IMPERIAL

SCALED

SCALable gEnerative founDational model for Computational Physics

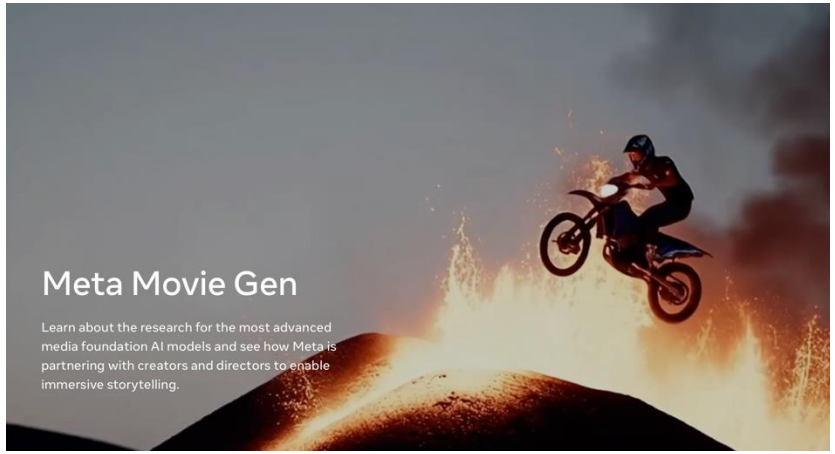
Yueyan Li, Nathalie Carvalho Pinheiro, Donghu_Guo, Leo Mok, Aniket Joshi, Boyang Chen, Romit Maulik, Fangxin Fang,Claire E Heaney, Christopher Charles_Pain

