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HORIZON EUROPE

DIDEAROT

Machine-learning based surrogate of composite micro-scale response in a multi-scale setting

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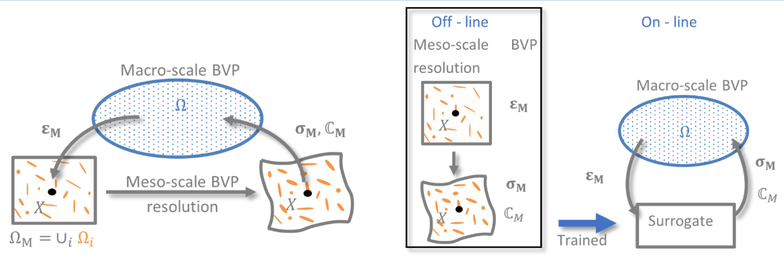
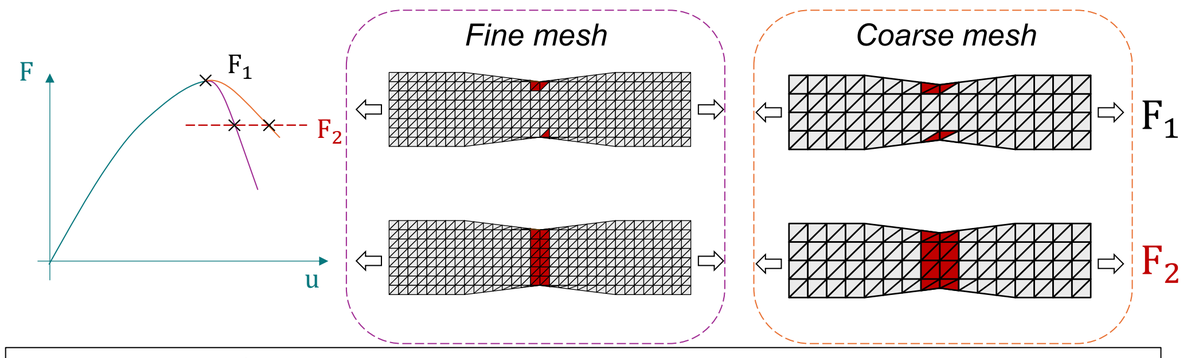
1. Accelerating multi-scale simulations



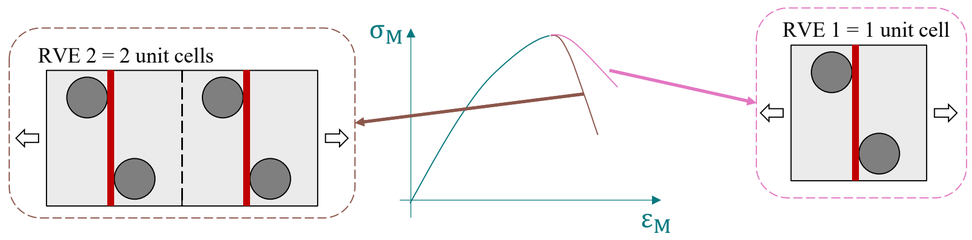
(a) Concurrent simulation (FE²) (b) Surrogate-based simulation

Machine learning-based surrogate for multi-scale simulations to become a reality

2. Multi-scale simulations with damage



1st Challenge: Mesh dependency issue at macro-scale



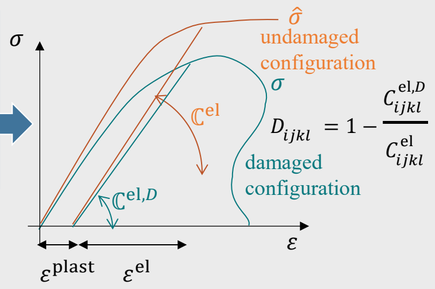
2nd Challenge: stress-strain curve of the RVE varies with its size

3. Encapsulating non-local framework

For a macro-scale point **X** and a time t:

1) Extraction of the elastic tangents $\mathbb{C}^{\text{el}}$ and $\mathbb{C}^{\text{el,D}}$ and the stress $\boldsymbol{\sigma}$

Constitutive model:
- Constitutive law
- Surrogate model:
  - RNN
  - DMN
  - ...



