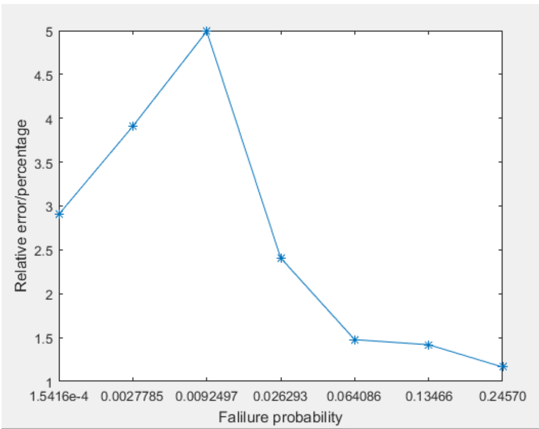
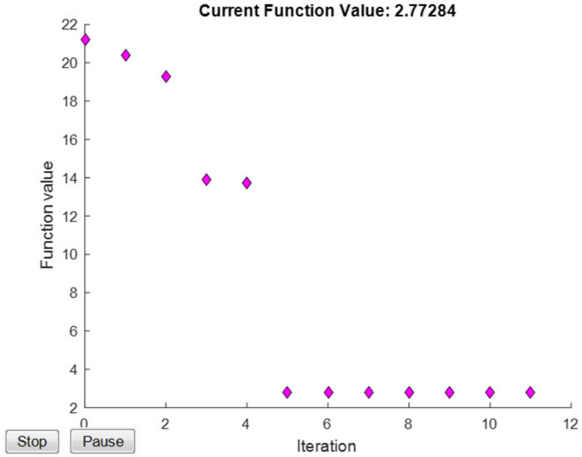
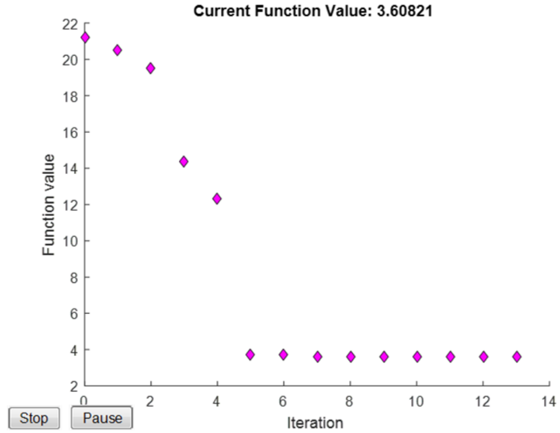
Pixel/Voxel level probabilistic solver – validation example (weakly nonlinear) 3

Table 6. Relative errors varying with failure probabilities

	Case (11)	Case (12)	Case (13)	Case (14)	Case (15)	Case (16)	Case (17)
Threshold /m	2.22×10^{-4}	2.21×10^{-4}	2.20×10^{-4}	2.19×10^{-4}	2.18×10^{-4}	2.17×10^{-4}	2.15×10^{-4}
pf_MC	0.24284	0.13275	0.06314	0.02566	0.008810	0.002674	1.4981×10^{-4}
N_MC	10^5	10^5	10^5	10^5	10^4	10^4	10^4
pf_ALPM	0.24570	0.13466	0.064086	0.026293	0.0092497	0.0027785	1.5416×10^{-4}
N_ALPM	11	12	12	12	13	12	13
Error	1.1640%	1.4184%	1.4761%	2.4075%	4.9909%	3.9080%	2.9037%



