Faculty of Sciences, Technology and Communication

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYD

Multiscale modelling of fracture…

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Saarland University, 20140131
Workshop Multiscale Simulations

Interreg IV-A
Großregion · Grande Région

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279578 - REALTCUT - Towards real time multiscale simulation of cutting in non-linear materials with applications to surgical simulation and computer guided surgery

the group…
November 2012

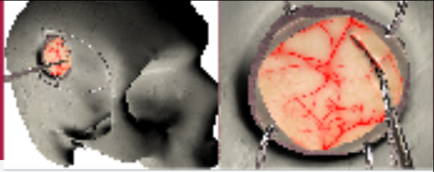
thank you

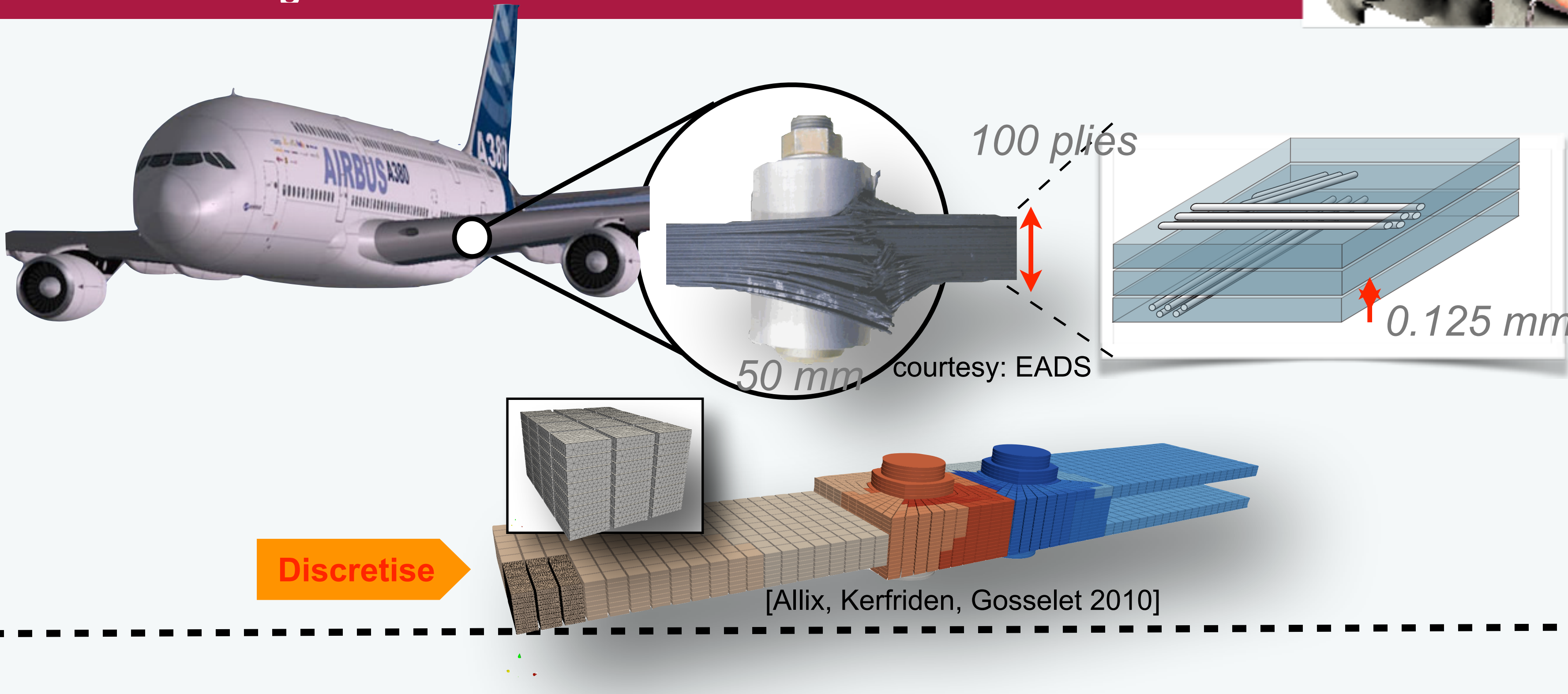
Research directions

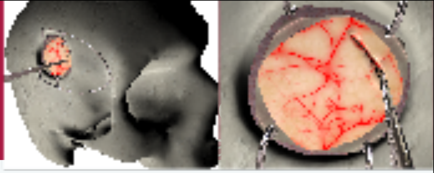
- Model reduction methods for fracture/ cutting
  - homogenisation (FE^2, …)
  - algebraic model reduction (e.g. POD)

- Advanced discretization methods
  - XFEM
  - Meshfree
  - IGA (FEM & BEM)

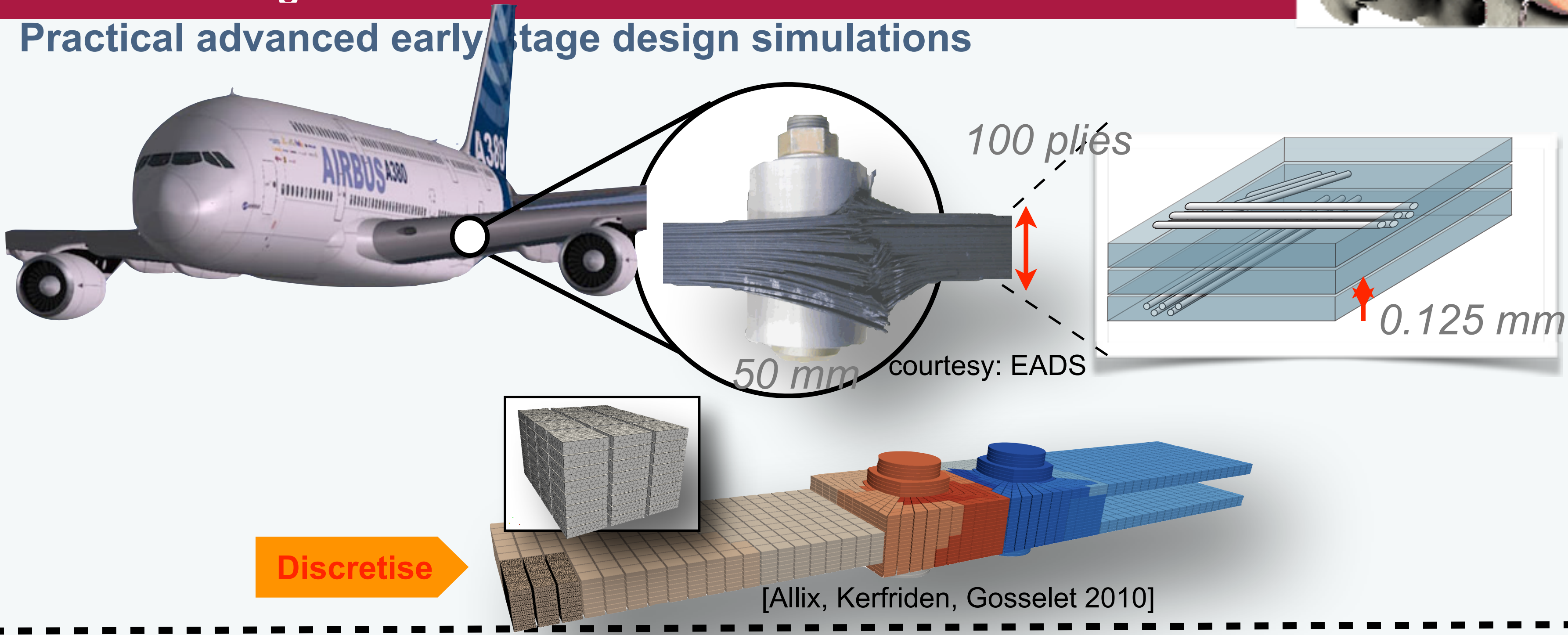
Engineering & Medical Multiscale Problems - fracture & cutting

