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Assessing the Accuracy of Different Remapping Methods in Adaptive Mesh Refinement

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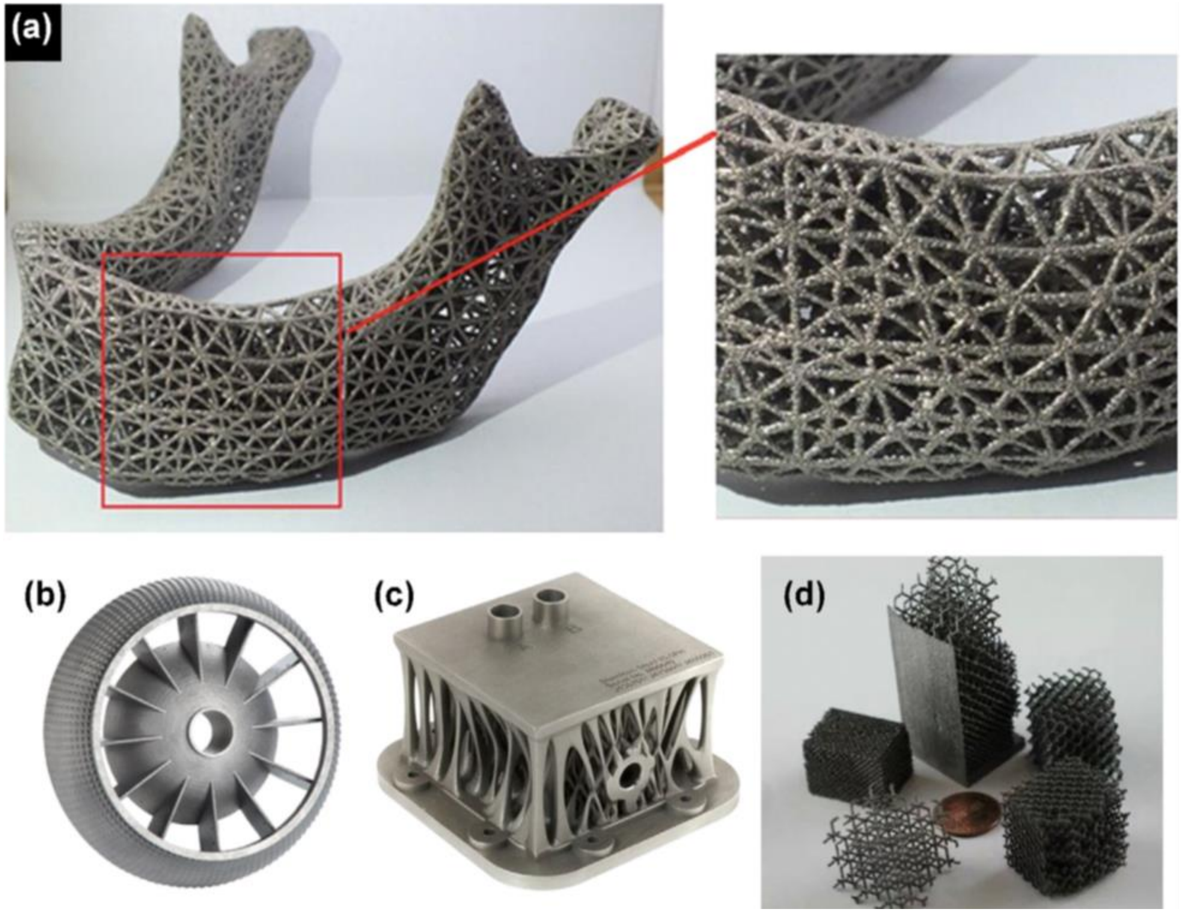
ESAFORM 2022
25th International Conference on Material Forming

27th-29th April 2022
Braga, Portugal

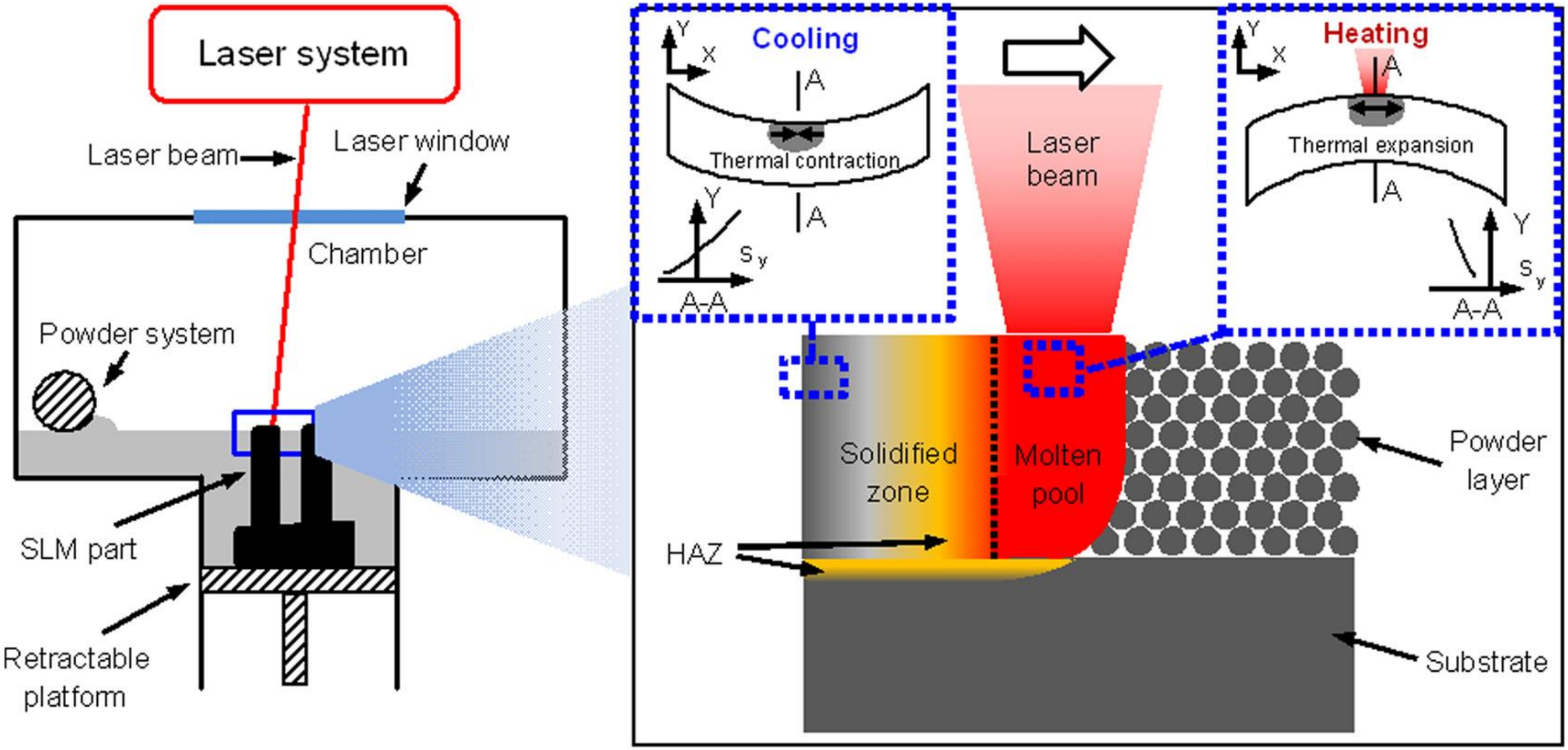
Selective Laser Melting (SLM)

- Parts are built by **successively adding material in a layer wise fashion**.
- Capable of **building parts with complex geometry**.