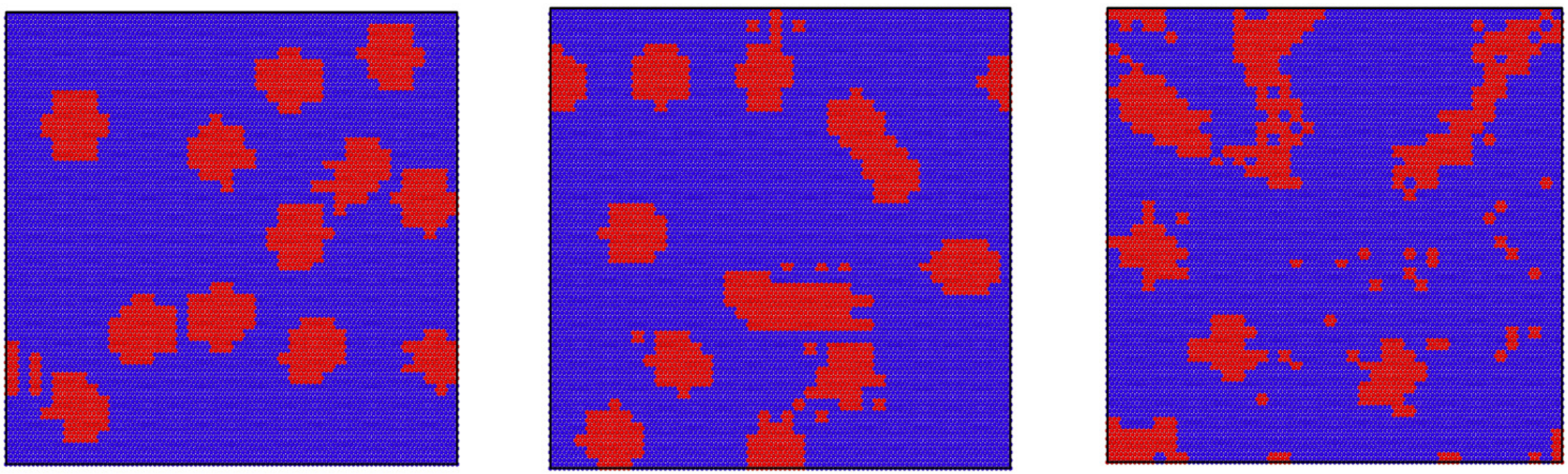




Pixel/Voxel level probabilistic solver – demo example with different clustering 1

Cluster function parameter

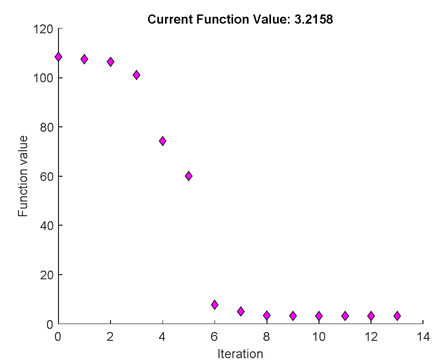
$\alpha = 0$ $\alpha = 0.5$ $\alpha = 1$

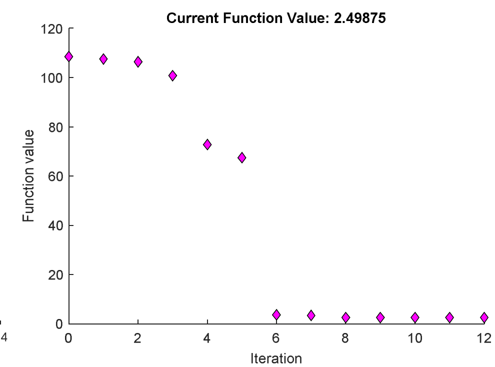


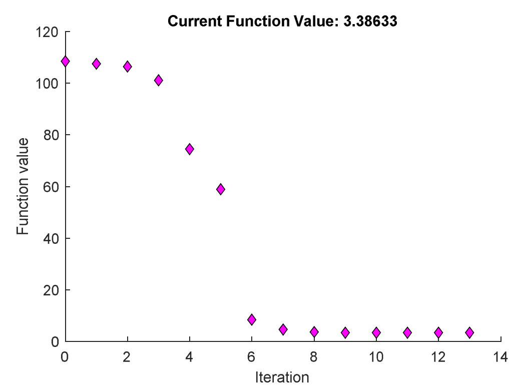
Pixel/Voxel level probabilistic solver – demo example with different clustering 2

Table 7. Probabilistic failure analysis results

	Threshold	Dimension	Number of function evaluations	p_f
Microstructure#1 $\alpha = 0$	1.13×10^{-3}	11759	14	7.4362×10^{-4}
Microstructure#2 $\alpha = 0.5$	1.13×10^{-3}	11759	12	0.1018
Microstructure#3 $\alpha = 1$	1.13×10^{-3}	11759	14	3.5417×10^{-4}