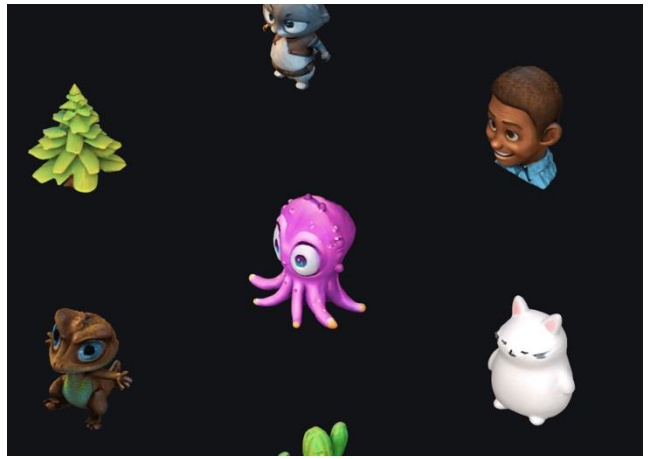
25/03/2025

Outline

Introduction:
From AIGC to Computational Physics

Introduction:
From AIGC to Computational Physics



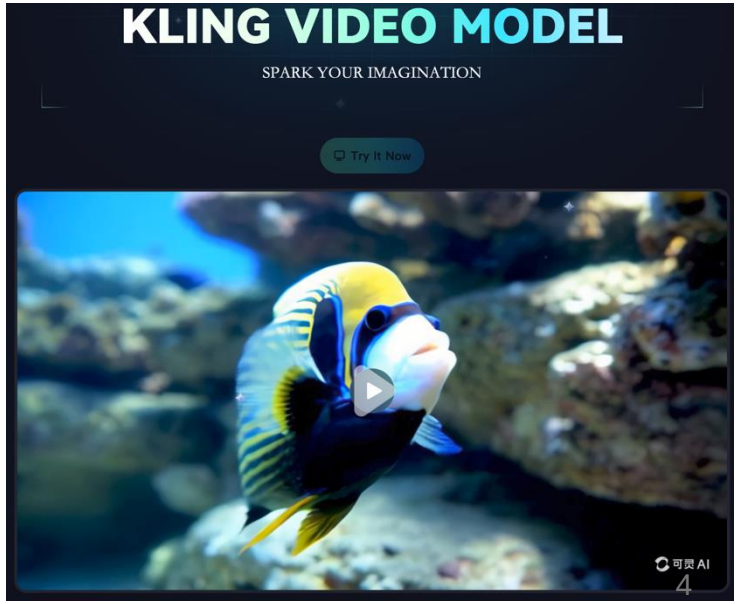


New #1 AI Video Generator

Hunyuan Video

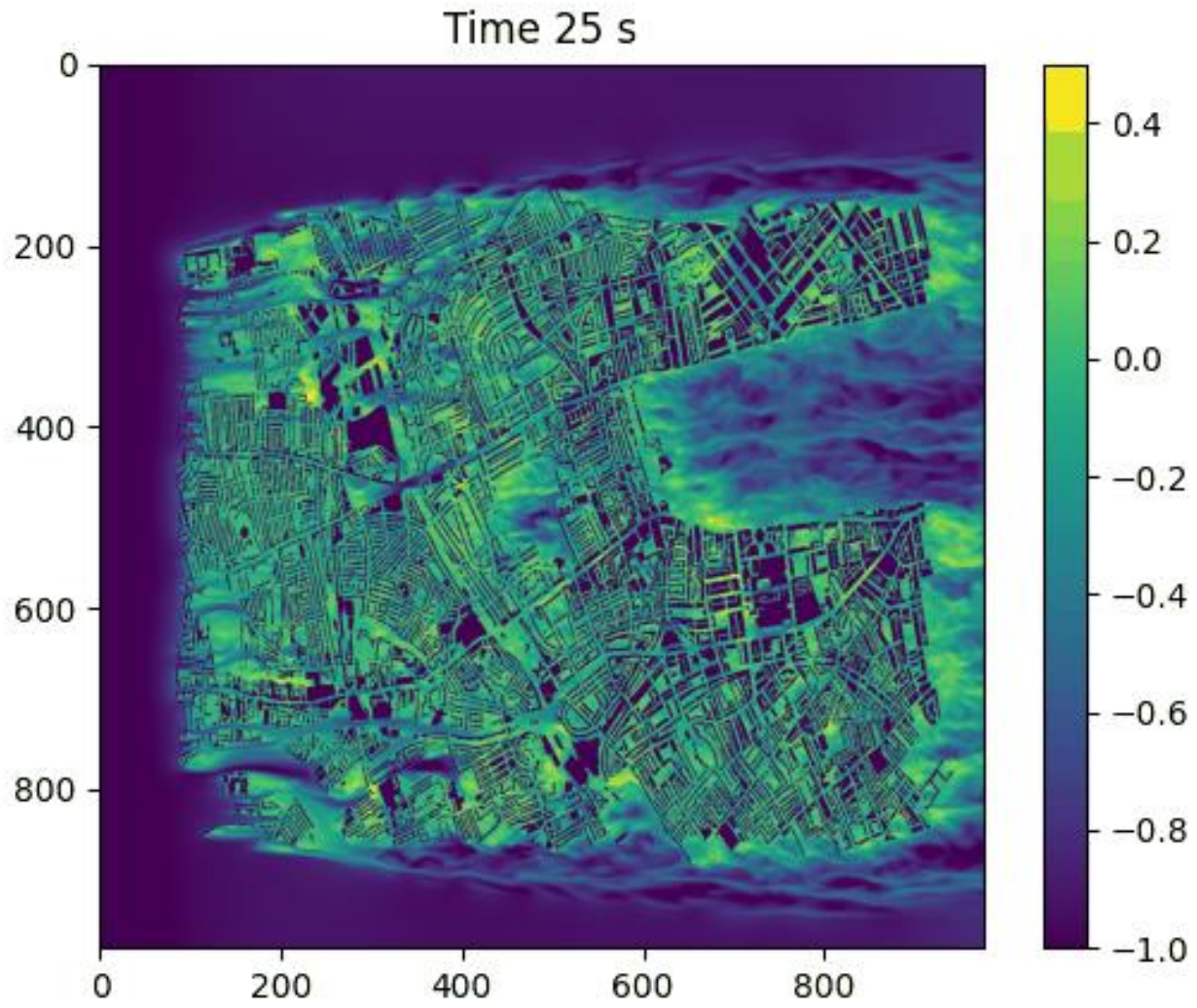
Hunyuan AI Video is a new, state of the art, AI Video Generator that creates high-quality videos from text descriptions. With 13B parameters and state-of-the-art performance, it's the most powerful open-source video generation model available.