Selective Laser Melting (SLM)

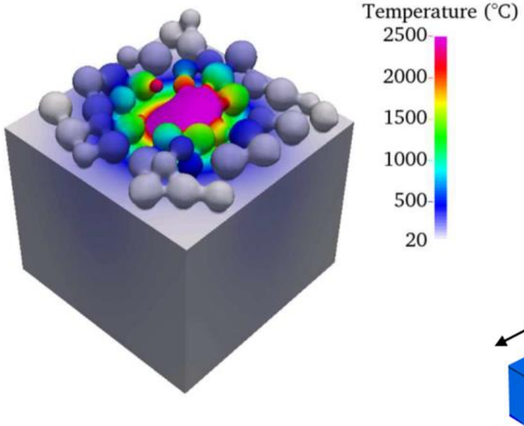
- **Powder material** is **deposited**.
- A **laser** is used to **selectively melt powder material** (powder → liquid).
- The **liquid material** cools down and **solidifies** (liquid → solid).



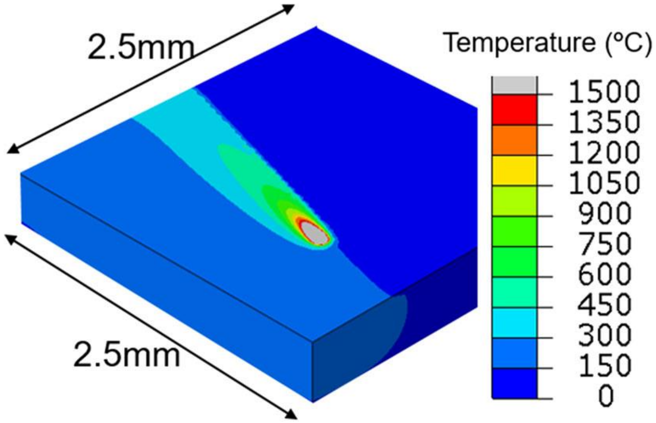
SLM numerical modelling

- SLM presents **multiphysics phenomena across multiple scales**.
  - **Micro-scale** – modelling the interactions between the laser and powder particles.
  - **Meso-scale** – modelling sub-regions of the process (typically scan vectors).
  - **Macro-scale** – modelling at part scale.

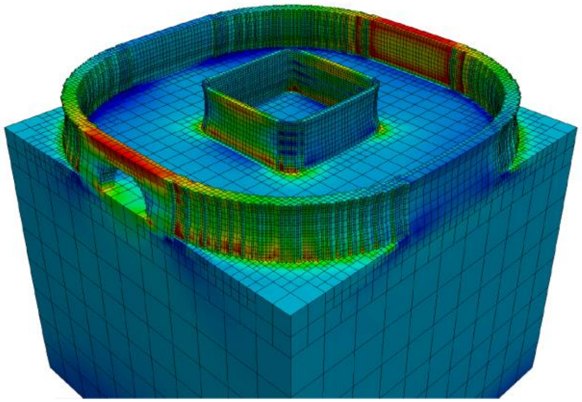
Micro-scale



Meso-scale



Macro-scale



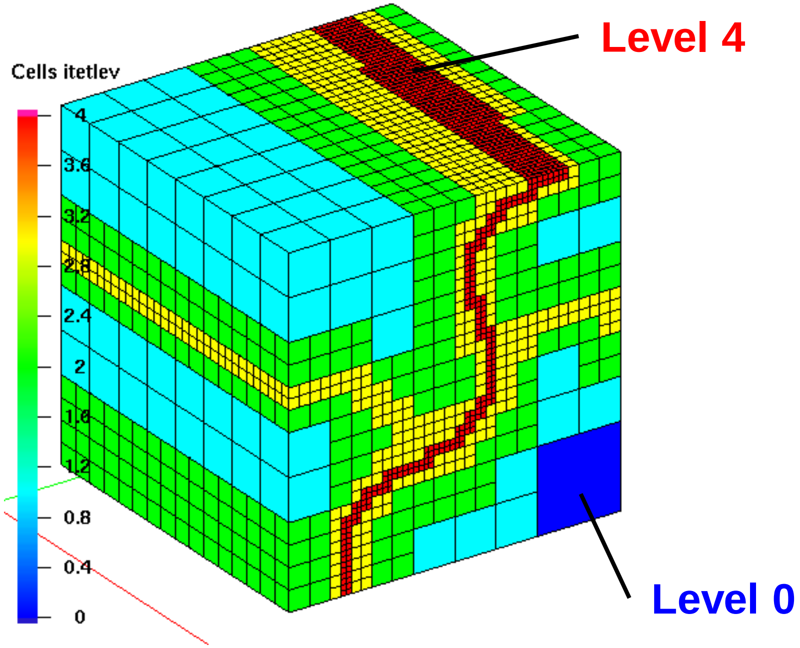
Finite element method (FEM)