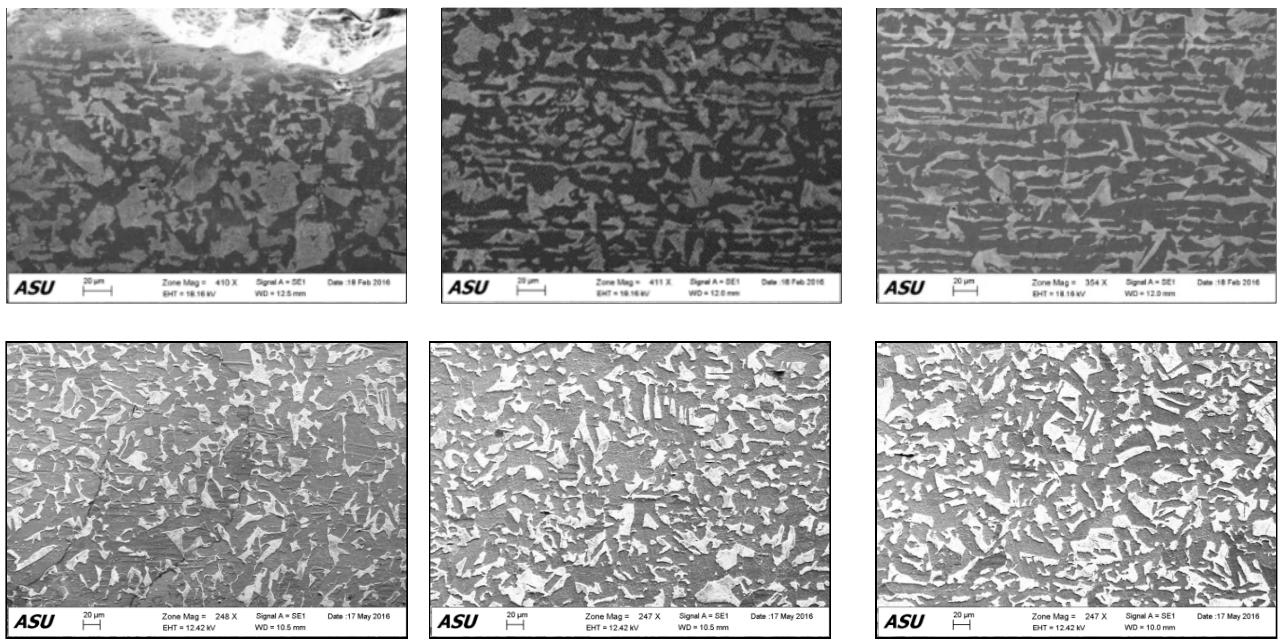


Pixel/Voxel level probabilistic solver – demo example with nonstationary microstructure 1

Depth increases from surface

Steel from pipe 45

Steel from pipe 47



- ❑ Need a unified microstructure representation and probabilistic strength estimation
- ❑ Inference of original manufacturing process for maintenance optimization

Pixel/Voxel level probabilistic solver – demo example with nonstationary microstructure 2

Bi-phase materials

- 16491 material particles

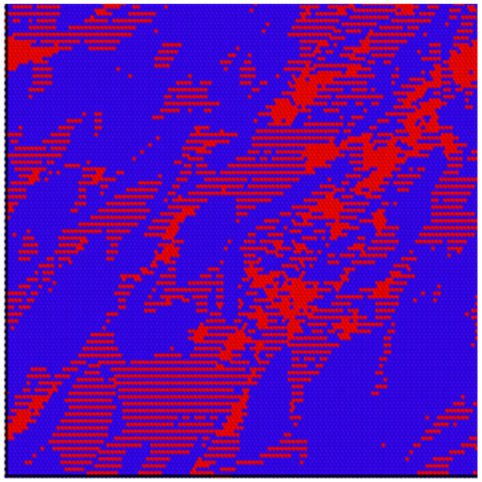


Table 1.Uncertainties of parameters

	Parameter type	value	Mean	C.O.V
E_1 Phase#1(red)	Normal	-	180GPa	0.02
E_2 Phase#2(blue)	Normal	-	220GPa	0.02
Loads f_i	Normal	-	$-2 \times 10^6 N$	0.02
Possion's ratio ν	Deterministic	0.3	-	-

The designed limit state function,

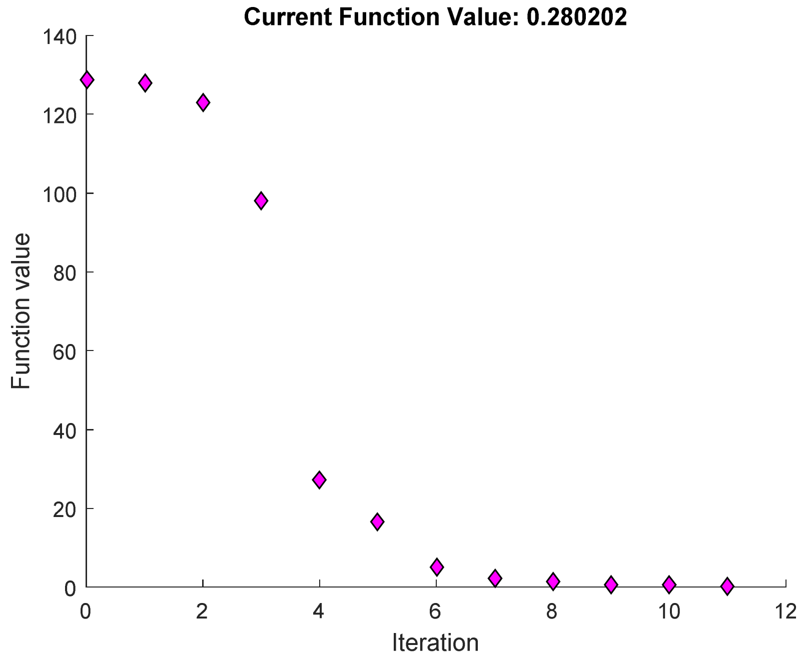
$$g_{16611}(\boldsymbol{u}, \boldsymbol{p}) = |u_o| - |1.16637 \times 10^{-3}| \geq 0$$