Start Creating Now



Introduction:
From AIGC to Computational Physics

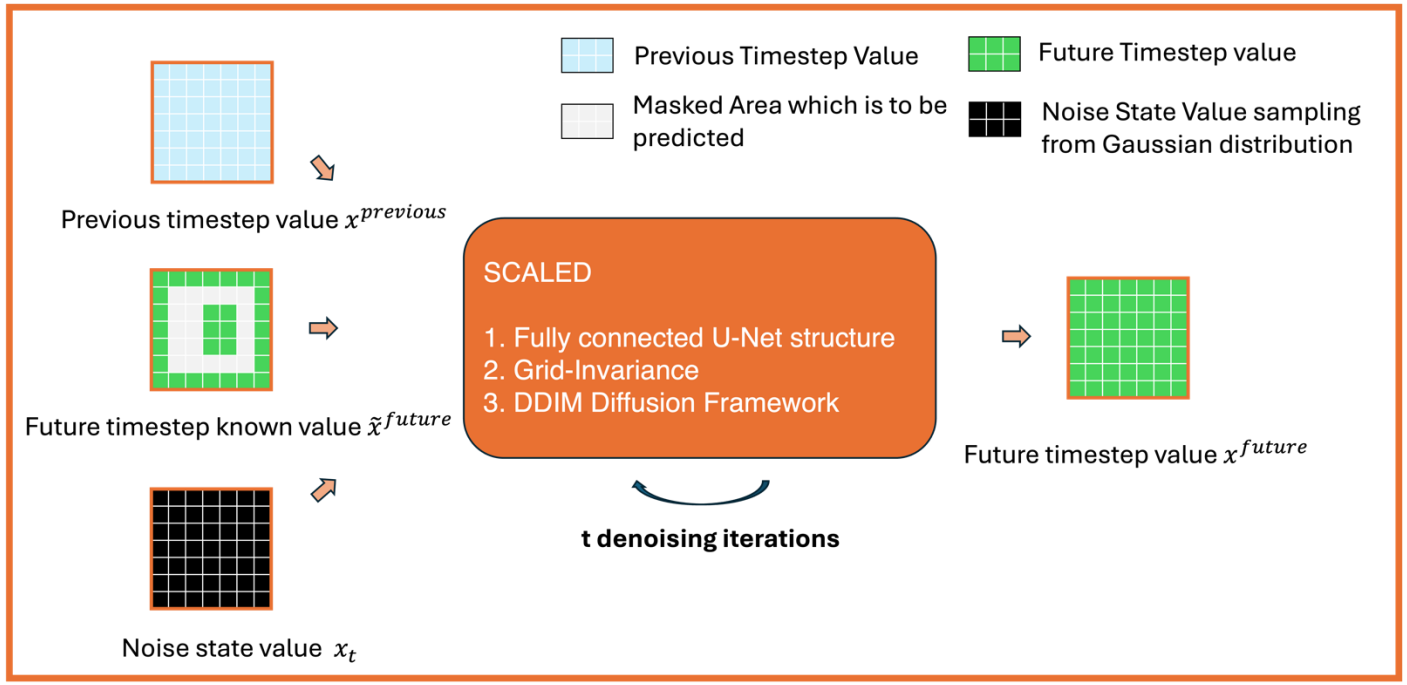
The cross-section shown in the figure represents fluid flow at 4 meters above ground level. The darkest areas in the central of the figure indicate building cross-sections, while the remaining regions depict the velocity of the fluid.