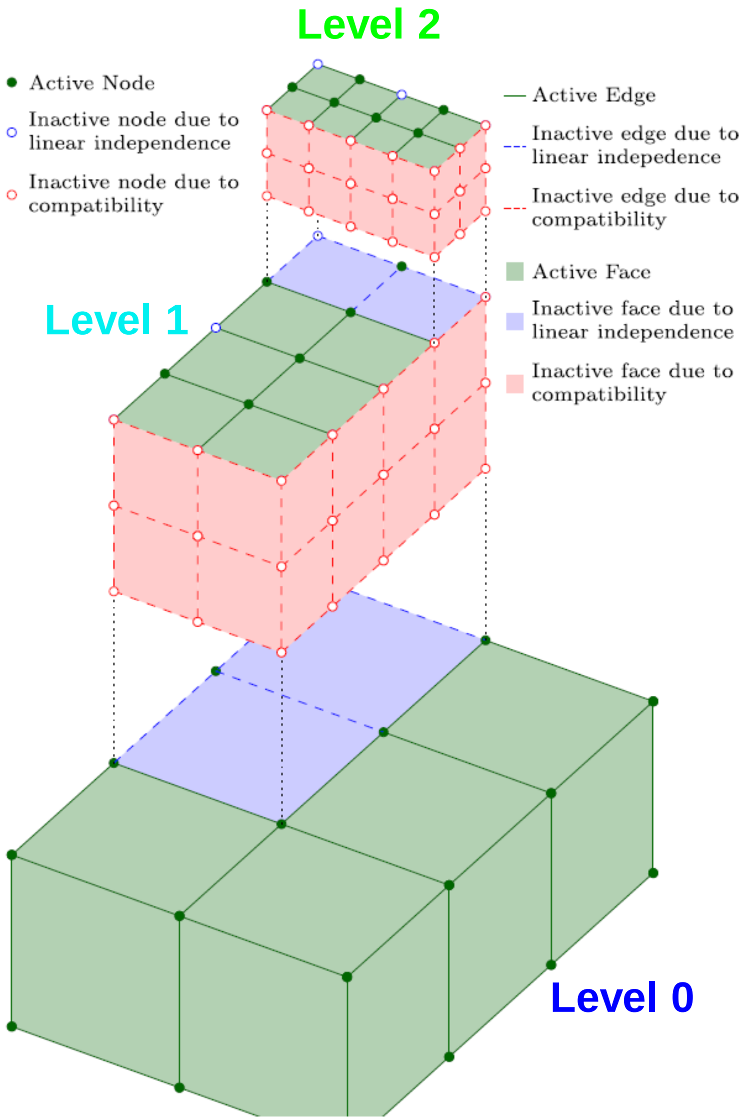
- Typically used in the **meso and macro-scale**.
- The numerical **solution accuracy** and the **computational time** are strongly **dependent** on the adopted **finite element mesh**.

Temperature field

Non-conforming meshes

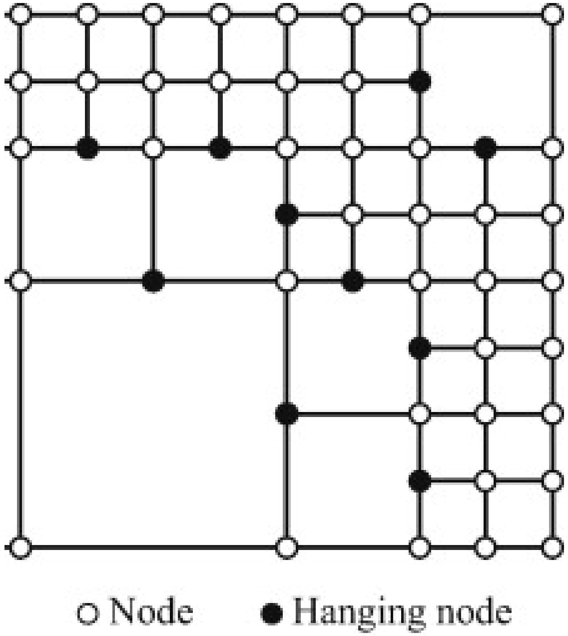
- **Advantages**:
  - ➢ Allow high mesh size gradients.
  - ➢ Hierarchical definition of the mesh.
- **Disadvantages:**
  - ➢ Presence of hanging nodes.





Hanging nodes

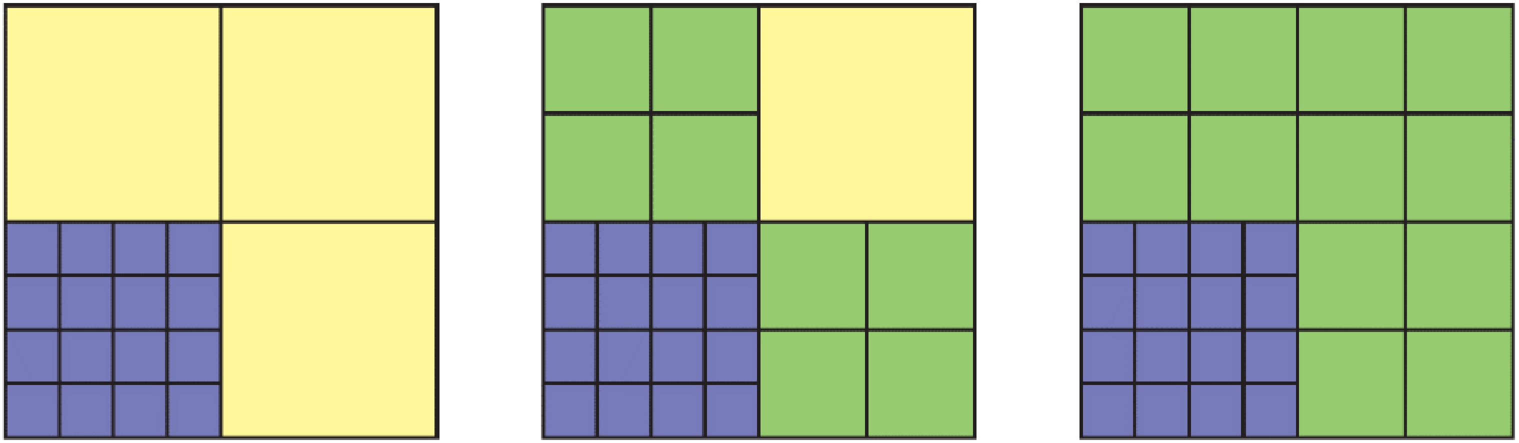
- Regularly occur when two elements of **different refinement levels** are **neighbors.**
- Node of an element **not shared by an adjacent element**.
- These nodes **require special treatment** to ensure the **continuity at the inter-element boundaries**.
  - Penalty method
  - Lagrangian method
  - Augmented lagrangian method



Mesh balance

- Creates **smoother mesh size gradients**.
- **Reduces the number of hanging nodes** at expense of a higher element count.

- **Face balance** – ensures no more than 1 hanging node per face.
- **Corner balance** – ensures no more than 1 hanging node per face and edge.