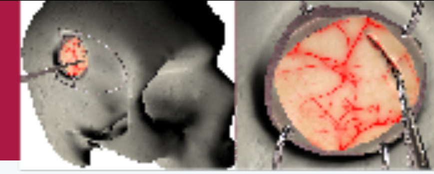




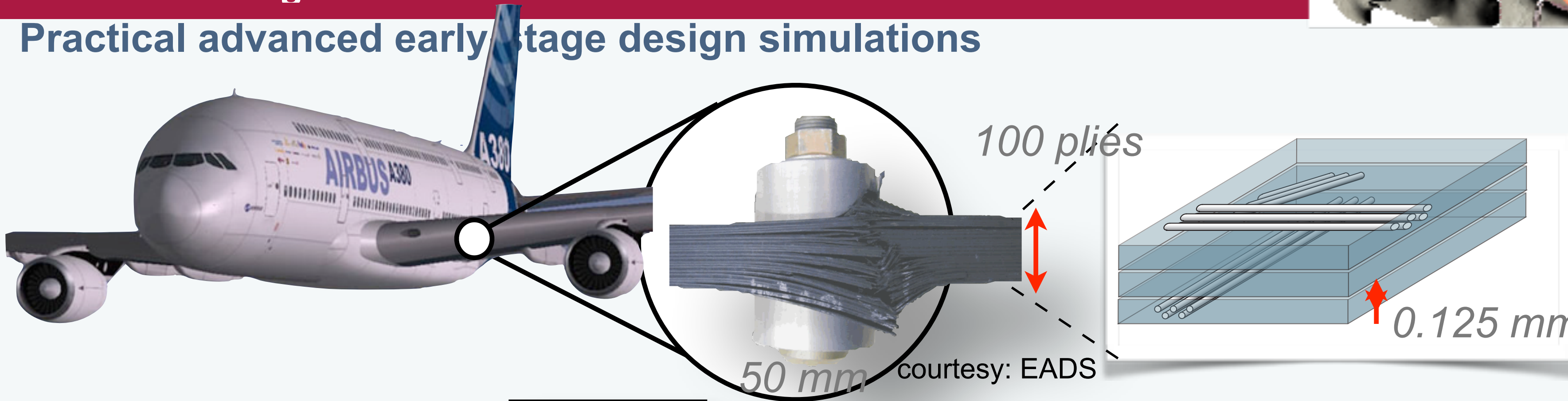


Practical advanced early stage design simulations

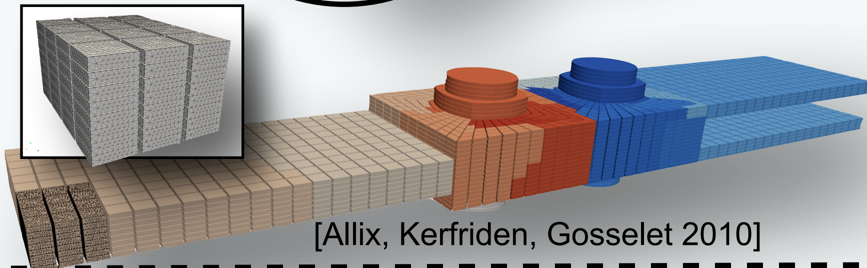




Practical advanced early stage design simulations



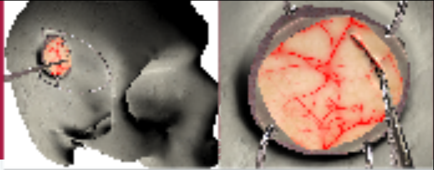
Discretise



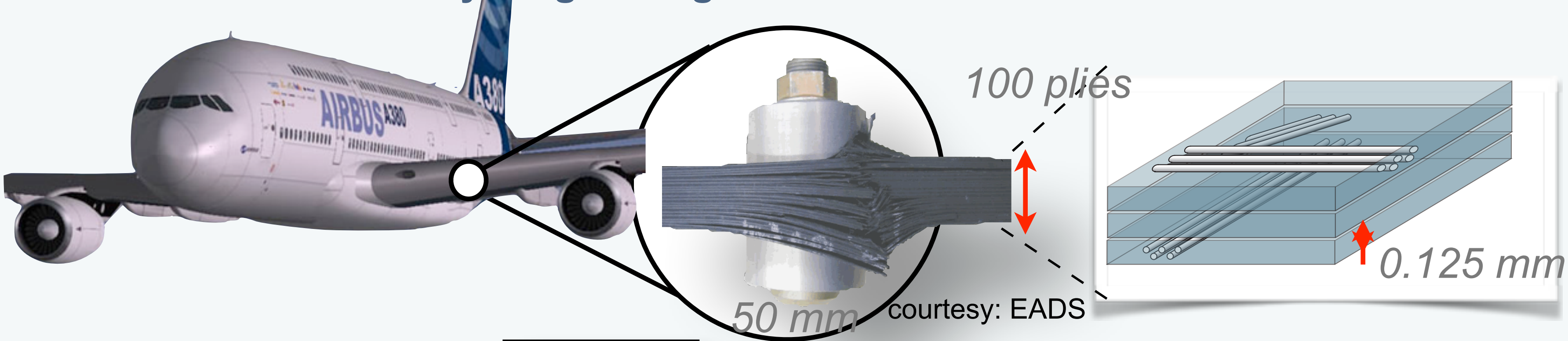
[Allix, Kerfriden, Gosselet 2010]

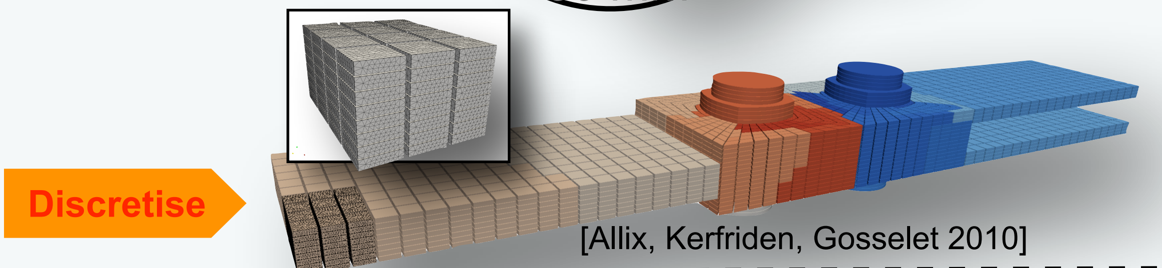
Surgical simulation (real time)

Engineering & Medical Multiscale Problems - fracture & cutting



Practical advanced early stage design simulations





Surgical simulation (real time)

- Reduce the problem size while maintaining accuracy in solving very large multiscale mechanics problems

Facilitate the transition from CAD to analysis for fracture sim.

Advanced discretisations to alleviate the mesh burden

eXtended FEM/BEM

Meshless

CAD / Analysis

Element technology

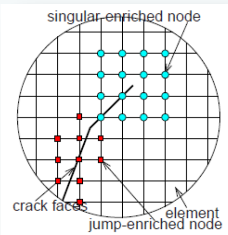
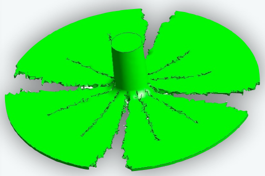
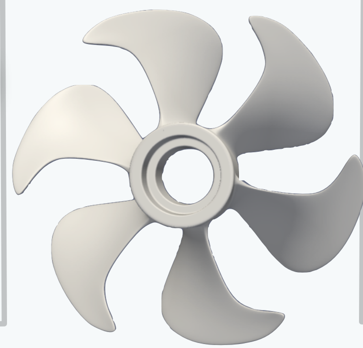


Figure 2: XFEM for cracks.





INSIST

Timon Rabczuk
Weimar

Isogeometric Analysis

Boundary Elements

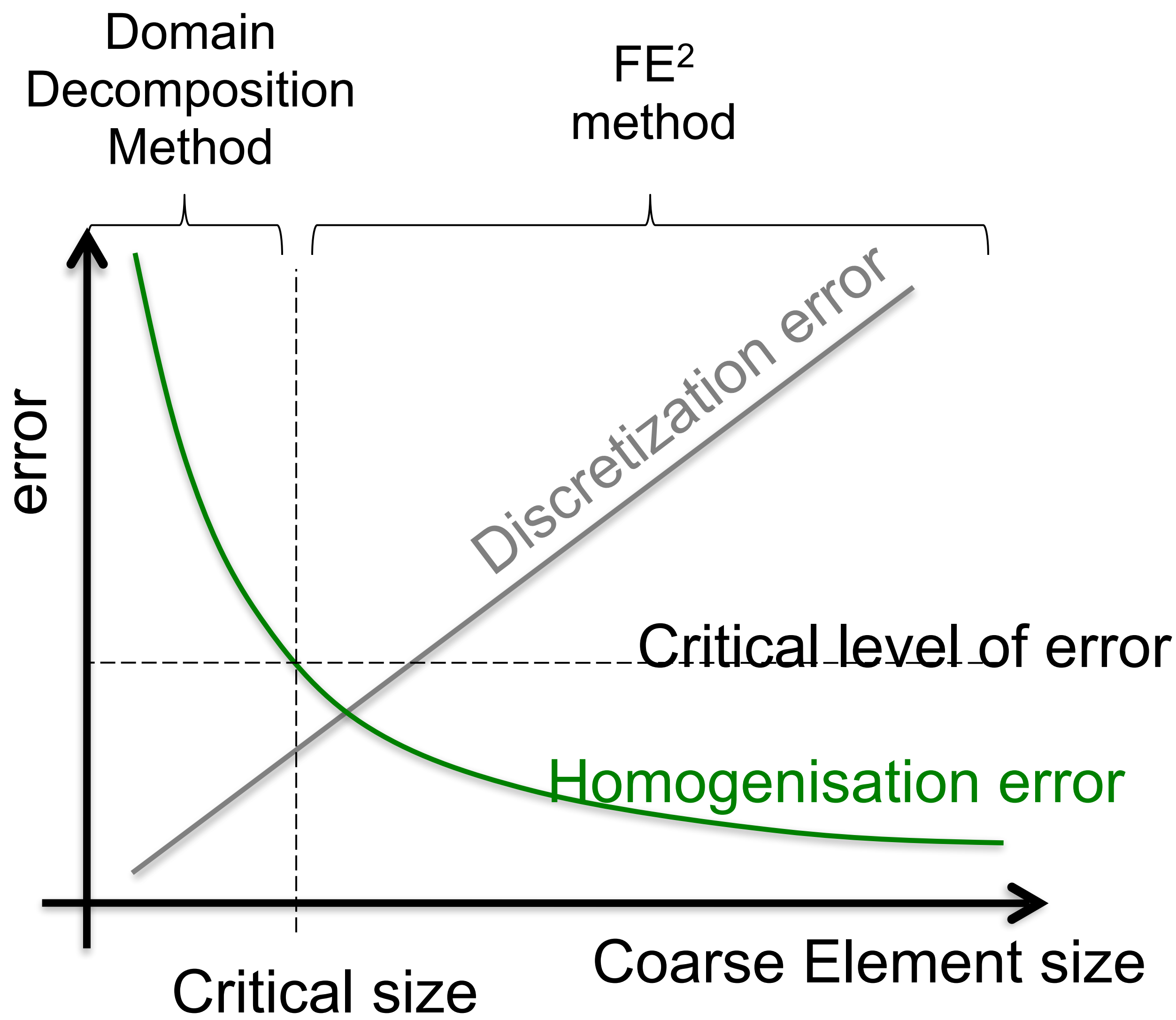
Ambient Space FEM

Isogeometric Boundary Element Analysis

Outline

- Introduction: Multiscale methods for Fracture
- Adaptive multiscale method
  - Strategy
  - Fine scale problem
  - Coarse scale problem
    - FE^2 method
    - Adaptive mesh refinement
  - Coupling fine and coarse discretisations
  - Results
    - L-shape problem
    - Notched bar under Uni-axial tension

