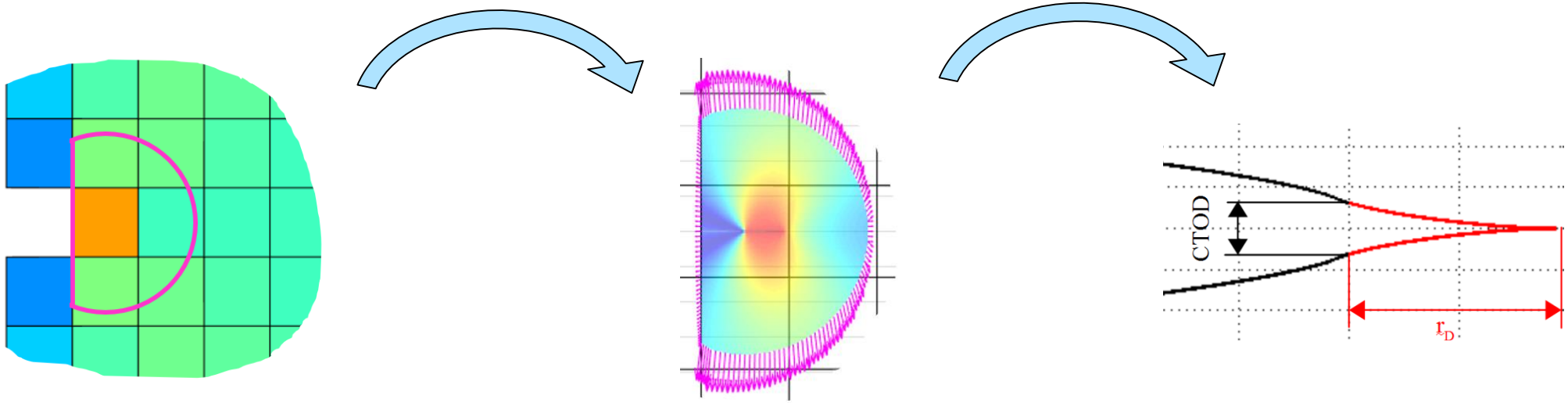
- **Poor predictability** of crack propagation in high strength materials using crash-typical element sizes due to
  - high gradients of material properties (e.g. in the coarse grained heat affected zone of spotwelds)
  - notch effects at alternative joints (e.g. self piercing rivets or flow drill screws)
- Discretization error in coarse meshes may lead to an underestimation of **local stresses and subsequently to a non conservative prediction** of material failure using damage models



Crack propagation algorithm

Main approach

- Element elimination **is not triggered** only by a damage model (Johnson Cook, EWK, etc.) at element level
- Analytical Crack Tip Stress Element containing a sharp crack is used to „correct“ the non physical crack tip (discretization error)
- Introduction of a supplementary fracture mechanical propagation criterion (e.g. Crack Tip Opening Displacement)

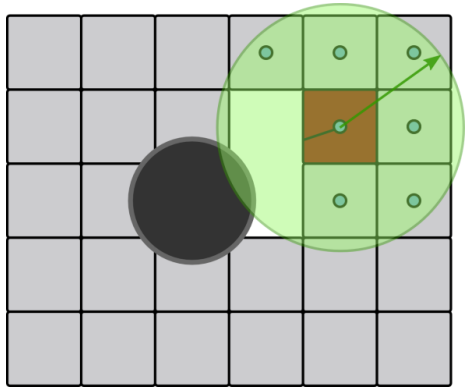


Crack propagation algorithm

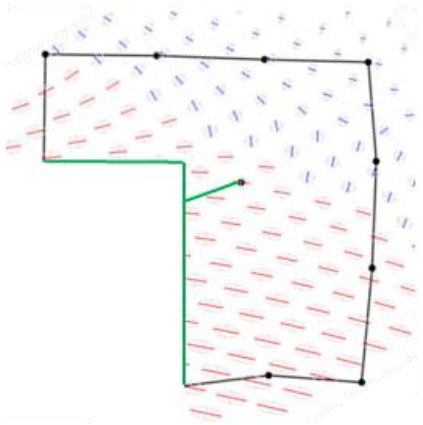
Non local approach

- Stresses in an „appropriate“ vicinity of the crack tip are approximated by a continous stress field (truncated Taylor series)
- The approximated stress field is applied at the boundary of a analytical crack tip element containing a sharp crack and a strip yield zone (L2-Stress-Element)
- Evaluation of a propagation criterion indicates wether the underlying shell element must be eliminated or not