Methodology:

- Diffusion Framework for Scalable and Statistic Stability
- Denoising Net: CNN for constructing Physics Relationship
- Domain decomposition for Scaling up

Methodology:
Overview of SCALED



SCALED model structure for predicting the future timestep value, with 3 inputs: the previous timestep value, future timestep known value and the noise state value sampling from gaussian distribution. The future timestep known value could come form

1. sensor data and buildings information,
2. entire domain boundary conditions and
3. information exchange between neighbours subdomains using domain decomposition method.

Methodology:
Denoising Net: CNN for constructing Physics Relationship

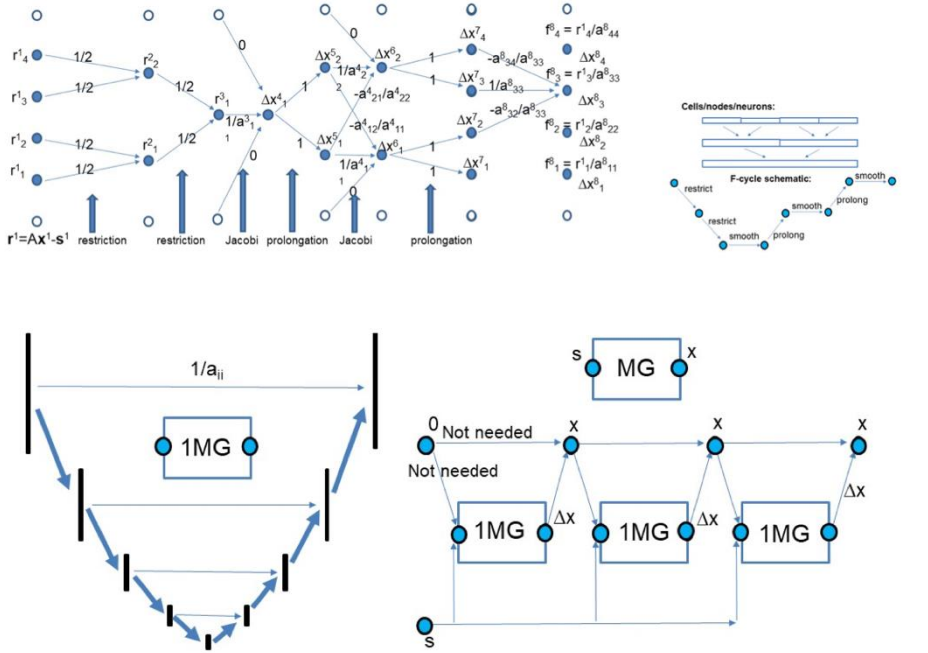
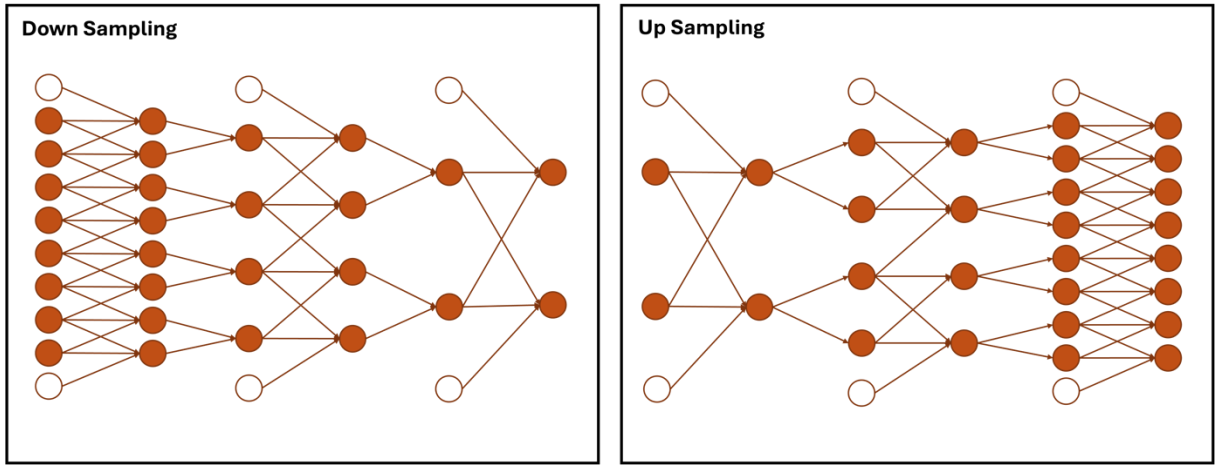