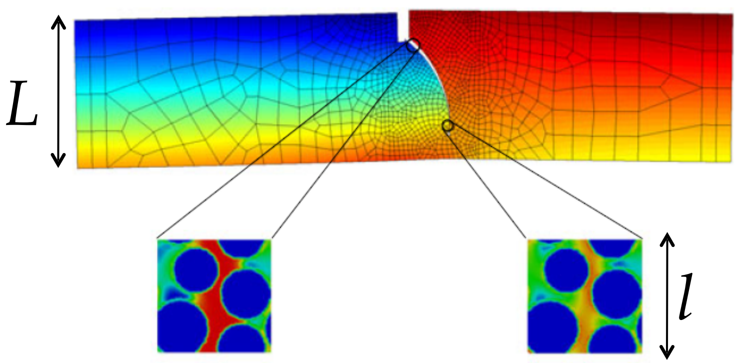
Error control in multiscale modelling



Multiscale methods for Fracture

- Non-concurrent

Damage zone is modelled by a macroscopic cohesive crack that homogenises the failure zone.

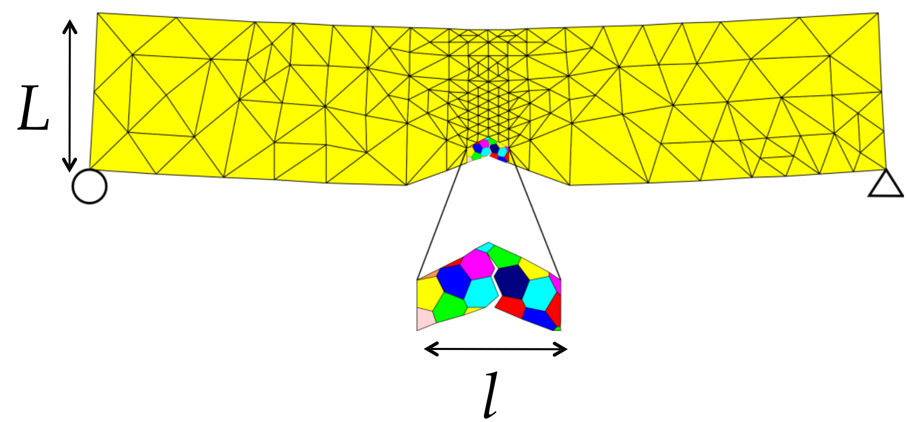


V.P. Nguyen 2012

$L/l >> 1$

- Concurrent

Damage zone is modelled directly at the microscale and coupled to the coarse scale.

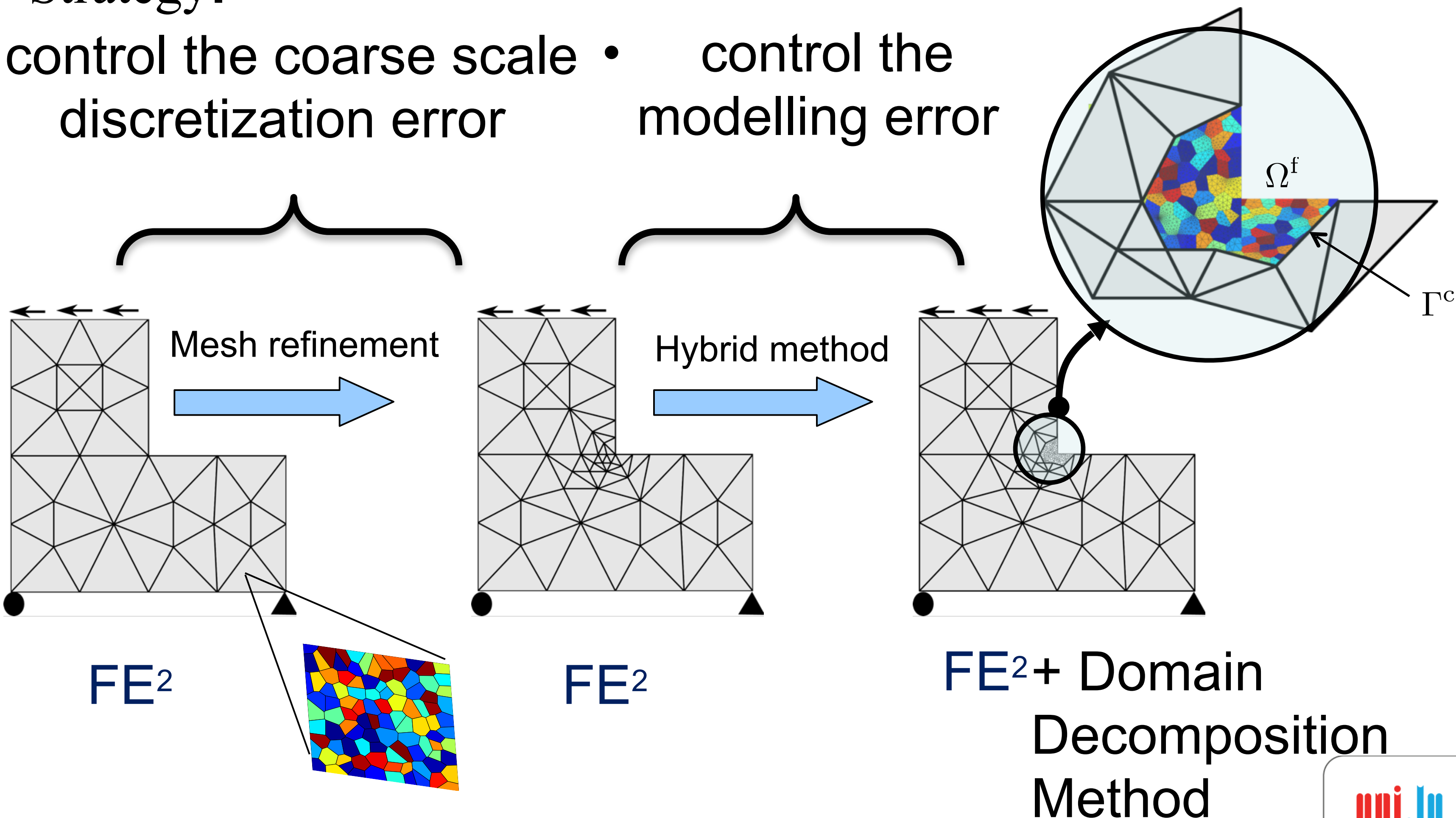


$L/l > 1$

Adaptive multiscale method: A Concurrent approach

➢Strategy:

- control the coarse scale discretization error
- control the modelling error



Fine Scale: micro-structure

➢Microscale problem:

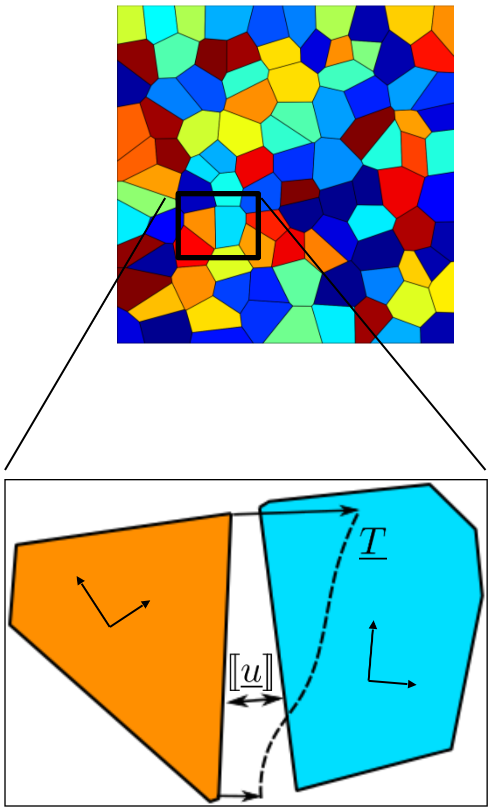
$$\int_{\Omega/\Gamma_c} \boldsymbol{\sigma}(\mathbf{u}) : \delta\boldsymbol{\varepsilon}\, \mathrm{d}\Omega + \int_{\Gamma_c} \mathbf{T}\cdot[\![\delta\mathbf{u}]\!]\mathrm{d}\Omega = \int_{\partial\Omega} \mathbf{f}\cdot\delta\mathbf{u}\mathrm{d}\Gamma$$

- Orthotropic grains

$$\forall \mathbf{x} \in \Omega/\Gamma_c, \quad \boldsymbol{\sigma} = \mathbf{C} : \boldsymbol{\varepsilon}$$