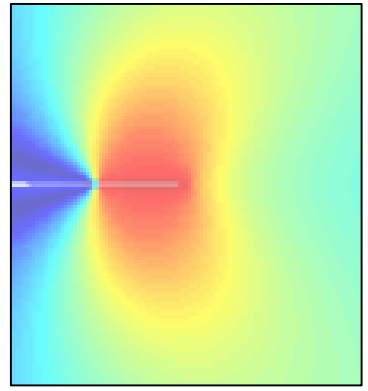
Access to integration point stresses in an appropriate vicinity of the virtual crack tip



Approximation of a continous stress field



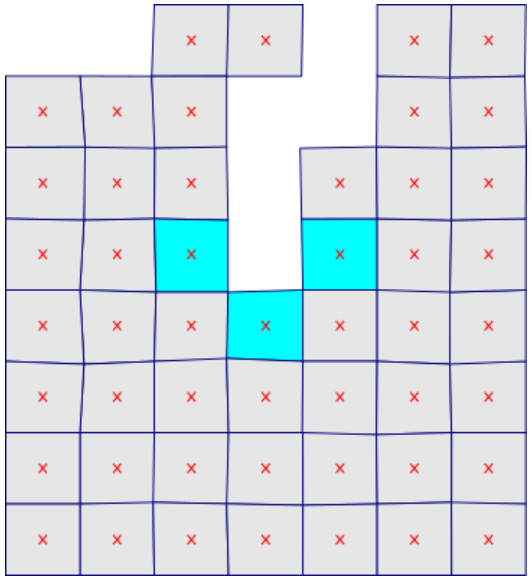
Evaluation of propagation criterion by means of analytical crack tip fields

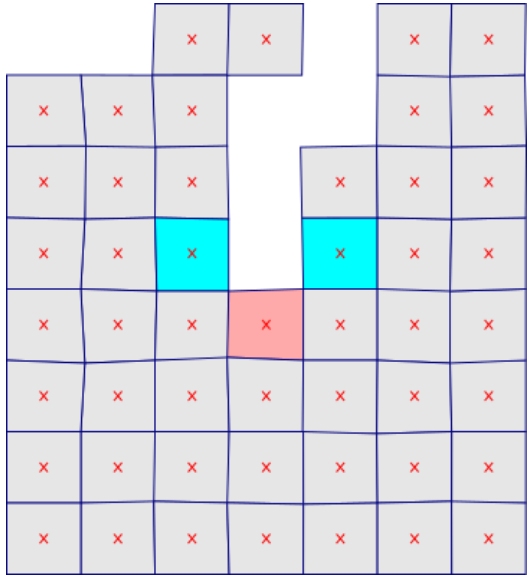


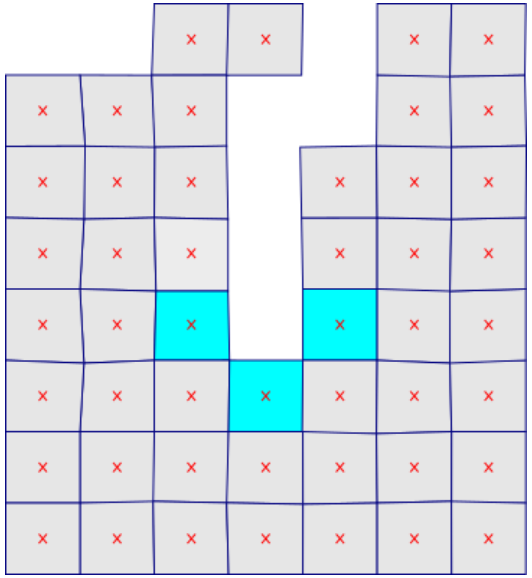
Crack propagation algorithm

Main algorithmic loop

- Cyclic screening of critical elements (Test-Elements)
- Evaluation of a propagation criterion at the virtual crack tip (e.g. Stress intensity factor, crack tip opening displacement) and comparison against an experimental determined crack resistance curve (R-curve)
- Elimination of the Test-Element, when indicated
- Identification of the next Test-Elements