Pixel/Voxel level probabilistic solver – demo example with nonstationary microstructure 3

Table 6. Probabilistic failure analysis results

	Dimension	Number of function evaluations	p_f
ALPM	16611	13	0.3897

* Ongoing work for demo only and values do not represent true failure probability

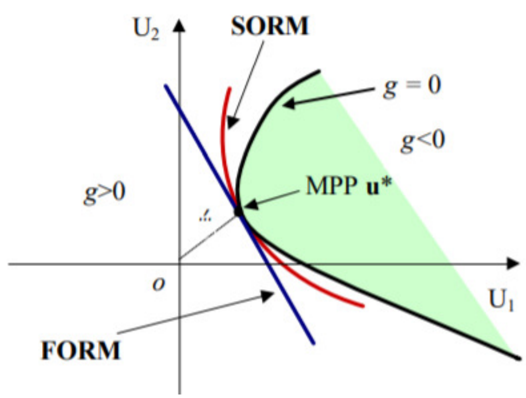


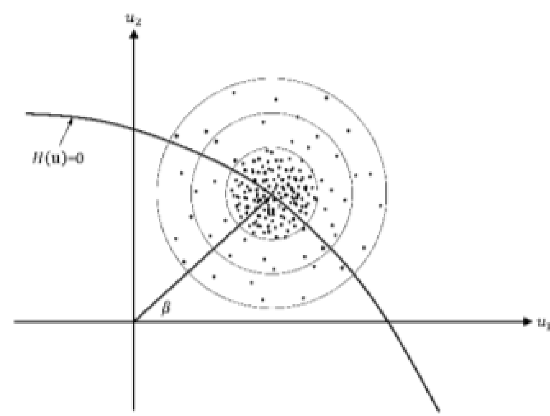
Conclusions and future work - 1

- Adjoint Lattice Particle Method (ALPM) is proposed as a probabilistic computational material tool *independent of dimensionality*
- Similar concept works for classical FEM as well, ***Ku=Q***

❖ Go beyond the linearity – current formulation is for linear or weakly nonlinear problem

❖ FORM-based MPP search is very valuable for other algorithms, such as SORM or importance sampling



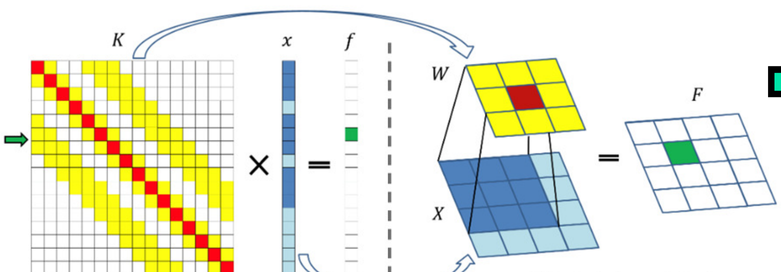


Conclusions and future work - 2

- Surrogate and/or dimension reduction for extreme dimension problem
- Physics-based learning – FEA-Net: extreme dimension handled by CNN type of network topology; significant reduction of training samples by physics constraints

FEA solver $K \cdot x = f$

Convolution $W \otimes X = F$

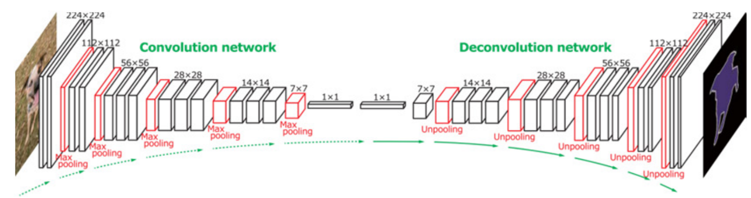


(a) Highly structured global stiffness matrix

(b) Equivalent convolution form of the matrix vector production

Analogy for network topology and FEA solution – FEA-Net

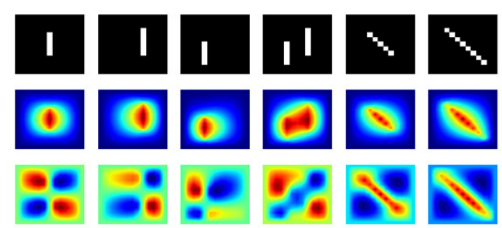
Fully **C**onvolutional **N**etwork



Loading location

Displacement-X

Displacement-Y



Yao, H., Ren, Y., & Liu, Y. (2019). FEA-Net: A Deep Convolutional Neural Network With Physics Prior For Efficient Data Driven PDE Learning. In *AIAA Scitech 2019 Forum* (p. 0680).

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