- Cohesive interface

$$\forall \mathbf{x} \in \Gamma_c, \quad \mathbf{T}_{|t} = T\left(\left([\![\mathbf{u}]\!]_{|\tau}\right)_{\tau\leq t}\right)$$

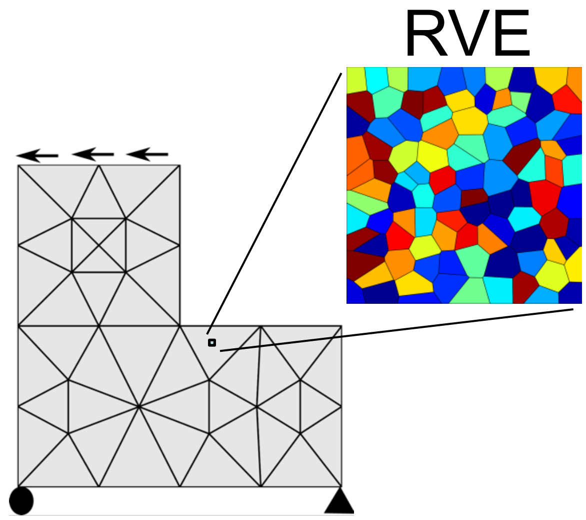


Coarse Scale

➢Macroscale problem:

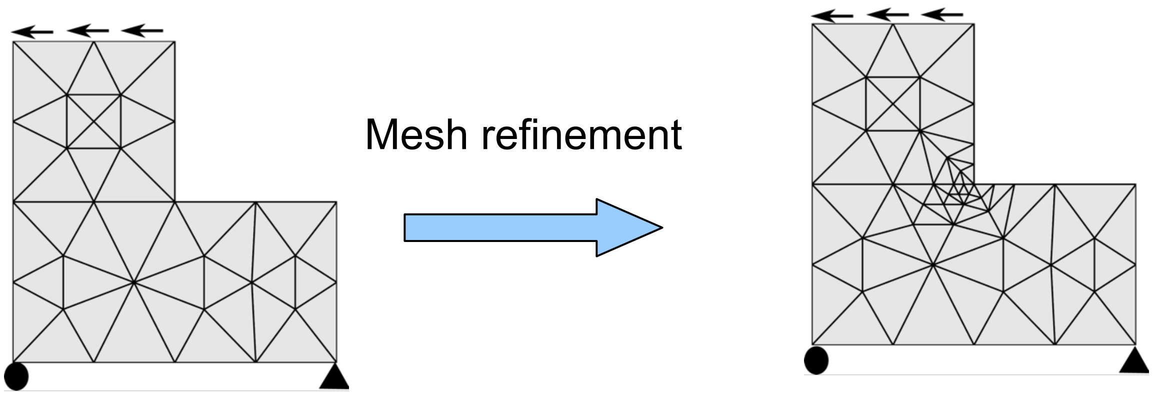
- FE² Method

Based on averaging theorem (computational homogenisation)



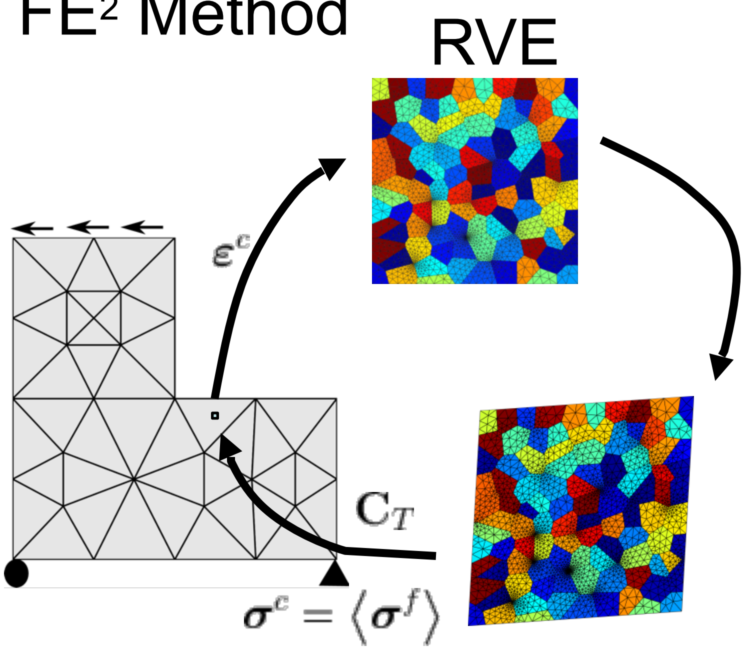
- Adaptive mesh refinement

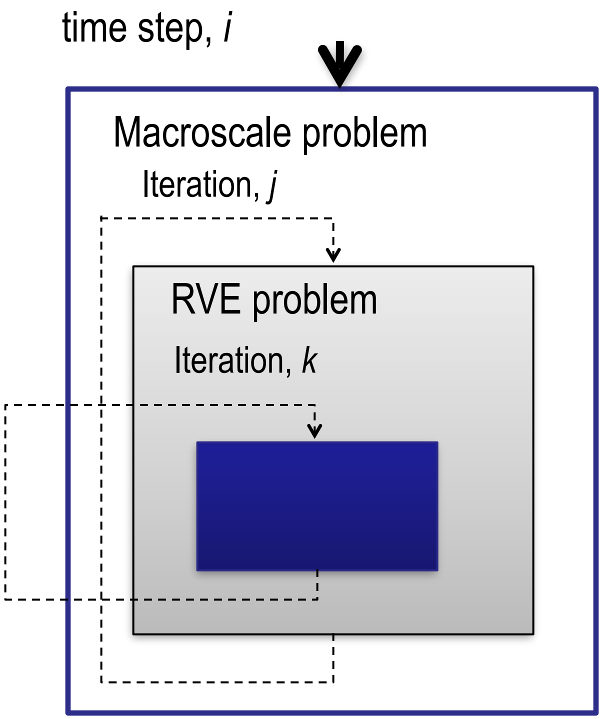
Error estimation by Zienkiewicz-Zhu-type recovery technique



Coarse Scale: FE2

- The FE² Method





❖ Shortcoming of the FE² Method :

Lack of scale separation

RVE cannot be found in the **softening regime**

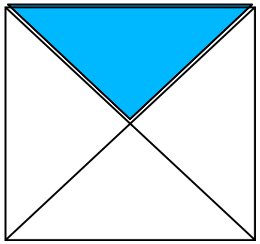
Coarse Scale: Adaptive mesh refinement

➢**Coarse scale Adaptive mesh refinement**

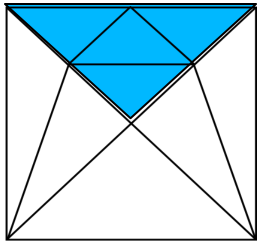
- Error estimation by Zienkiewicz-Zhu-type recovery technique

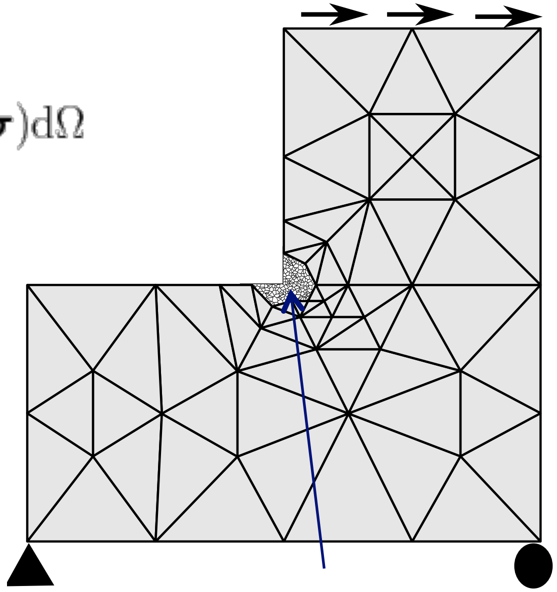
$$\|e\| = \int_{\Omega_c} (\boldsymbol{\sigma}^* - \boldsymbol{\sigma}) : \left(\frac{\partial \boldsymbol{\sigma}}{\partial \boldsymbol{\varepsilon}}\Big|_{\mathbf{u}^c} \right)^{-1} : (\boldsymbol{\sigma}^* - \boldsymbol{\sigma}) \mathrm{d}\Omega$$