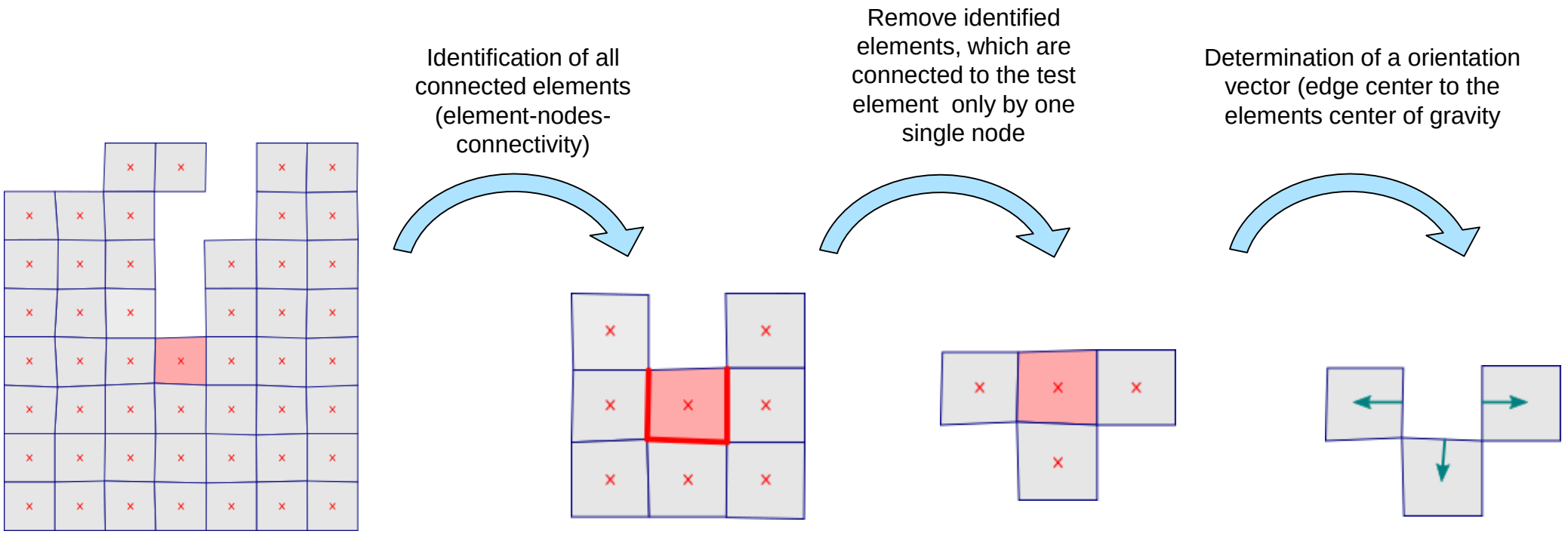




Crack propagation algorithm

Identification of the next Test-Elements

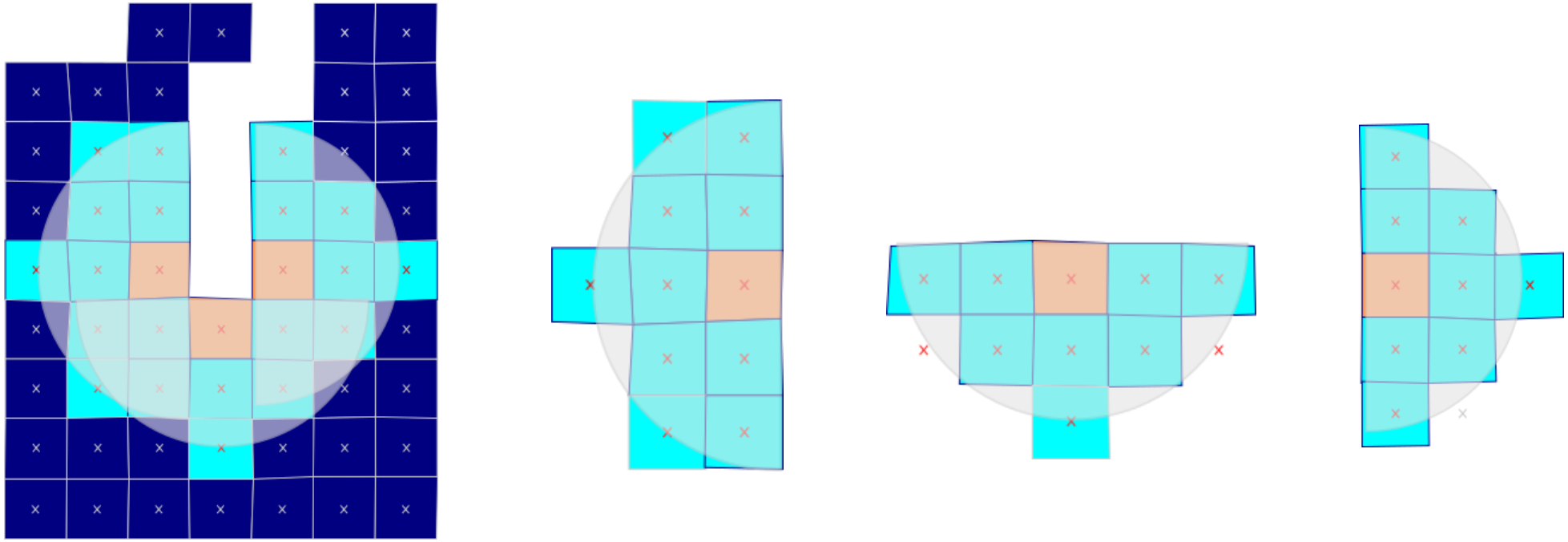
- Element is critical due to the propagation criterion (→ red element)
- Identification of the elements which are connected with a common edge
- Determination on orientation vectors in the remaining elements for the further determination of the element patches (non local approach)