2) Computation of:
- A damage $\mathbb{D}$
- An apparent plastic strain $\boldsymbol{\varepsilon}^{\text{plast}}$

3) Computation of non-local counterparts

$$\widetilde{D}_{\text{a}} - l_{\text{d}}^2 \boldsymbol{\nabla}^2 \widetilde{D}_{\text{a}} = D_{\text{a}}$$

$$\tilde{\varepsilon}_{\text{b}}^{\text{plast}} - l_{\text{p}}^2 \boldsymbol{\nabla}^2 \tilde{\varepsilon}_{\text{b}}^{\text{plast}} = \varepsilon_{\text{b}}^{\text{plast}}$$

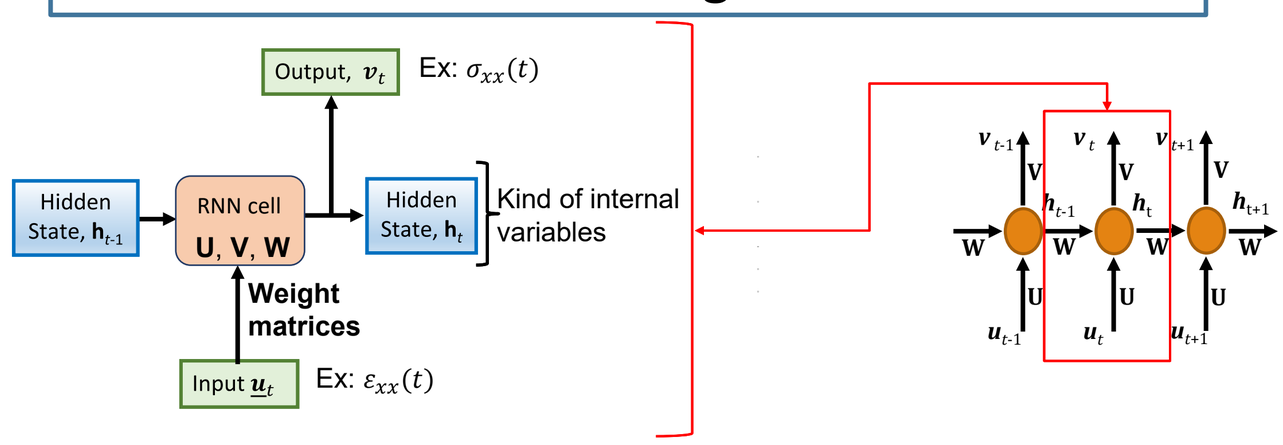
Non-local lengths tuned to recover G_c

4) Computation of $\boldsymbol{\sigma}_{\text{rec}}$:

$$\boldsymbol{\sigma}_{\text{rec}} = \left[(\mathbb{U} - \widetilde{\mathbb{D}}) \odot \mathbb{C}^{\text{el}}\right] : \left(\boldsymbol{\varepsilon} - \tilde{\boldsymbol{\varepsilon}}^{\text{plast}}\right)$$

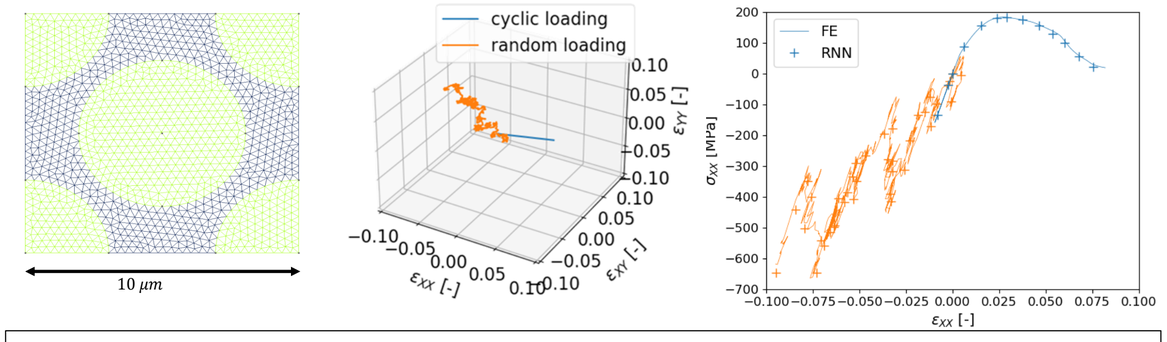
Reconstruct a non-local form from a local constitutive model