Element to refine



Refined mesh





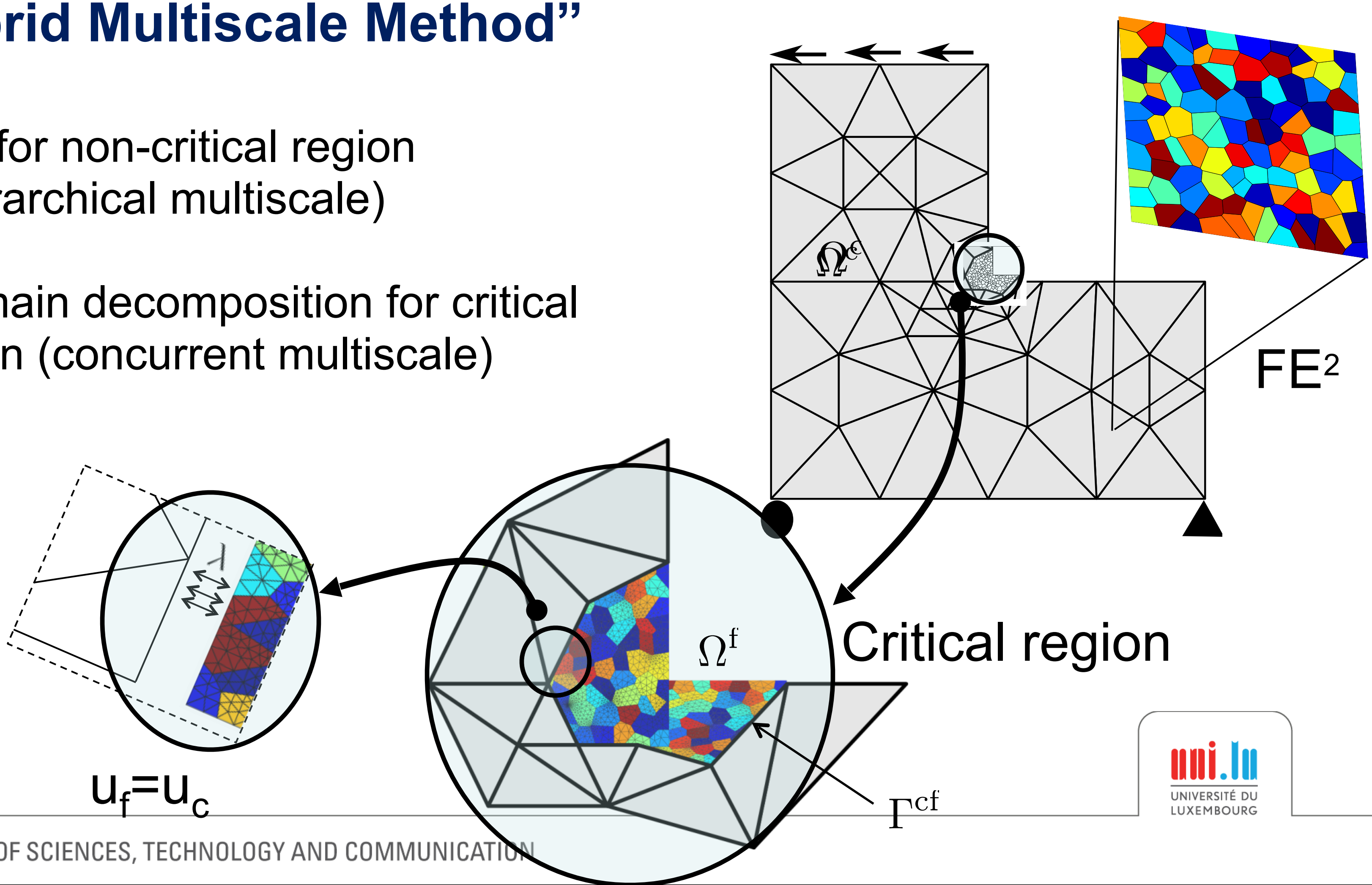
Error due to the discretisation of Ω^{f} neglected

•Convergence criterion: $\frac{\|e\|}{\|\sigma\|} < Tol$

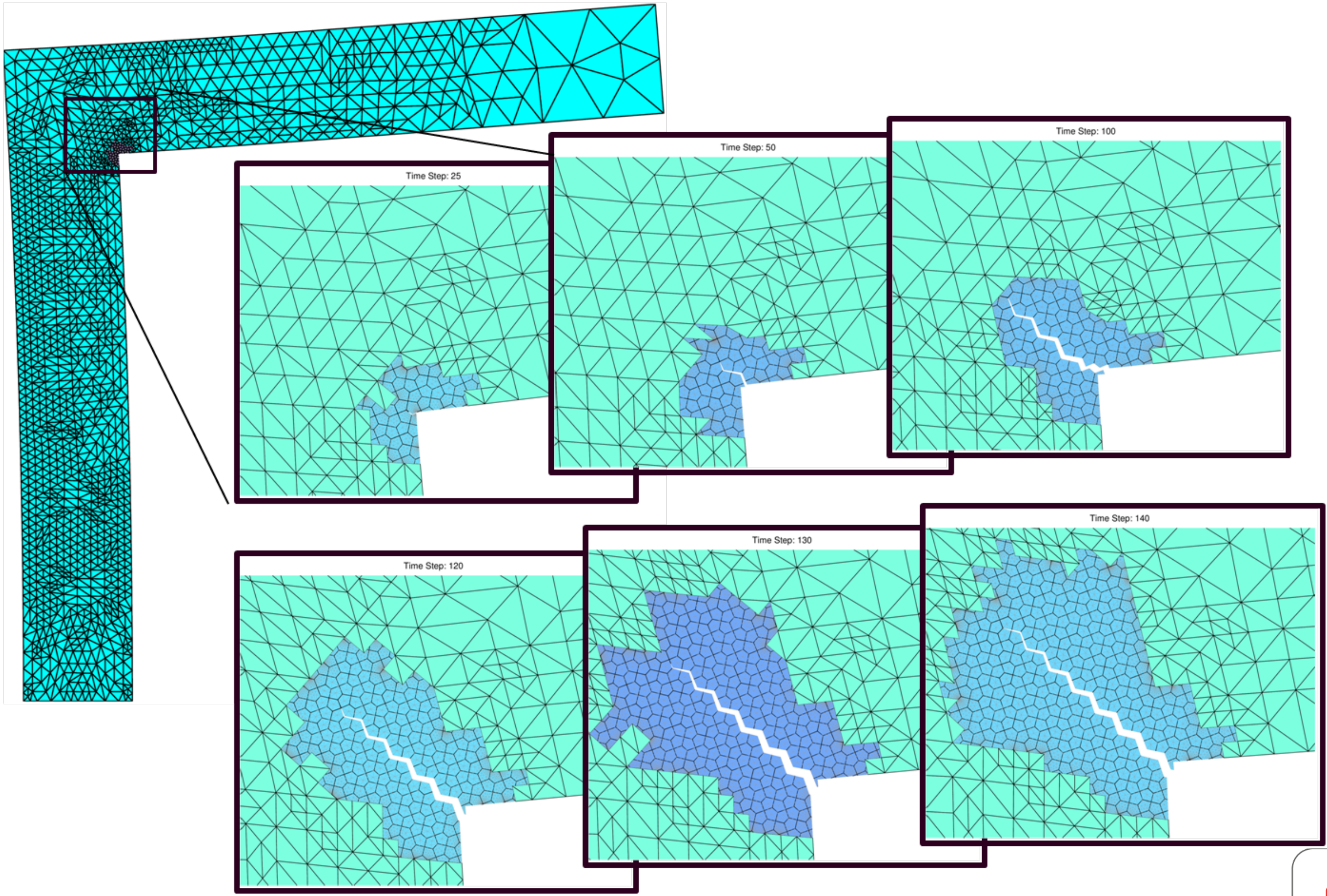
Fine-Coarse scales Coupling

What is the solution for the FE² **shortcoming:**
"Hybrid Multiscale Method"

- FE^2 for non-critical region (hierarchical multiscale)
- Domain decomposition for critical region (concurrent multiscale)



Results: L-shape



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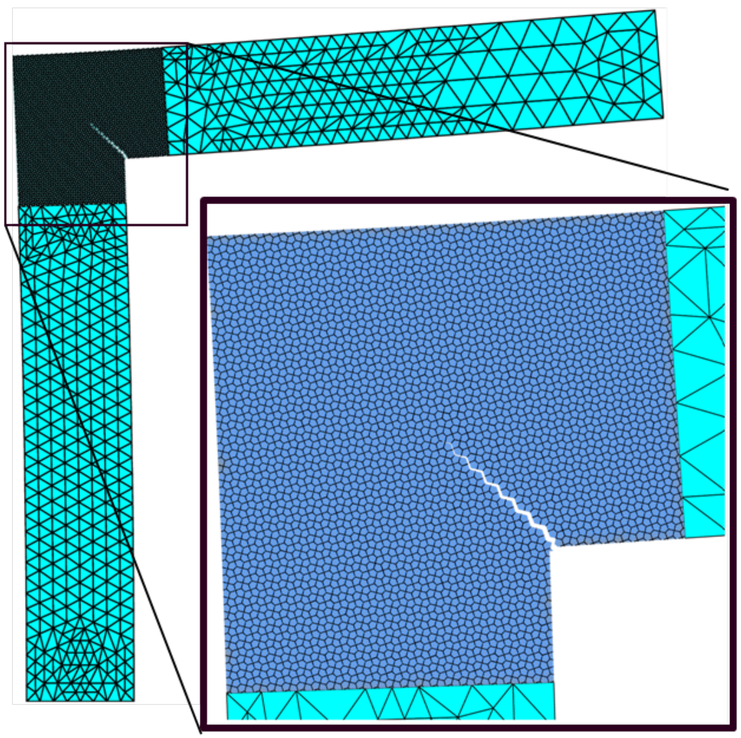
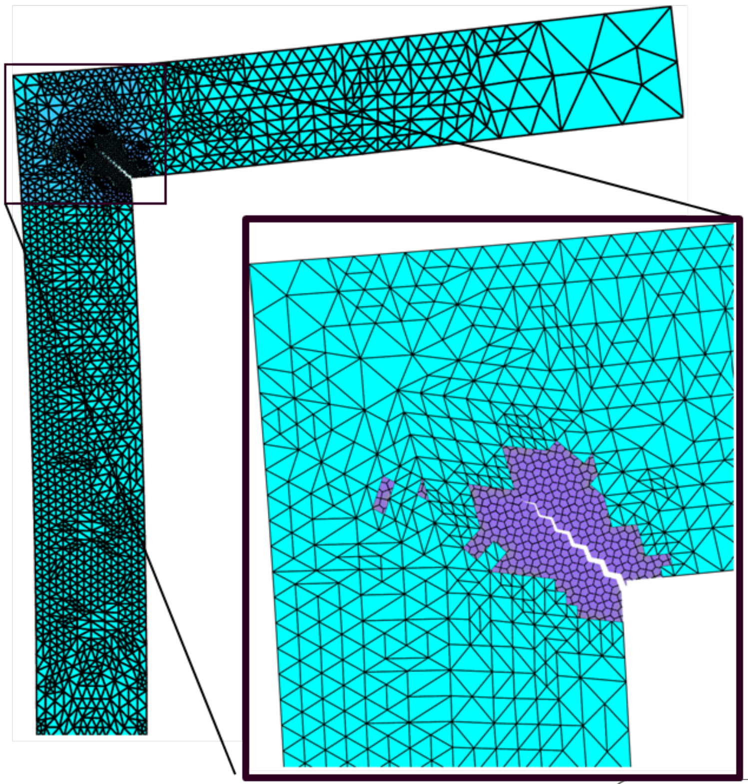
Results: L-shape