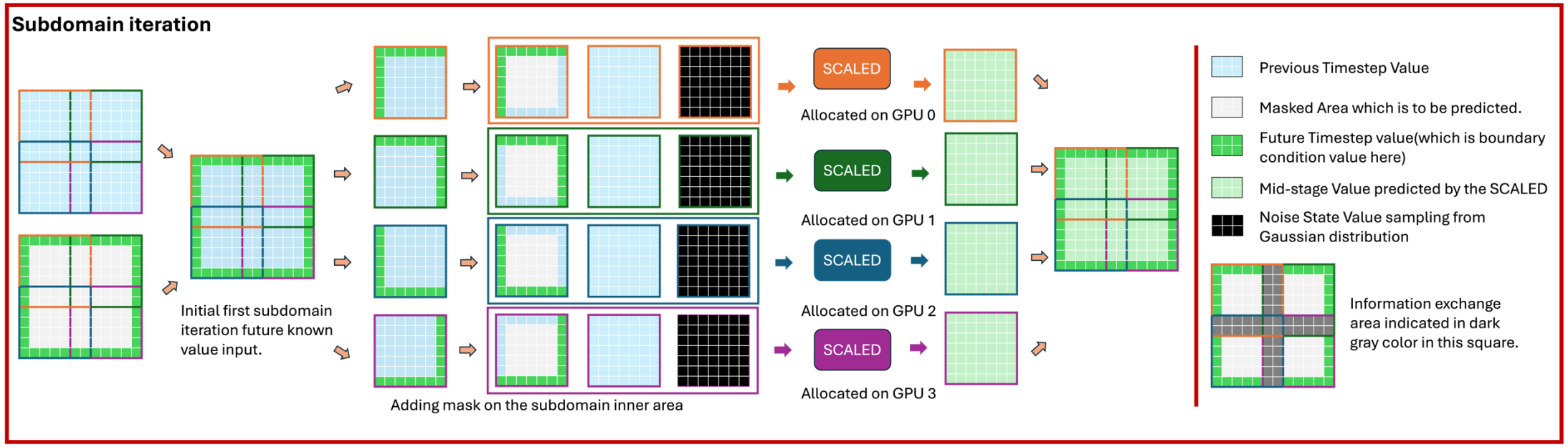
Figure 1: Schematic showing the how the CNNs are repurposed to produce a multigrid method. Top row left: How a 1D CNN multigrid method works with biases f. Top right: The four 1D cells that have two levels of coarsening and the schematic showing how this multigrid method works. Bottom row left: Schematic showing how one multigrid cycle works using layer skipping to pass the residual between the layers akin the U-net — this is a better alternative to using biases for the residuals. Bottom row right: Schematic showing how three multigrid cycles are brought together to form an overall matrix solution method.

NN4PDEs model structure with grid-invariant U-Net model structure. U-Net model structure is designed for implement multi-grid method.