4. RNN as a surrogate model



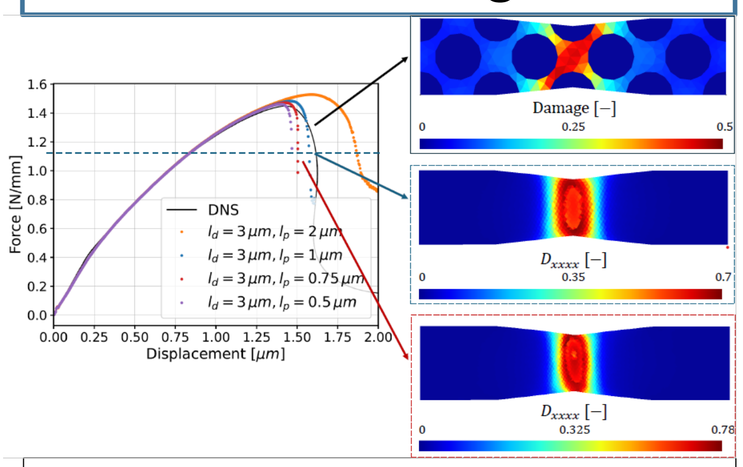
The vector of hidden variables $\boldsymbol{h}$ play the role of internal variables so that the outputs (stress tensor, undamaged elastic operator and damaged elastic operator can be predicted from the inputs (strain) history

5. RNN training for UD composites



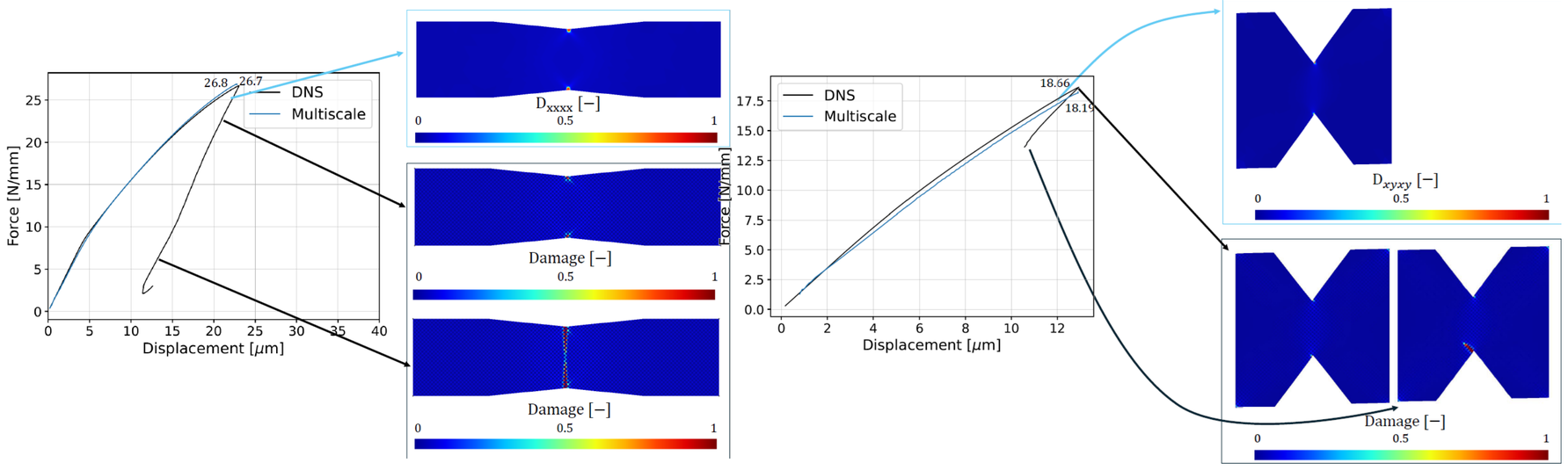
RNN is trained using random and cyclic loading paths; accuracy of testing data is assessed

6. Calibration of (macro) non-local lengths



Non-local lengths l_d, l_p are identified to recover the same fracture energy as DNS results

7. Toward structural simulations



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