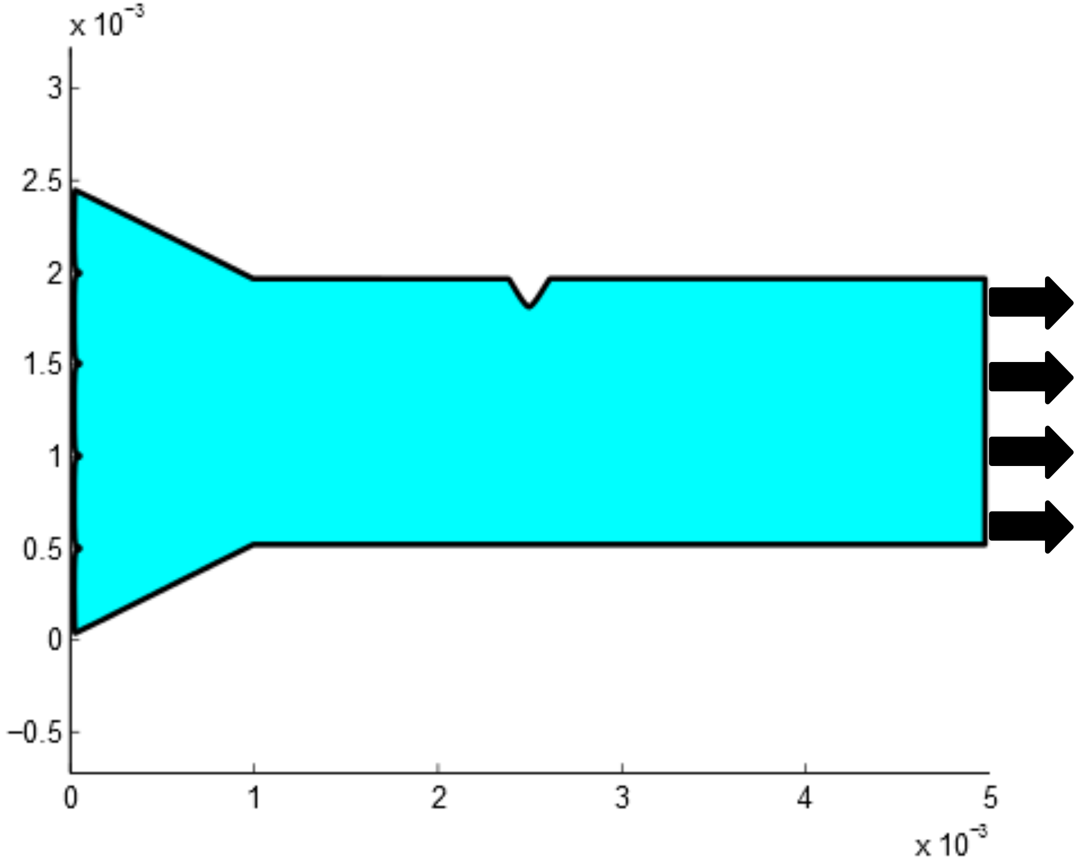
Direct Numerical Solution



Adaptive Multiscale method



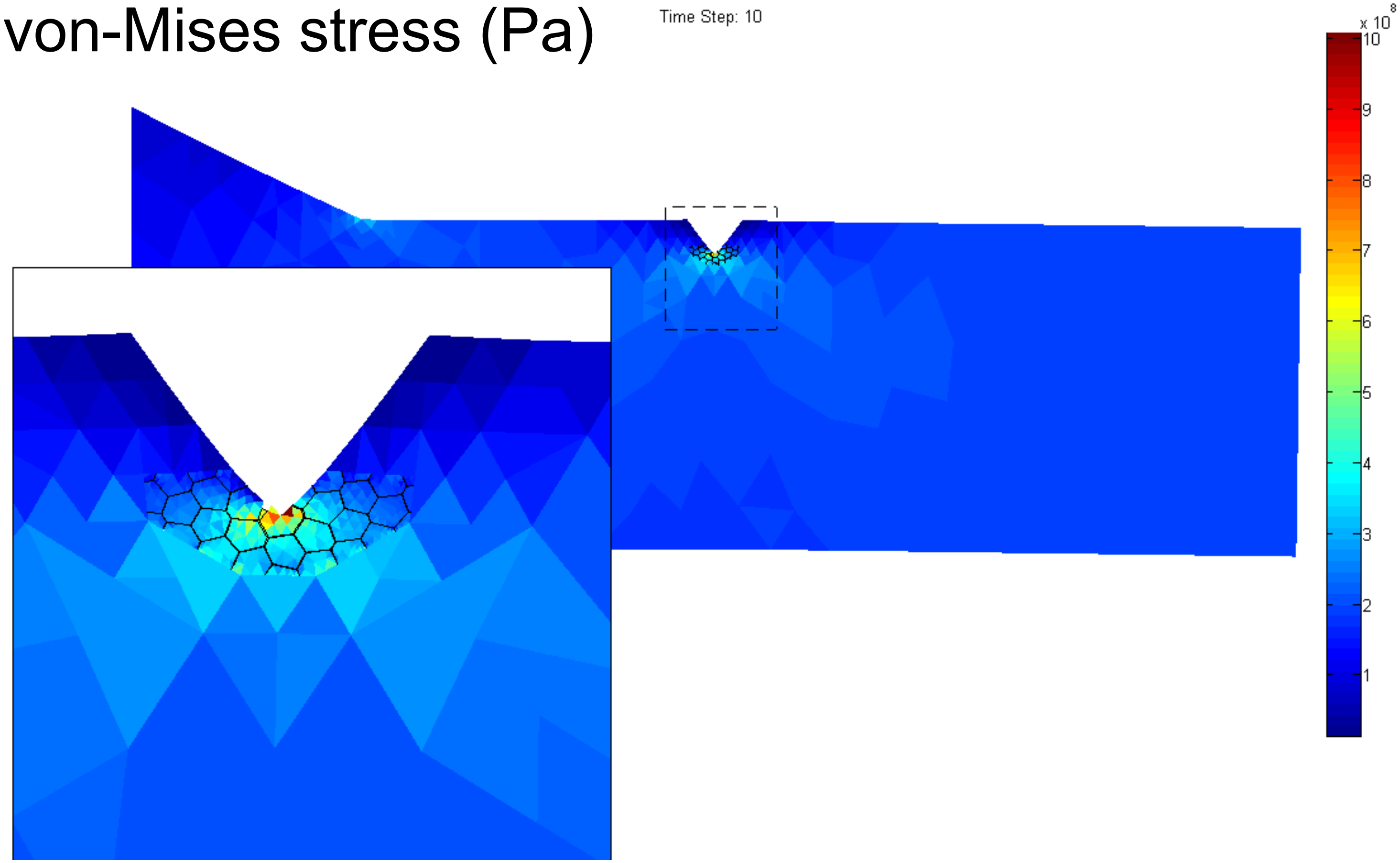
Results: uni-axial tension



❖ Sizes are in mm

Results: uni-axial tension

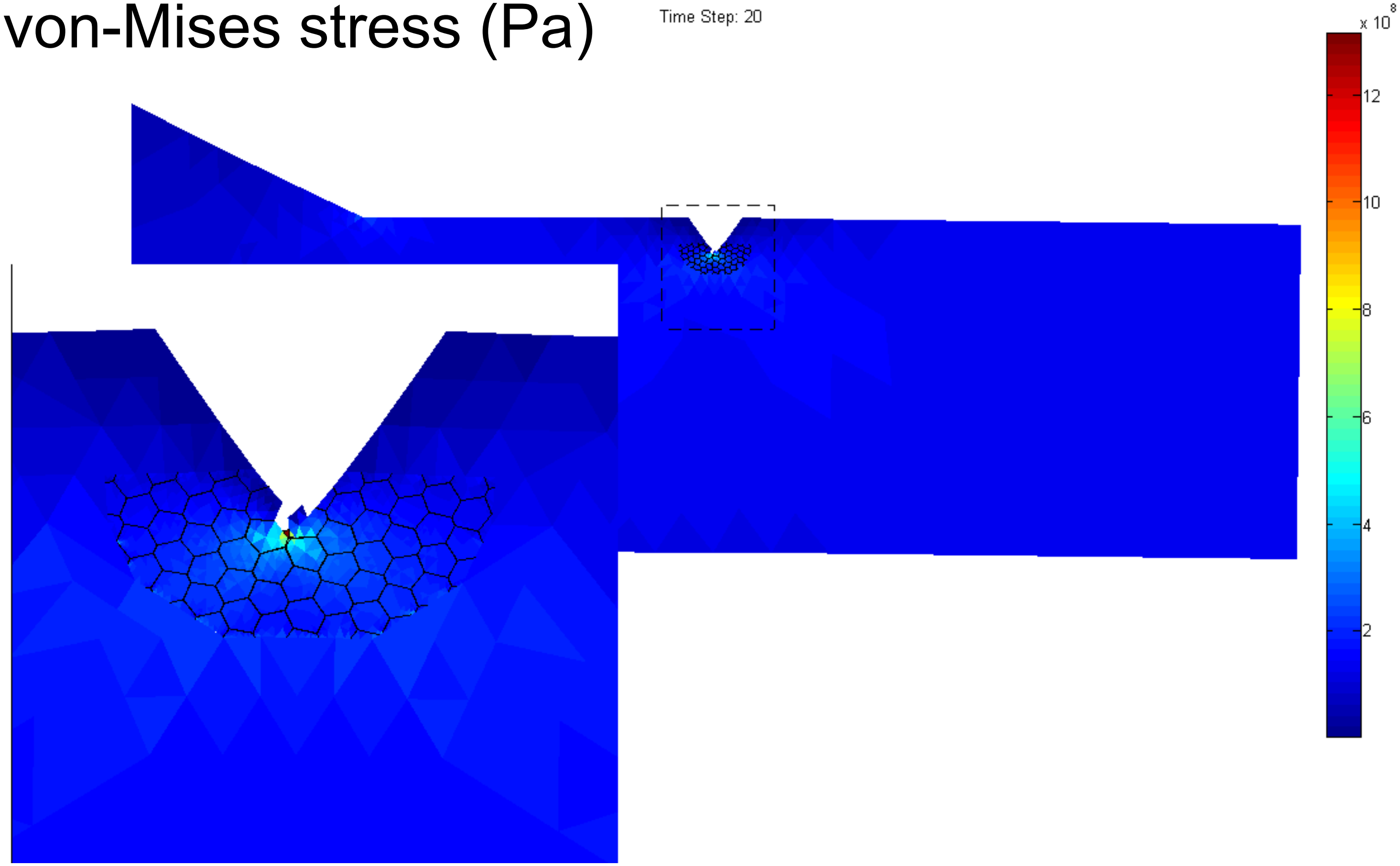
von-Mises stress (Pa)



❖ 100X (magnification of displacement)