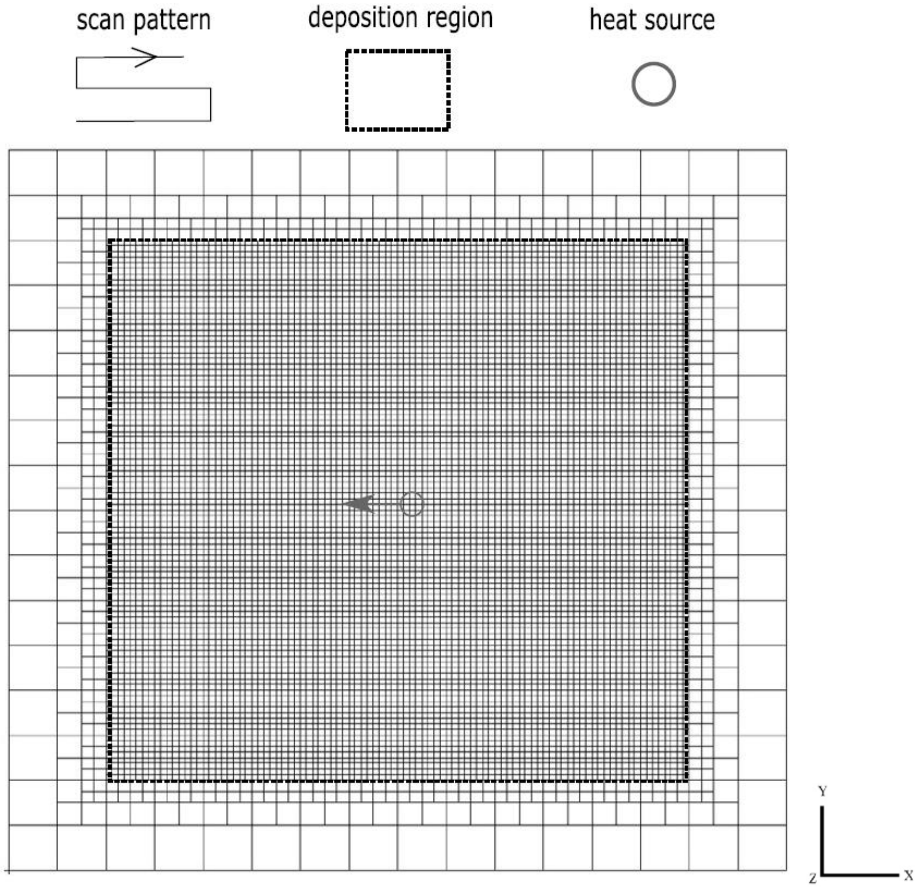
Unbalanced

Face balanced

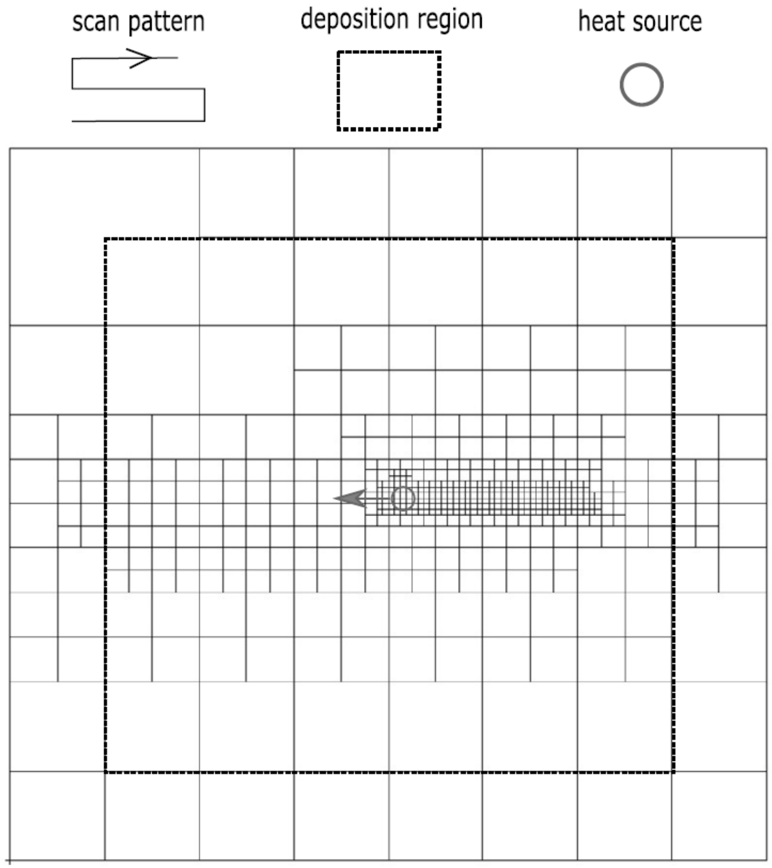
Corner balanced

Adaptive Mesh Refinement (AMR)

- **Static AMR** – Mesh remains unchanged during simulation.
- **Dynamic AMR** – Mesh is changed during simulation.



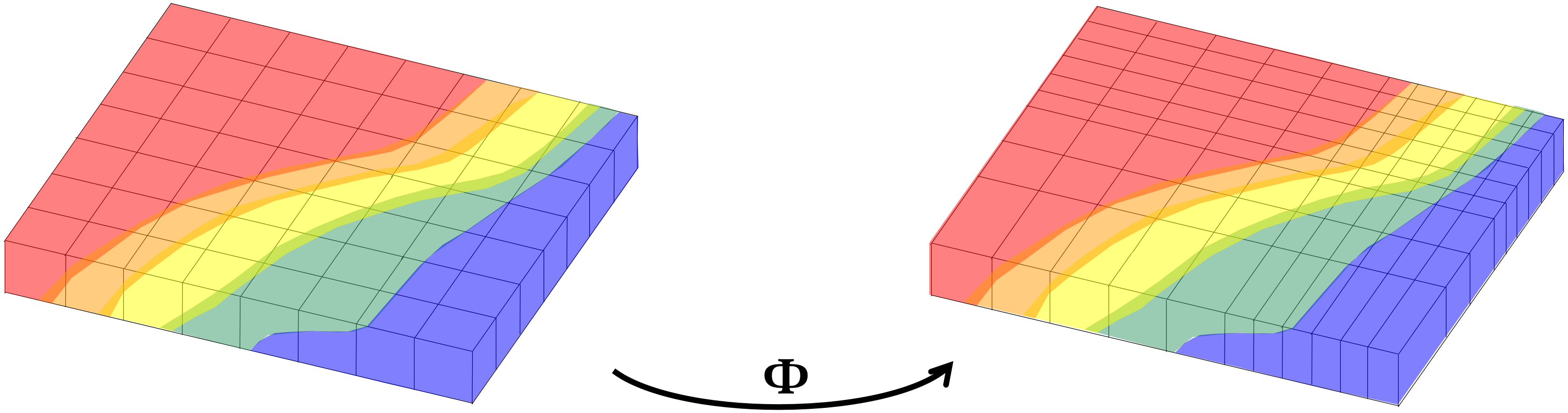
Static nonconforming mesh



Dynamic nonconforming mesh

Adaptive Mesh Refinement (AMR)

- **Dynamic AMR** requires variable remapping.