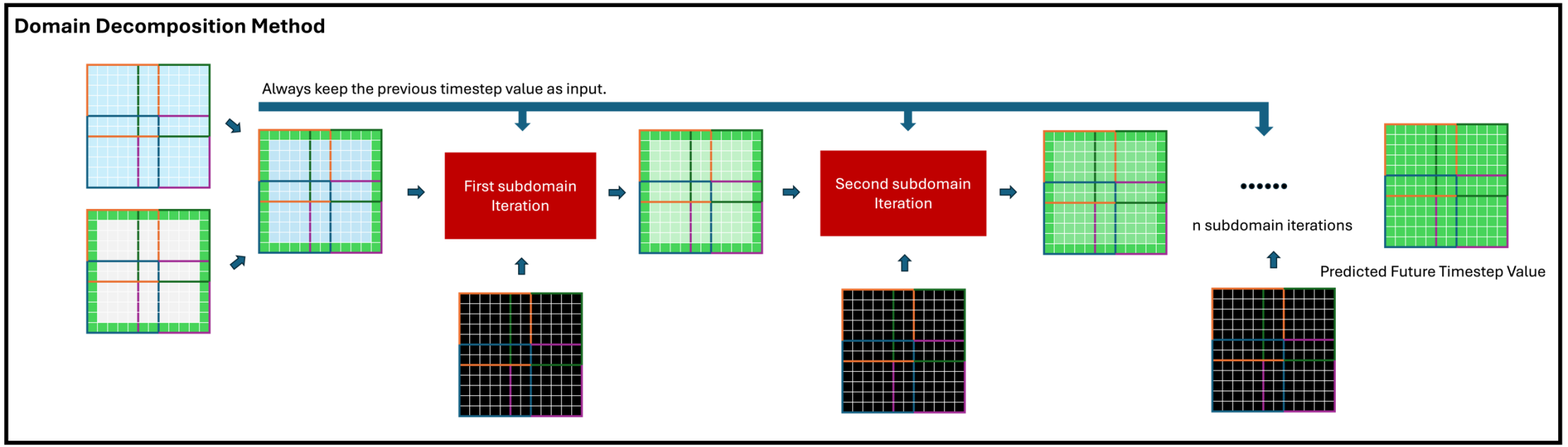
U-Net Backbone which is similar with NN4PDEs designed for grid-invariant and geometry invariant feature for SCALED.

Methodology:
Domain decomposition for Scaling up



Subdomain iteration procedure for partial-domain parallelisation, where the computational field is split into four subdomains (orange, green, blue, purple), each allocated to a different GPU. Inside each subdomain, the interior (light-blue ``masked area'') is predicted using SCALED, which incorporates future timestep known boundary values (green cells) and noise value (black grid). The subdomains then exchange updated boundary information (dark grey overlap regions) to ensure consistency across the entire domain.

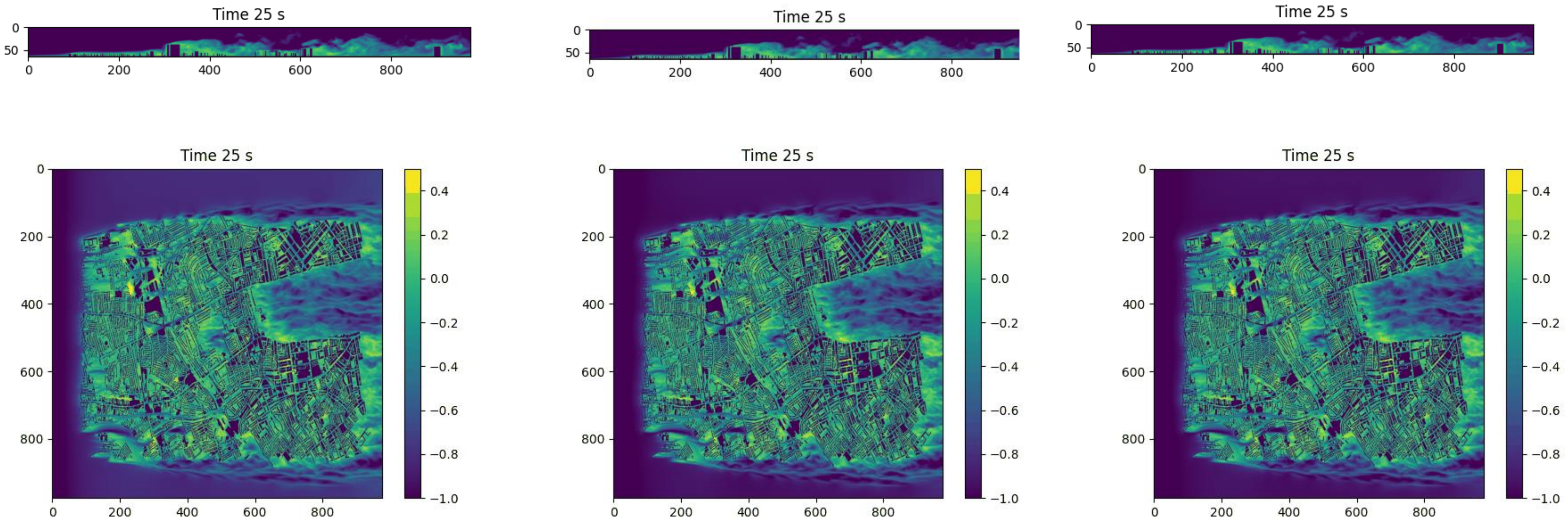
Methodology:
Domain decomposition for Scaling up