Crack propagation algorithm

Identification of element patches for the non local approach

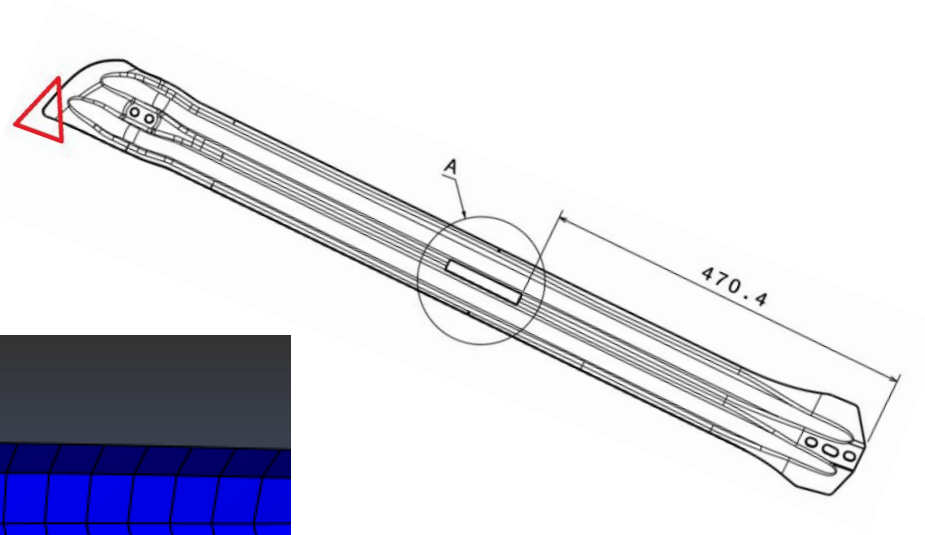
- Specification of a minimal number of elements for each patch (e.g. $n_{min} = 5$)
- Specification of a minimal search radius (element patch must contain the plastic zone)
- Incremental identification of connected elements based on connectivity information