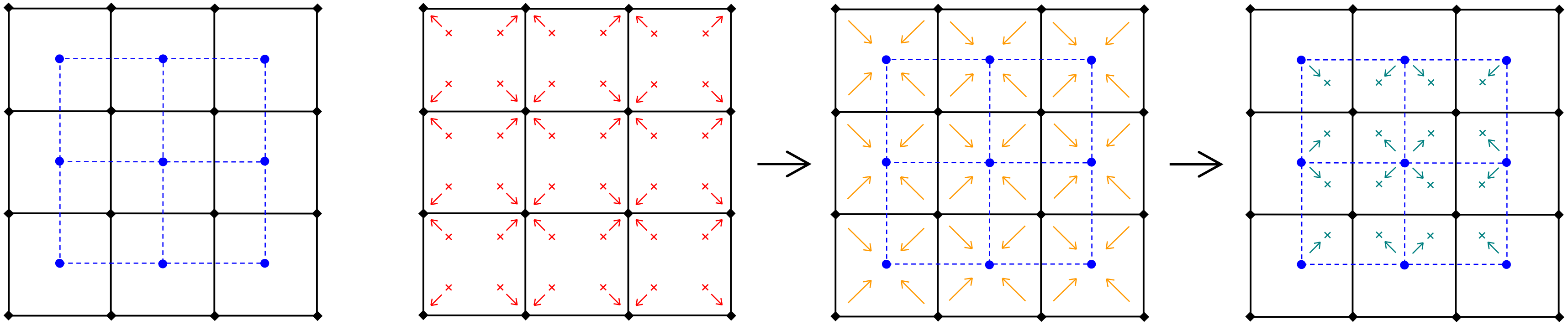


Transfer Operator

- **Remapping of all numerical variables**
  - Nodal variables: displacement, temperature, etc.
  - State variables: stress, strain, density, etc.

Remapping algorithms

- **Inverse isoparametric mapping**



Original meshes **Extrapolation** **Interpolation I** **Interpolation II**

$$\alpha_i = \sum_{ig=1}^{ng} \left[\tilde{N}_{ig\,i}(\xi,\eta,\zeta)\right]^{-1} \alpha_{ig}$$

$$\alpha_j = \sum_{i=1}^{n} \tilde{N}_{i\,j}(\xi,\eta,\zeta)\,\alpha_i$$

$$\alpha_{ig} = \sum_{j=1}^{n} \tilde{N}_{j\,ig}(\xi,\eta,\zeta)\,\alpha_j$$

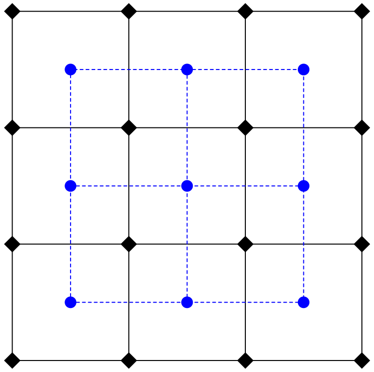
Variable Remapping

Remapping algorithms

- **Dual Kriging (DK)**

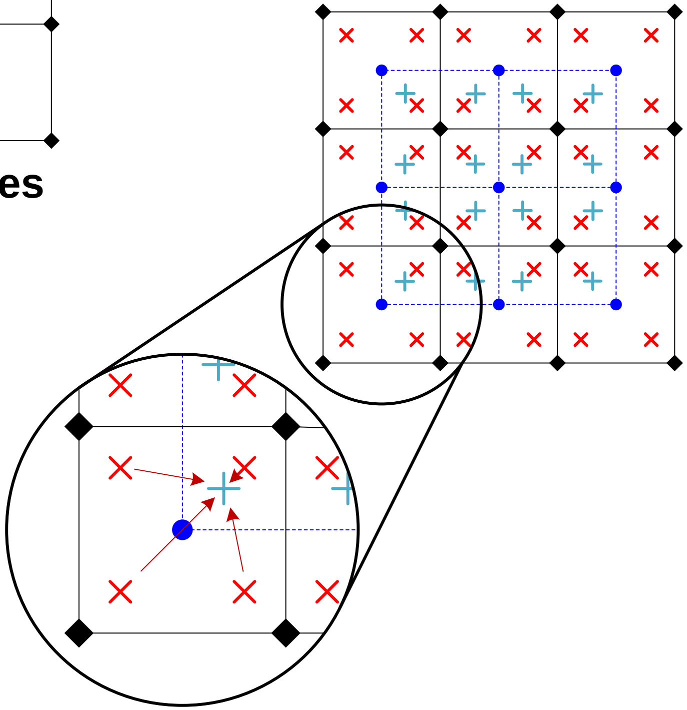
DK function

$$F\left(X_o, Y_o, Z_o\right) = C_0 + C_1 X_o + C_2 Y_o + C_3 Z_o + \sum_{J=1}^{N} \lambda_J K\left(h_{0J}\right)$$