Results: uni-axial tension

von-Mises stress (Pa)



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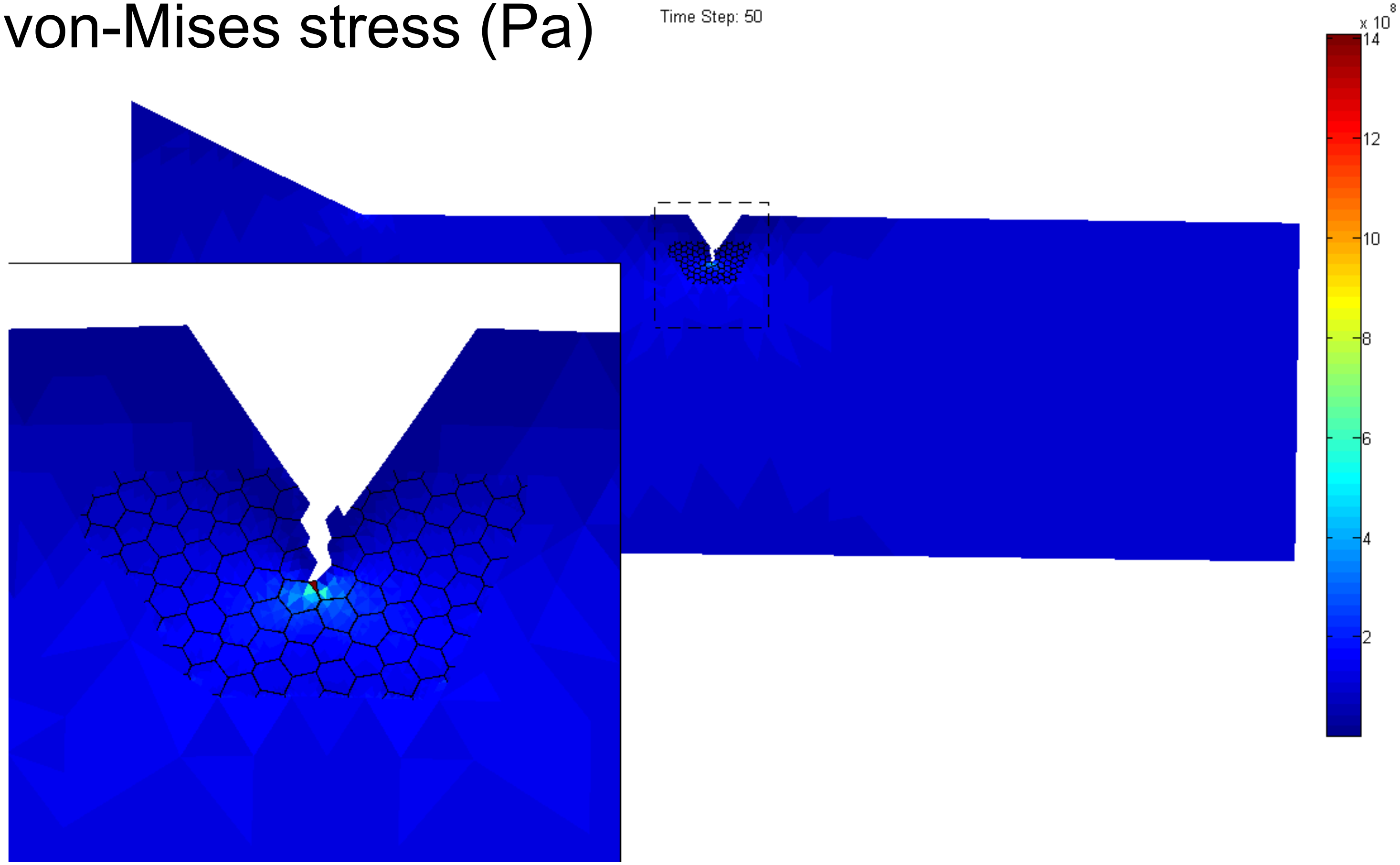

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Results: uni-axial tension

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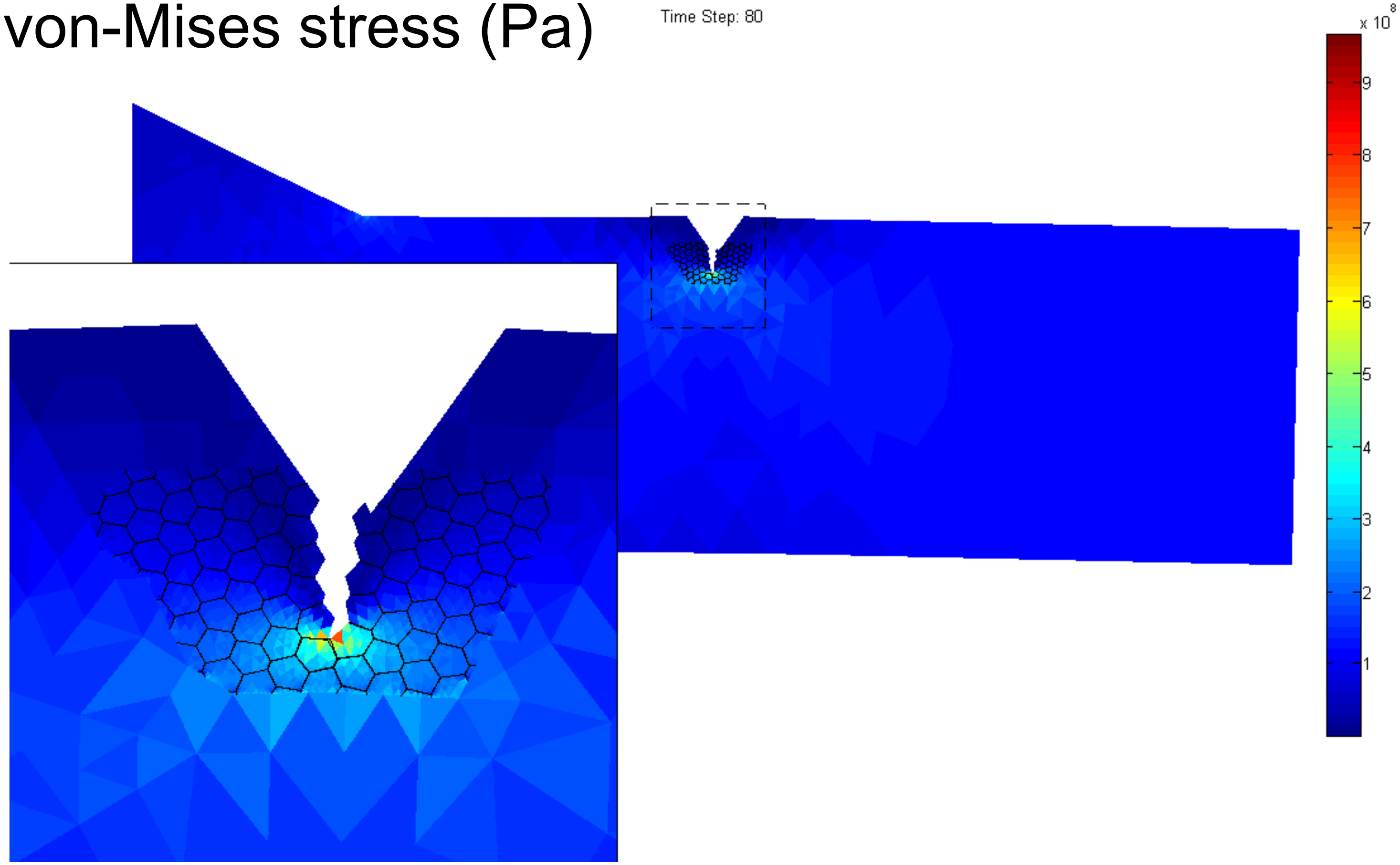