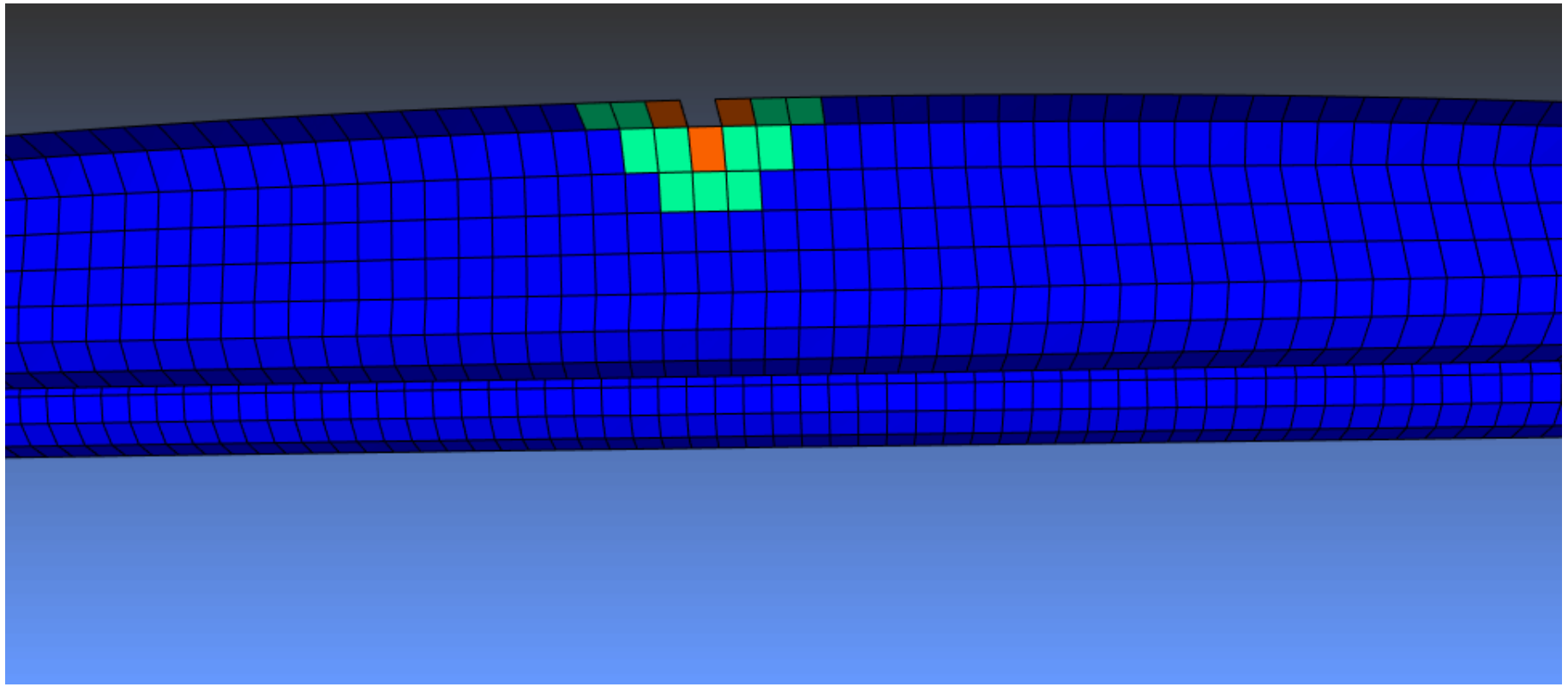


Crack propagation algorithm

Demonstrator (Door beam three point bending simulation)

- The first Test-Elements (orange) are initially preset
- Element-Patches (cyan) are automatically identified