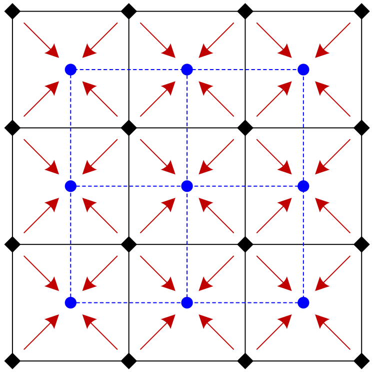


Original meshes

State variables



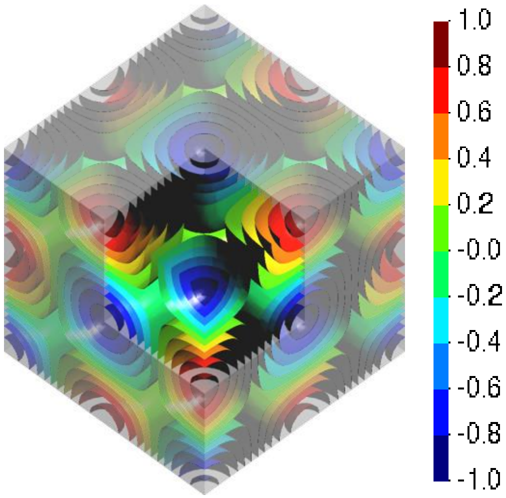
Nodal variables

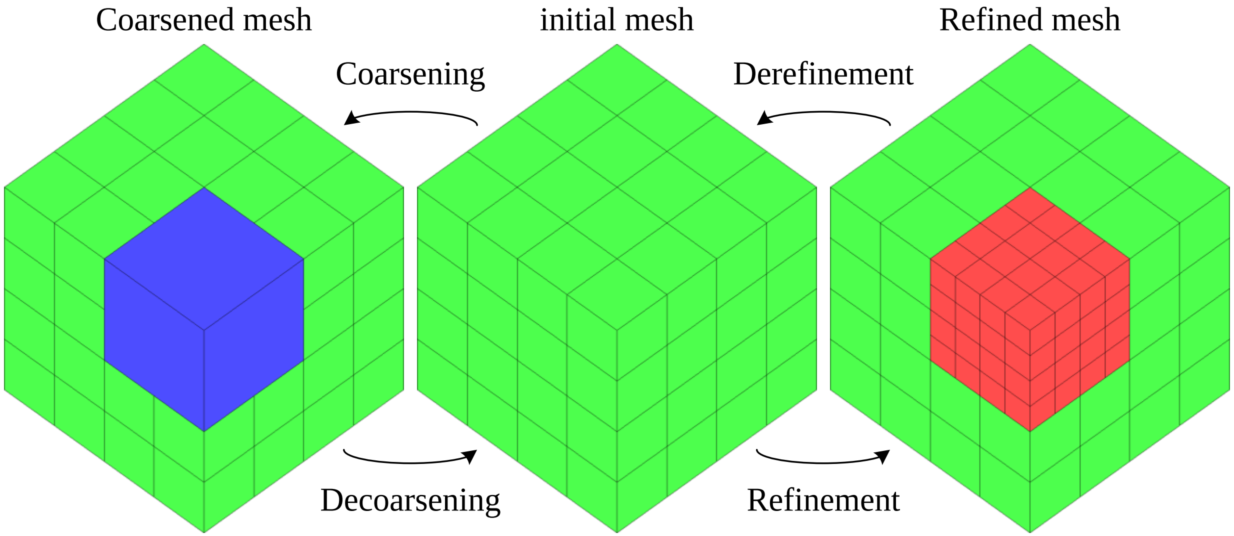


Remapping of a mathematical function

$$f(x,y,z)=\cos(\pi x)\times\cos(\pi y)\times\cos(\pi z)$$

- x, y and z range between -1 and 1.
- The state variable is always in the range [-1, 1].
- The **error** is defined as the **difference between the approximated and the analytical value**.





Coarsened mesh

initial mesh

Refined mesh

Coarsening

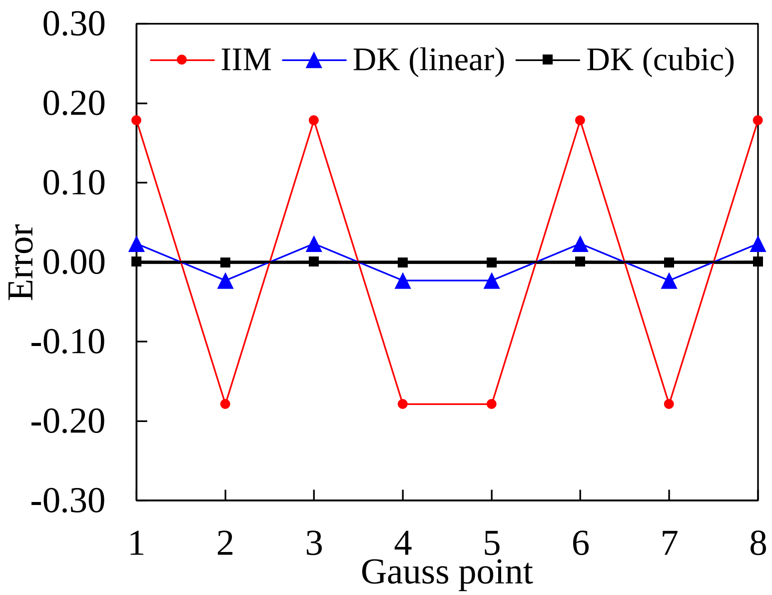
Derefinement

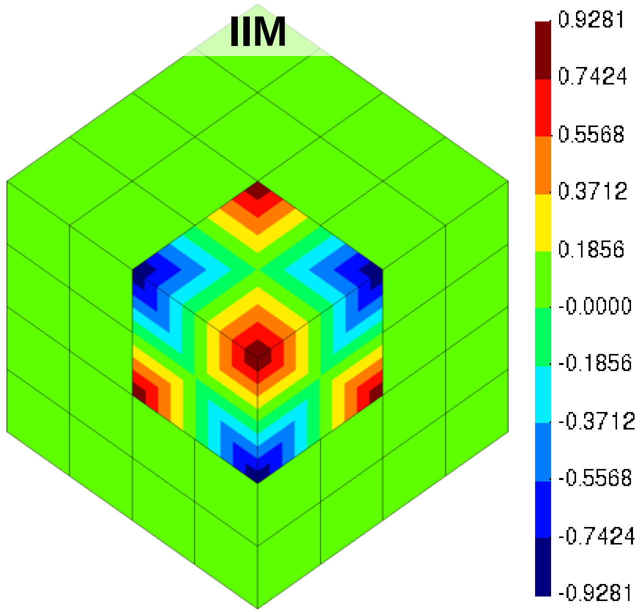
Decoarsening

Refinement

Remapping of a mathematical function

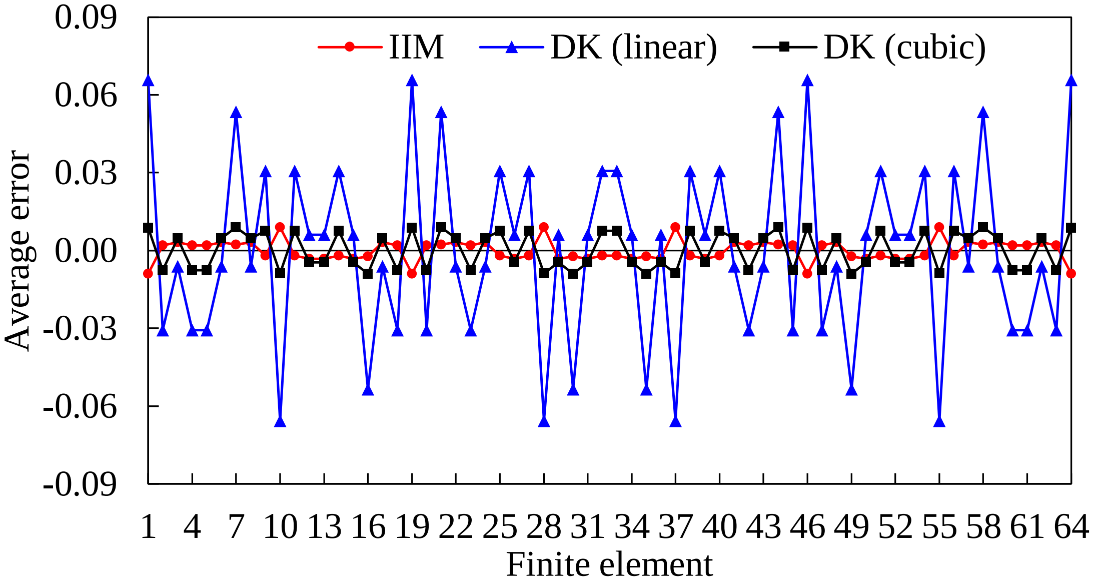
- **Coarsening procedure (Initial mesh → Coarsened mesh)**
  - ➢ DK with cubic spline covariance function presents negligible error.
  - ➢ DK with linear spline covariance function increases the error to about 0.02
  - ➢ IIM method provides the worse solution (error about 10 times larger than DK (linear))