Domain decomposition workflow illustrating how the entire grid, partitioned into four subdomains, iteratively updates from the previous timestep value (light-blue cells) to the final predicted future timestep (green cells). Each iteration incorporates noise (black subdomains), applies boundary exchanges between subdomains (colored borders), and repeats until convergence is reached, producing the overall prediction after n subdomain iterations.

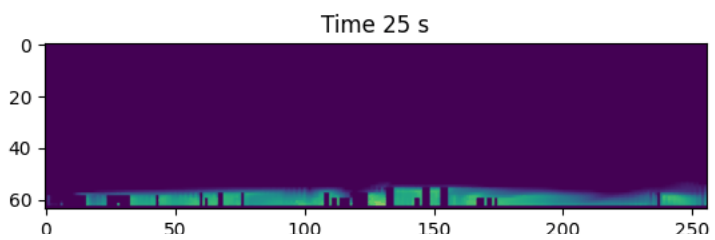
Model Result
Scalable/Grid-invariant/Geometry-invariant

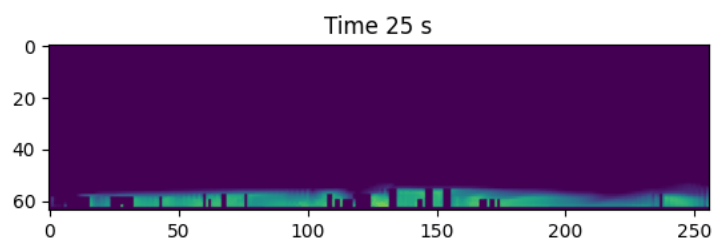
Model Result demonstration
Flow Past South Kensington