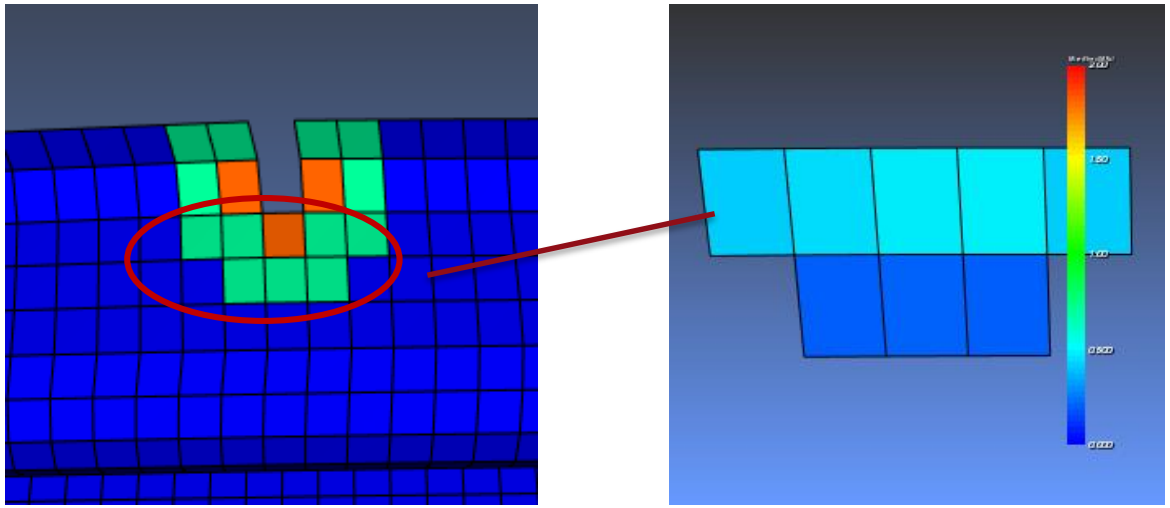


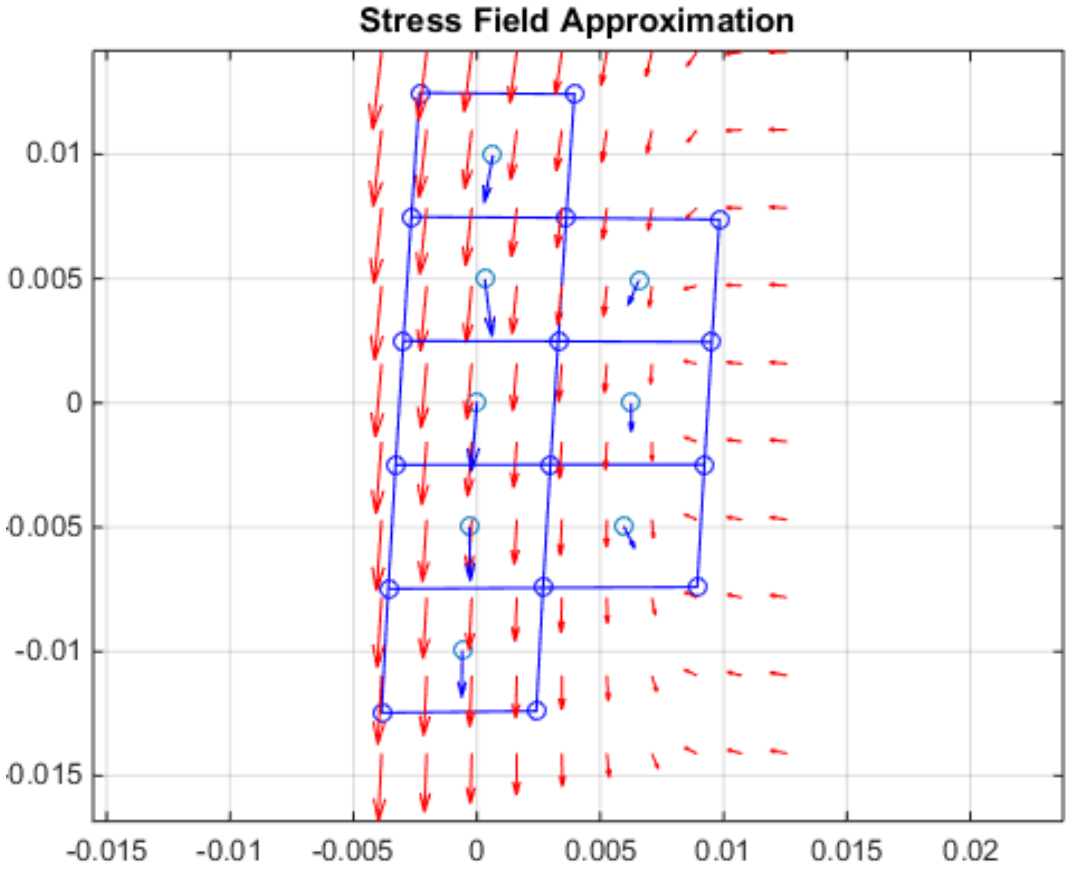


Crack propagation algorithm

Stress-Approximation in the Element-Patch

- Taylor series: $\underline{\sigma}(\underline{x}) \approx \underline{\sigma_0} + \nabla\underline{\sigma}\left(\underline{x_0}\right)\left(\underline{x} + \underline{x_0}\right)+\ldots$
- Coefficients are fitted by means of the stress-tensors in the integration points