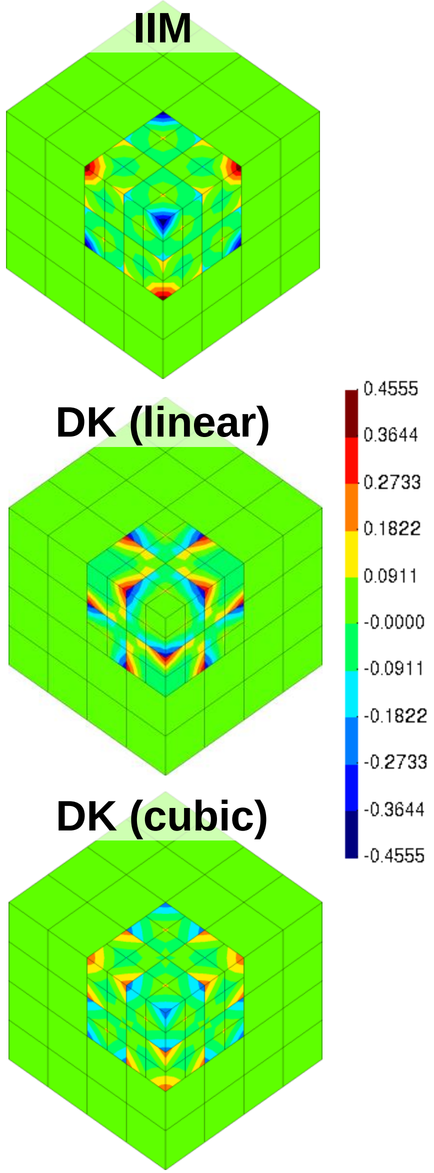




Remapping of a mathematical function

- **Refinement procedure (Initial mesh → Refined mesh)**
    - DK (linear) provides the worse estimative.
    - IIM develops identical element average error to DK (cubic)
    - In IIM, most of the GP (87.5%) have error values close to zero



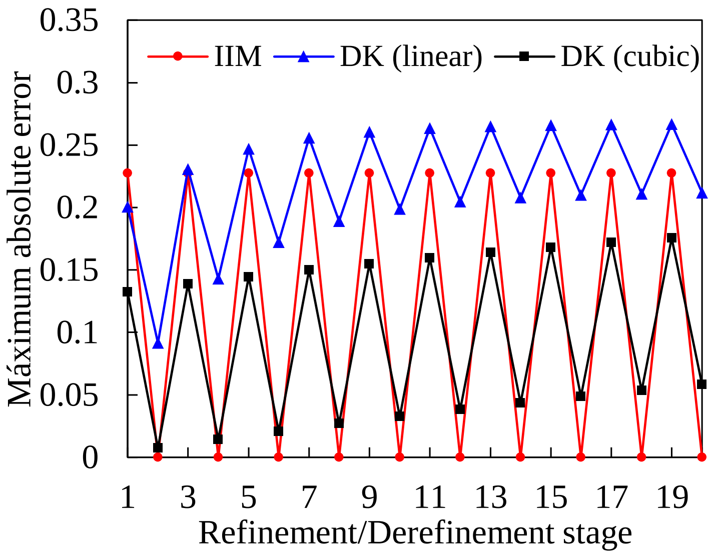


Remapping of a mathematical function

- **Error propagation**
  - ➢ IIM performance was independent of the analyzed cycle.
  - ➢ DK (linear) and DK (cubic) displayed error propagation.
  - ➢ DK (cubic) presents the lowest maximum error value.

