Accelerating Multiscale Simulations using Uncertainty-Driven Phase-Field Mixtures of Constitutive Models

J. Storm[1,*], W. Sun[2], I. B. C. M. Rocha[1], F. P. van der Meer[1]
[1] Delft University of Technology, Department of Civil Engineering and Geosciences, P.O. Box 5048, Delft, 2600GA, Zuid-Holland, The Netherlands
[2] Columbia University, Department of Civil Engineering and Engineering Mechanics, Mail Code: 4709, New York, NY 10027, New York, United States of America

Accelerating multiscale models using data-driven techniques is a rapidly evolving research field. While surrogate models offer promising speedups for multiscale simulations, creating comprehensive training datasets that capture the constitutive behavior for all loading conditions remains computationally intensive.

Here, we propose an adaptive mixture methodology that combines a fast surrogate and the original model it was trained to replace. This approach eliminates the requirement for surrogate accuracy across all possible loading scenarios, substantially reducing the data generation burden. We implement this by introducing phases in the computational domain, corresponding to the original constitutive model and the surrogate, as shown in Figure 1. The choice for a probabilistic surrogate makes it possible to let these phases evolve through a phase-field driven by the surrogate uncertainty. This is visualized in Figure 2. When the uncertainty increases, the phase-field gradually switches the constitutive model from the surrogate to the original model.

We discuss the requirements of this approach to achieve accurate and stable results and compare the phase-field to a purely local approach that does not enforce spatial smoothness. Through numerical examples, we demonstrate how this mixture of models can accelerate multiscale simulations.
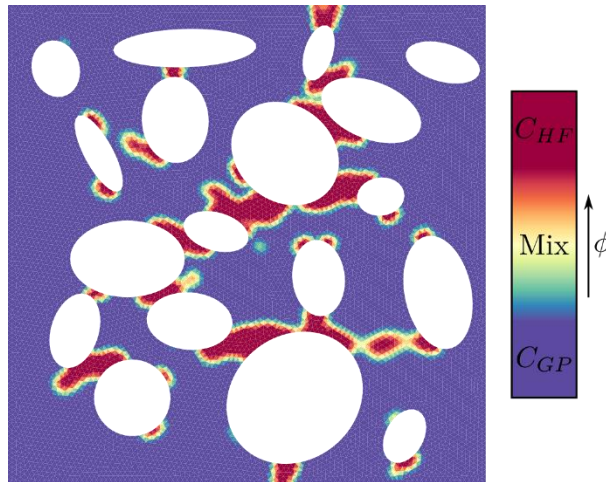

Figure 1: Overview of a simulation with a mixture of constitutive models. C_{HF} and C_{GP} are the high-fidelity and Gaussian Process surrogate constitutive models respectively.
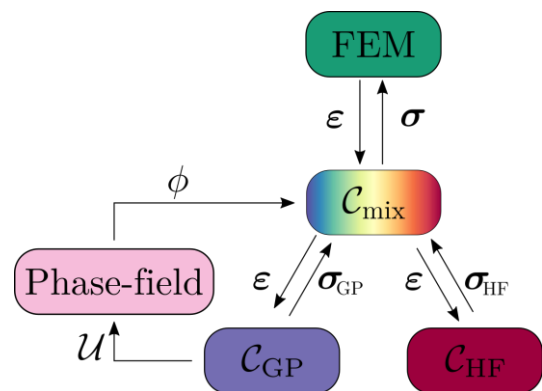

Figure 2: Overview of how the mixture constitutive model interacts with the other models.

*Corresponding author: j.storm@tudelft.nl