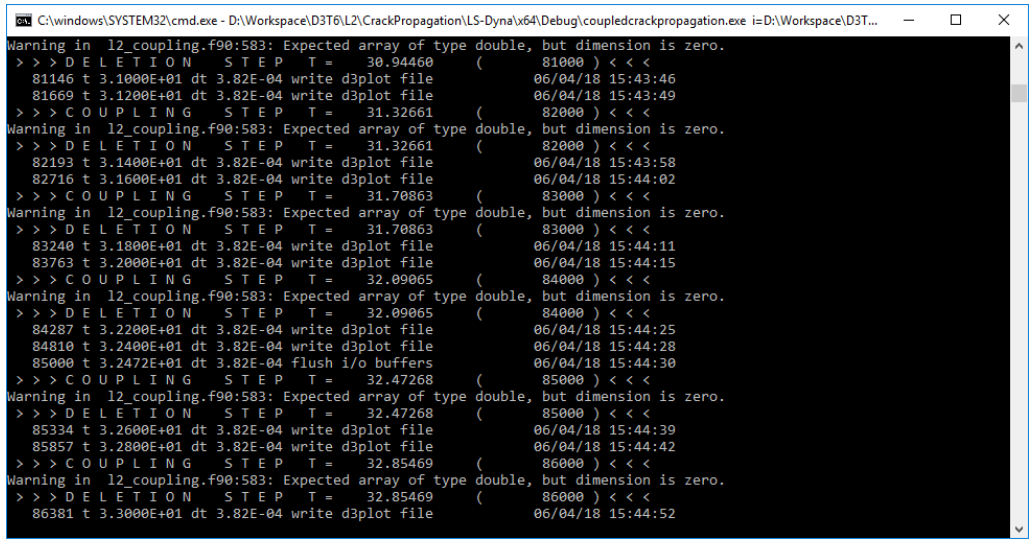


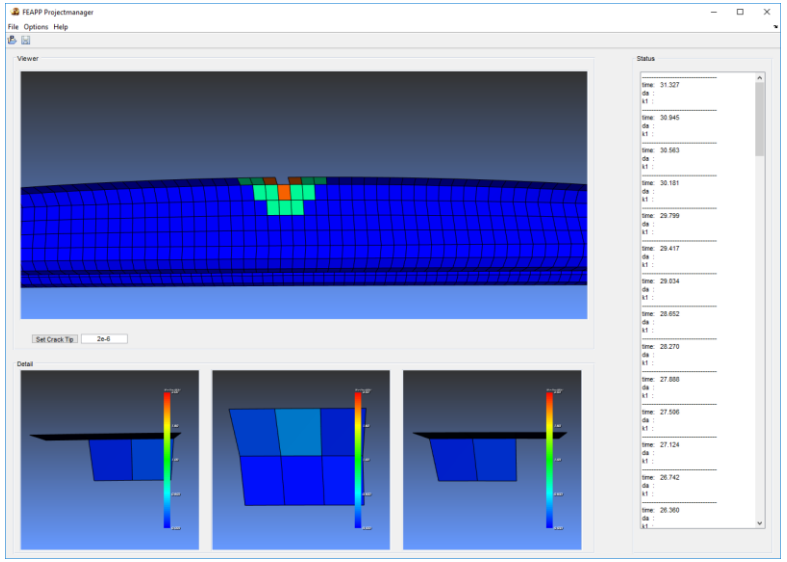


Prototypical Implementation

Current Status of Implementation

- Currently only for smp with a TCP/IP-coupling with Matlab
- All access operations in LS-Dyna are encapsulated in a specific Fortran module



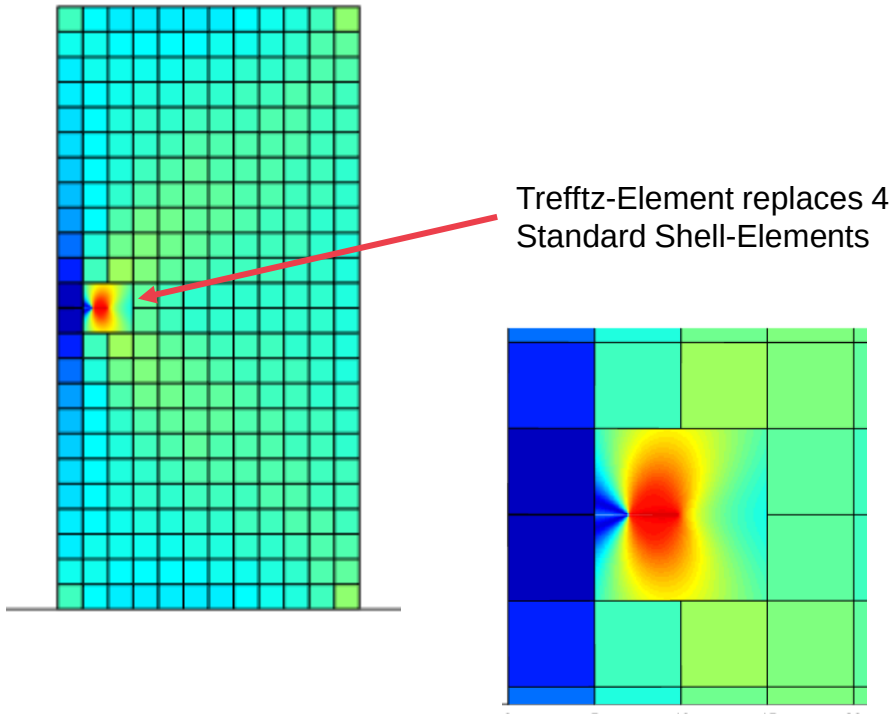


Fortran Subroutine uctrl → Wrapper Fkt. C to C++ → C++ WinSock Client → Socket Server (Java) → Matlab