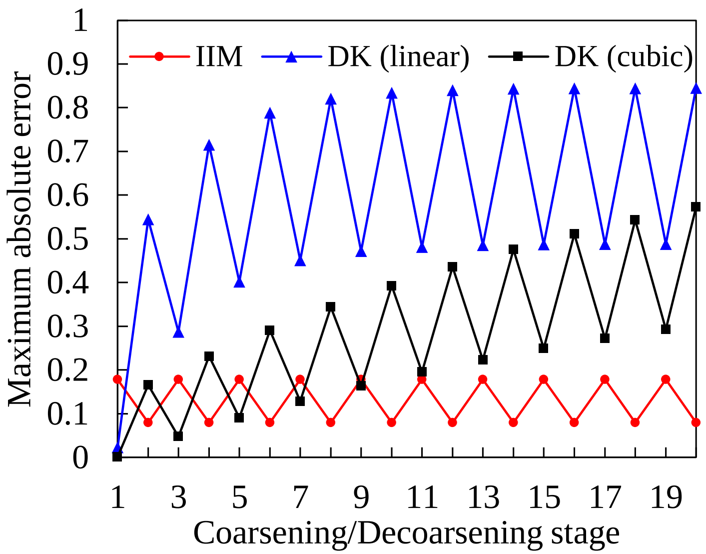
10 cycles

Initial mesh → Refined mesh



10 cycles

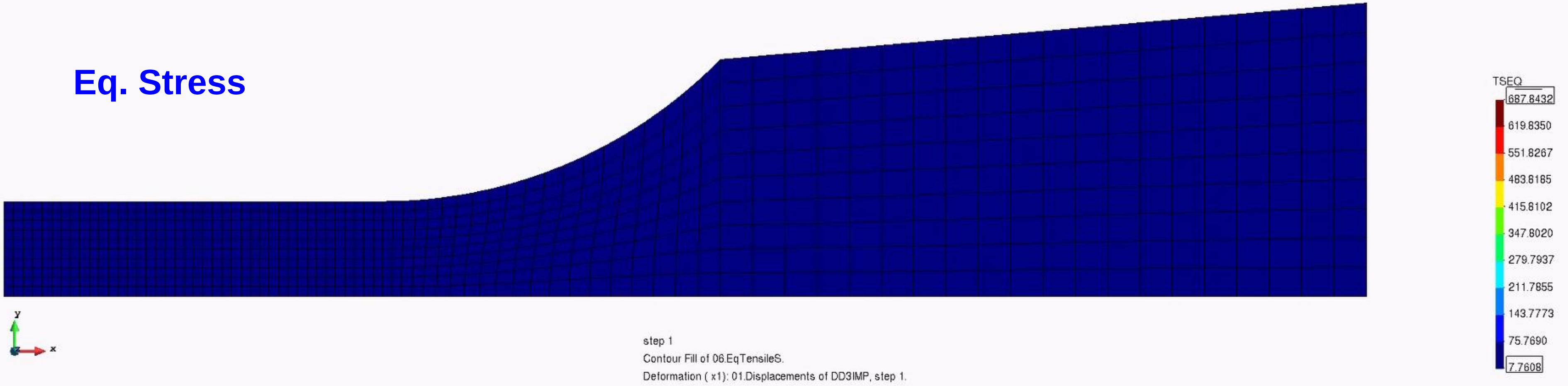
Initial mesh → Coarsened mesh



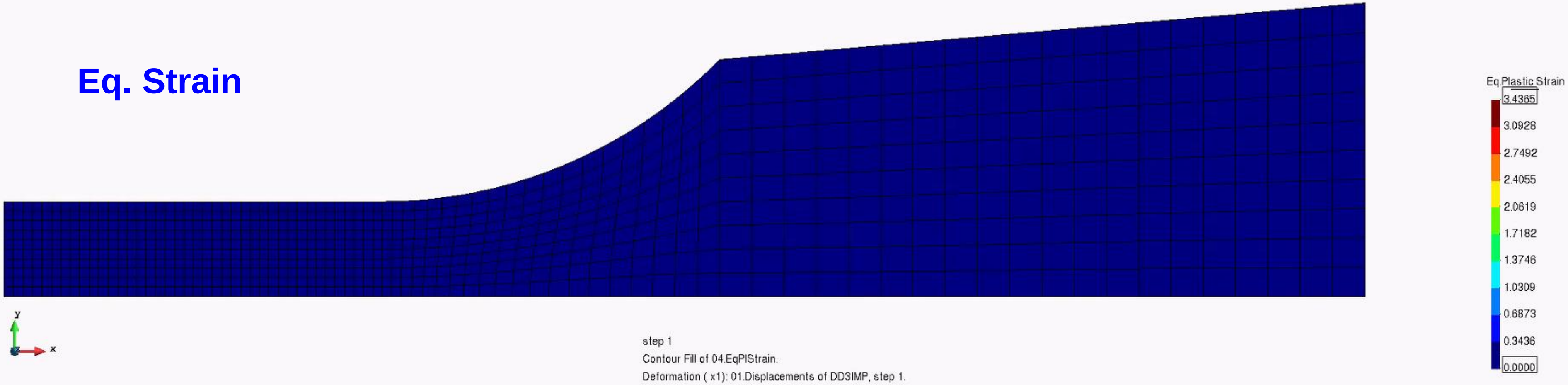
Tensile test

- 1/8 of a **standard flat specimen** is modelled. Symmetry conditions are applied.
- **Refinement criteria:** strain gradient.

Eq. Stress



Eq. Strain



Conclusions

- The **accuracy** of each remapping method **was evaluated** both in the **refinement and coarsening** stages.
- The **accuracy** of the remapping methods **was lower in the refinement** in comparison with the coarsening.
- The effect of the **covariance function** on the DK method has a **significant impact on the accuracy**.
- **DK with cubic spline** covariance function **performed better** than the **DK with linear spline** covariance function.
- **Error** in the approximation of the state variable **is lower using the DK** method **compared with** the **IIM** method.
- The **IIM method**, unlike the DK method, **does not suffer from error propagation**.
- The simulation of a **tensile test** showed **similar performance** when comparing both remapping methods.

Acknowledgements

This research work was sponsored by national funds from the **Portuguese Foundation for Science and Technology (FCT)** under the project with reference **PTDC/EME-EME/31657/2017** and by European Regional Development Fund (ERDF) through the Portugal 2020 program and the Centro 2020 Regional Operational Programme (CENTRO-01-0145-FEDER-031657) under the project MATIS (CENTRO-01-0145-FEDER-000014) and UID/EMS/00285/2020.

The first author is also grateful to the FCT for the **PhD grant** with reference **2020.05267.BD**.

Projetos Cofinanciados pela UE:

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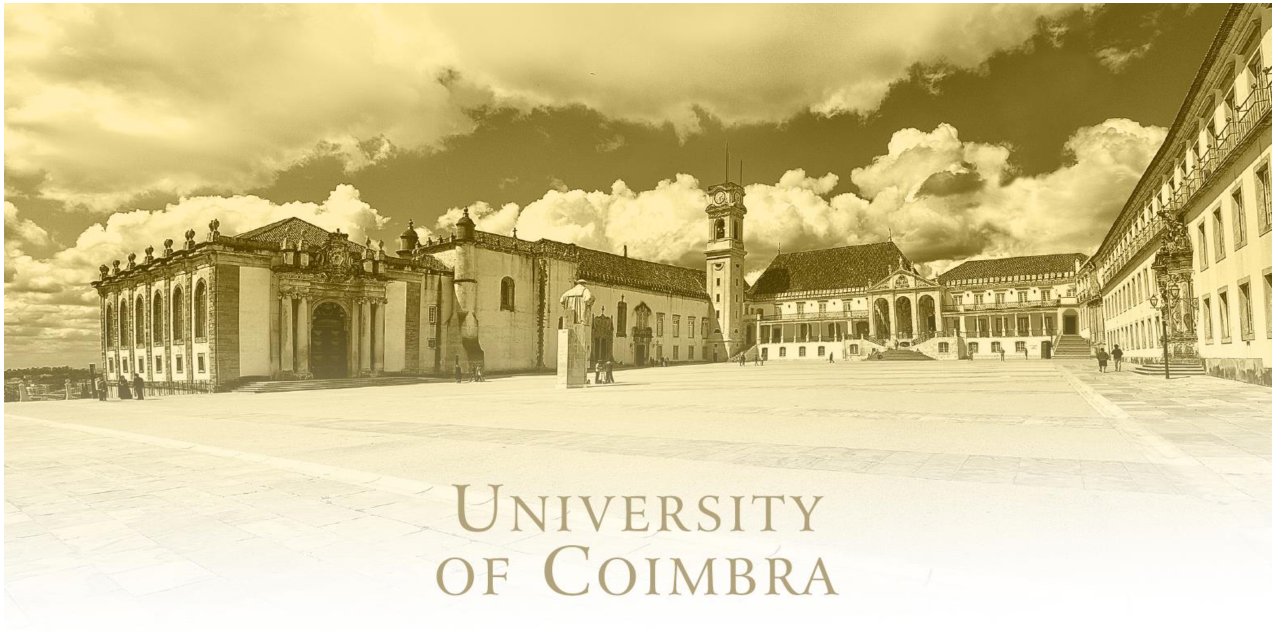

Thank you for watching!