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Results: uni-axial tension

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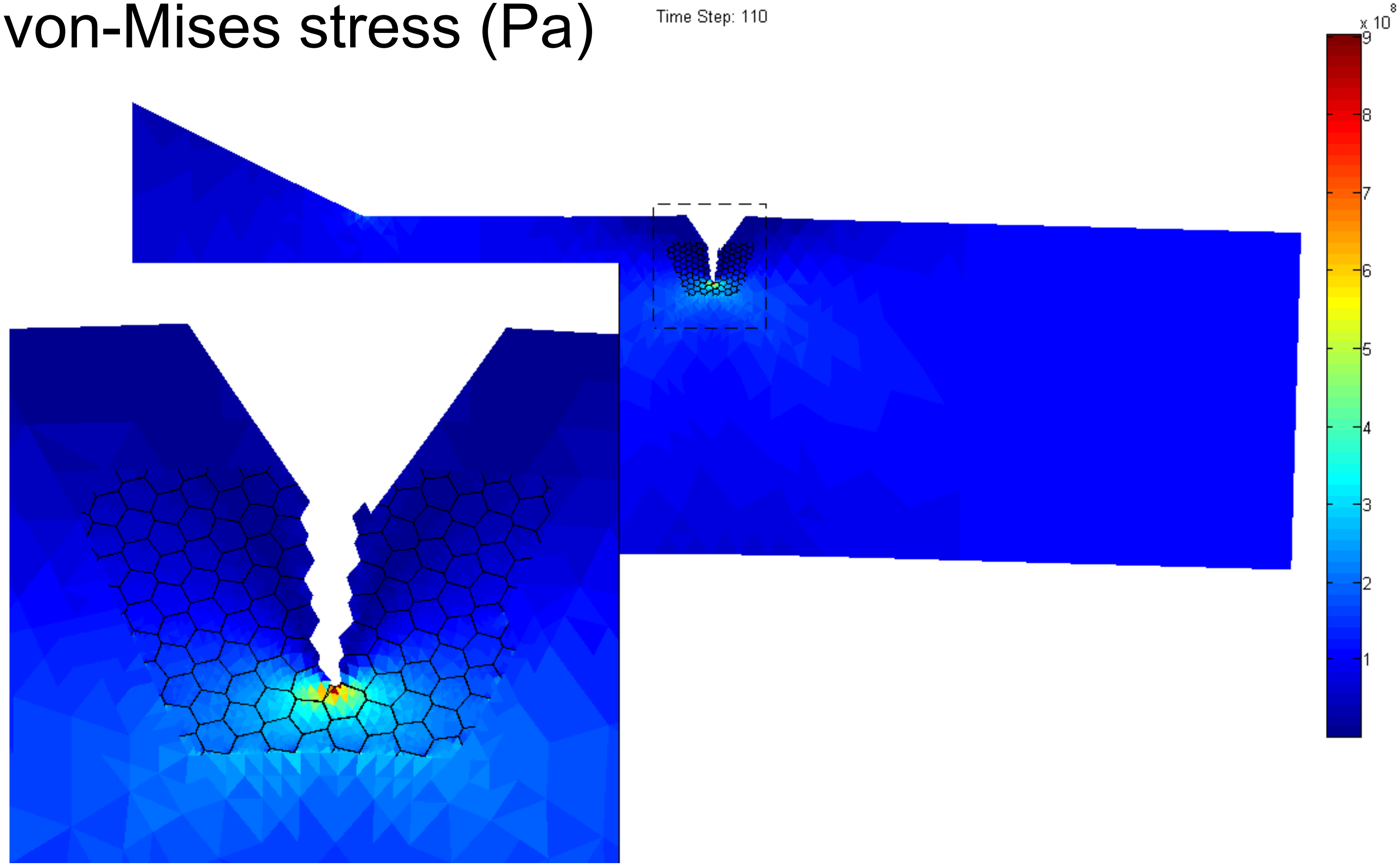


❖ 100X (magnification of displacement)

Adaptive Multiscale Method

An adaptive multiscale method was developed for discrete fracture in polycrystalline materials:

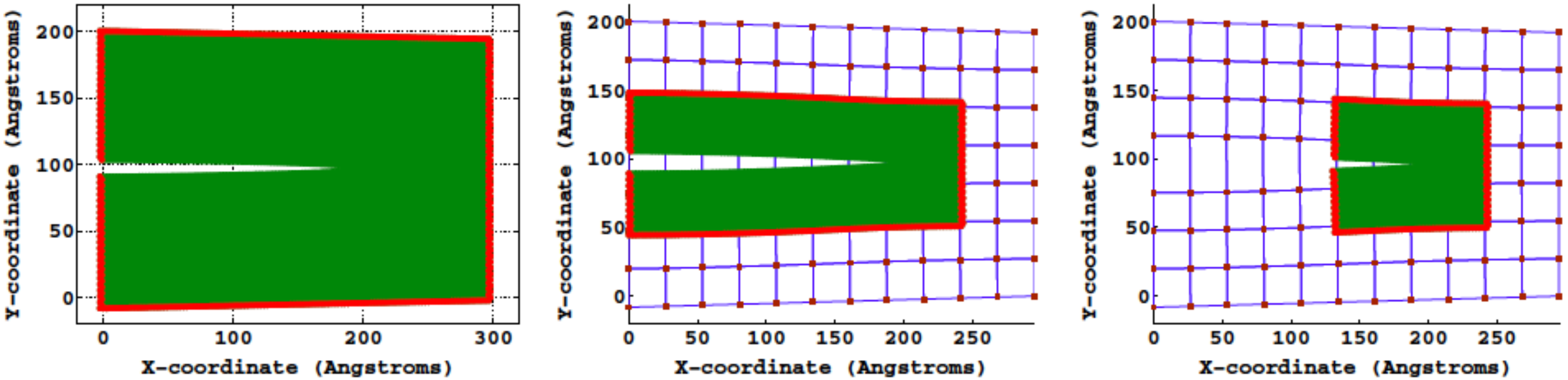
- An unstructured mesh is used for the coarse scale problem

- A local arc-length was used to control crack speed in the fully resolved region.

- A recovery based error indicator was employed to limit discretization error at each time step.

Perspectives

- coarsening once the crack is open
- molecular dynamics at the fine scale



- real-life problems! :)
- coupling with algebraic model reduction (POD)

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SourceForge

TWO POST DOCS
TWO FACULTY POSITIONS AVAILABLE

OPEN SOURCE CODES

PERMIX: Multiscale, XFEM, large deformation, coupled 2 LAMMPS, ABAQUS, OpenMP - Fortran 2003, C++

MATLAB Codes: XFEM, 3D ISOGEOMETRIC XFEM, 2D ISOGEOMETRIC BEM, 2D MESHLESS
DOWNLOAD @ http://cmechanicsos.users.sourceforge.net/

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COMPUTATIONAL MECHANICS DISCUSSION GROUP

Request membership @
http://groups.google.com/group/computational_mechanics_discussion/about

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Publications - model reduction

- http://orbilu.uni.lu/handle/10993/12024
- http://orbilu.uni.lu/handle/10993/12012
- http://orbilu.uni.lu/handle/10993/10207
- http://orbilu.uni.lu/handle/10993/12454
- http://orbilu.uni.lu/handle/10993/12453
- http://orbilu.uni.lu/handle/10993/14475
- http://orbilu.uni.lu/handle/10993/10206

Mesh-burden reduction

- http://orbilu.uni.lu/handle/10993/12159
- http://orbilu.uni.lu/handle/10993/14135
- http://orbilu.uni.lu/handle/10993/13847
- http://orbilu.uni.lu/handle/10993/12157
- http://orbilu.uni.lu/handle/10993/11850

Demos

- Surgical simulation
  - http://www.youtube.com/watch?v=KqM7rh6sE8s
  - http://www.youtube.com/watch?v=DYBRKbEiHj8
- Multi-crack growth
  - http://www.youtube.com/watch?v=6yPb6NXnex8
  - http://www.youtube.com/watch?v=7U2o5bFvj8E

Demos

- http://www.youtube.com/watch?v=90NAq76mVmQ
- Solder joint durability
  - http://www.youtube.com/watch?v=Ri96Wv6zBNU
  - http://www.youtube.com/watch?v=1g3Pe_9XN9I

Damage tolerance assessment directly from CAD

- http://www.youtube.com/watch?v=RV0gidOT0-U
- http://www.youtube.com/watch?v=cYhaj6SPLTE
- http://orbilu.uni.lu/handle/10993/12159
- http://orbilu.uni.lu/handle/10993/14135
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