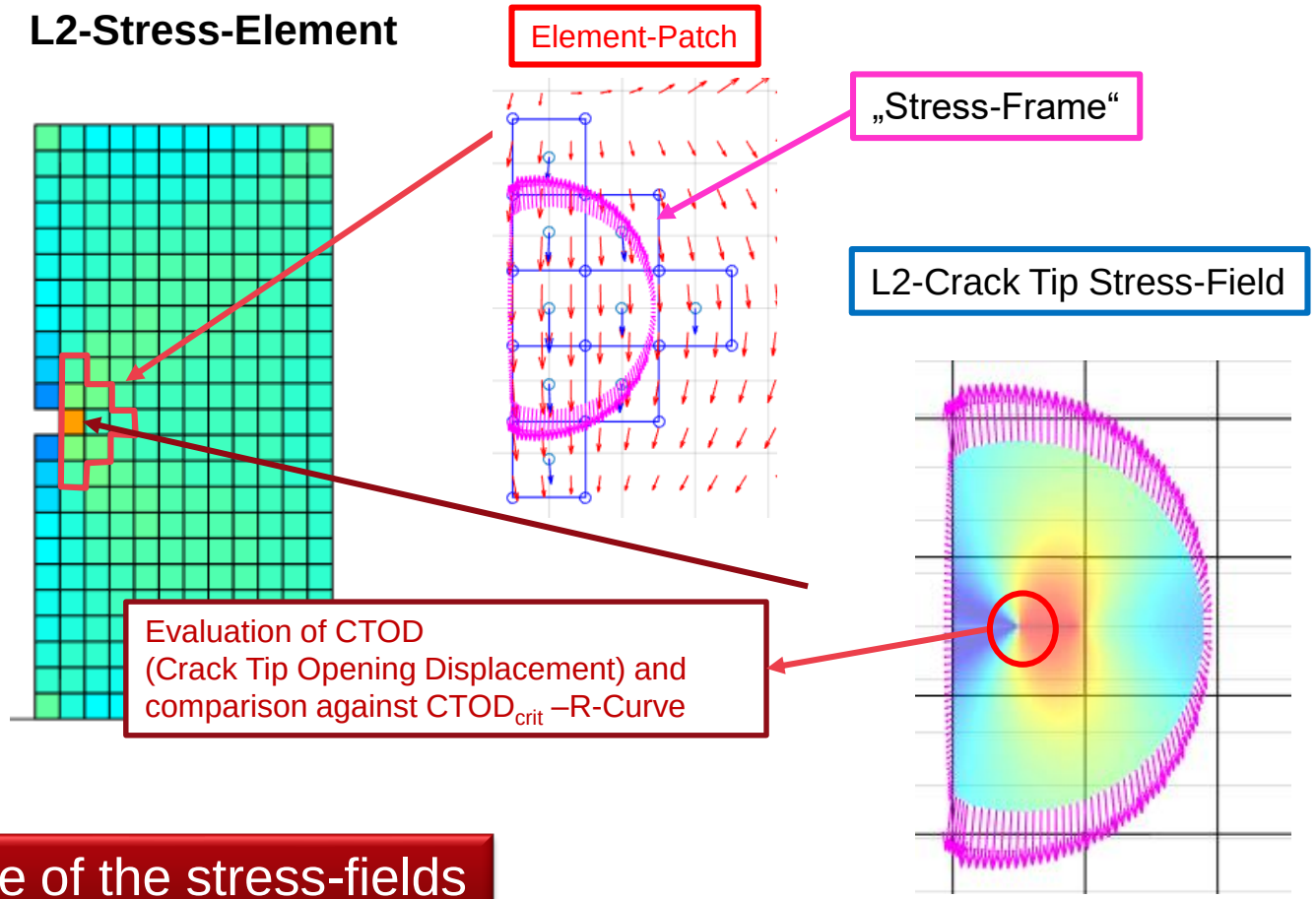
Prototypical Implementation

Validation against Hybrid Trefftz Element

Hybrid Trefftz-Method



L2-Stress-Element



Good accordance of the stress-fields

See: Kunter K., Heubrandtner T., Suhr B., Pippan R.: „A hybrid crack tip element containing a strip-yield crack-tip plasticity model”, Engineering Fracture Mechanics, Volume 129, October 2014, Pages 3-13

Conclusion and Outlook

Conclusion

- A concept for the simulation of crack propagation using a fracture mechanical criterion was presented
- The concept uses a non local stress approach to reduce the discretization error in coarse meshes
- The crack tip criterion is evaluated by means of analytical Trefftz-stress elements
- The overall algorithm was prototypical implemented using a LS-Dyna-Matlab TCP/IP software coupling

Outlook

- Implementation of a local flattening algorithm for a more accurate stress approximation in curved element patches
- Implementation of the whole algorithm in Fortran

ACKNOWLEDGEMENT

This work was accomplished at the VIRTUAL VEHICLE Research Center in Graz, Austria. The authors would like to acknowledge the financial support of the COMET K2 - Competence Centers for Excellent Technologies Programme of the Austrian Federal Ministry for Transport, Innovation and Technology (bmvit), the Austrian Federal Ministry of Science, Research and Economy (bmwfw), the Austrian Research Promotion Agency (FFG), the Province of Styria and the Styrian Business Promotion Agency (SFG).

They would furthermore like to express their thanks to their supporting industrial and scientific project partners, namely Audi AG, Porsche AG, Magna Steyr Fahrzeugtechnik AG & Co KG and to the Österreichische Akademie der Wissenschaften - Erich Schmid Institut für Materialwissenschaften.