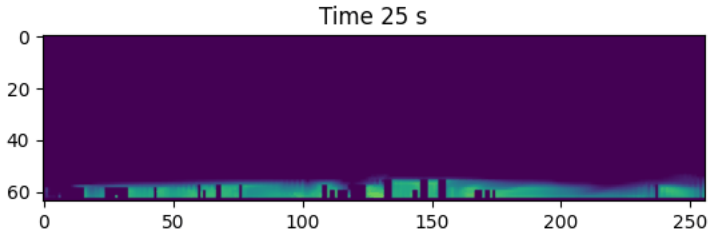


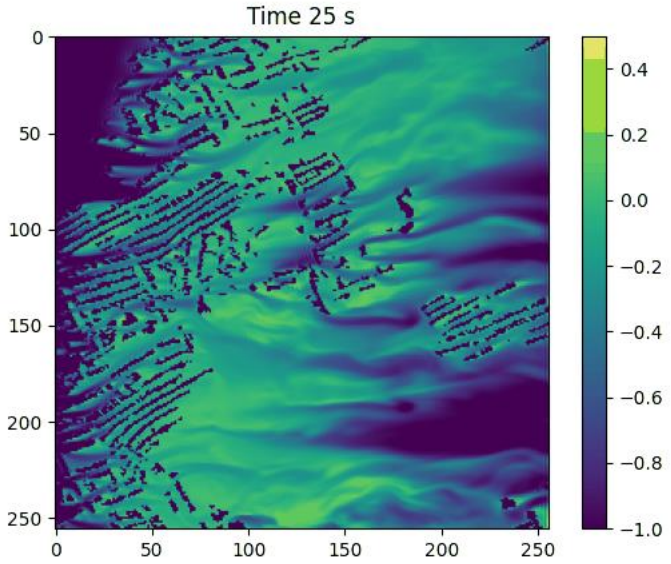
Gound Truth SCALED Result UNET Result

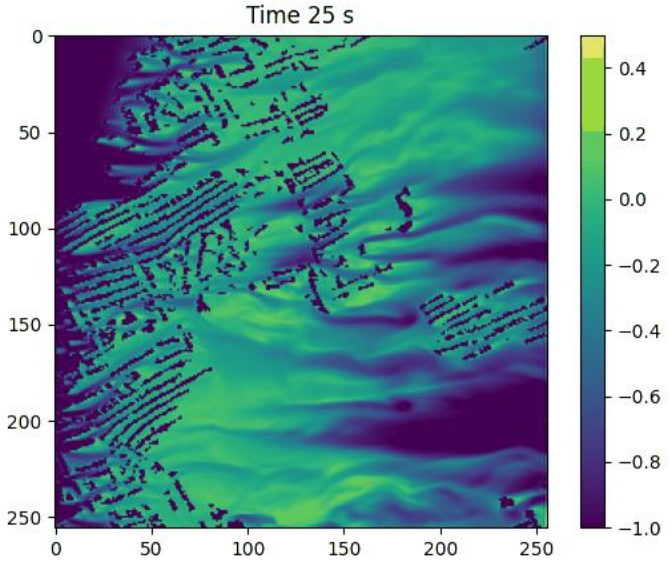
Model Result demonstration
Flow Past Generated Area

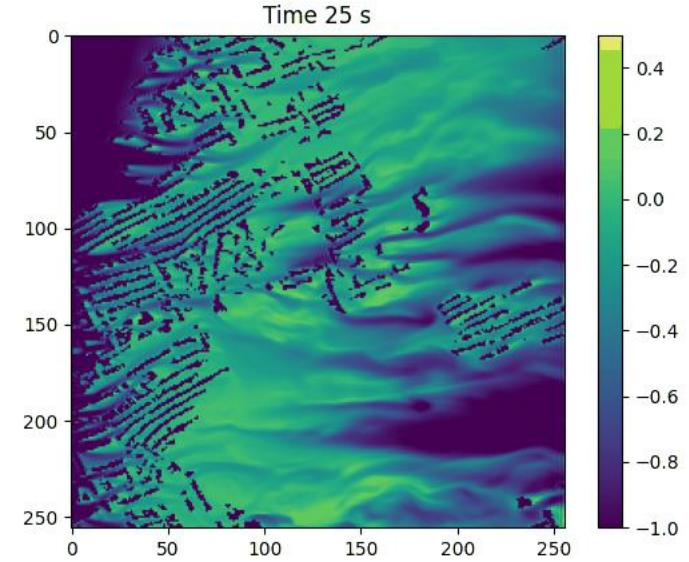










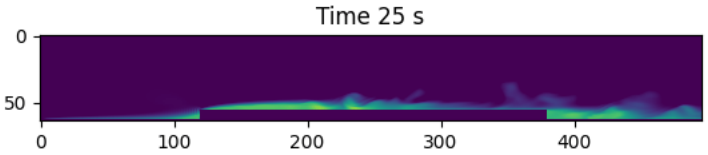


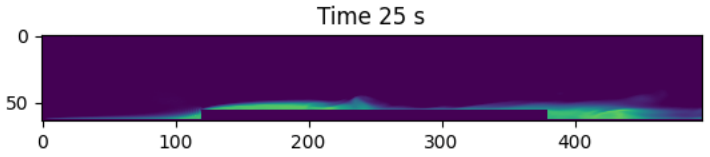
Gound Truth

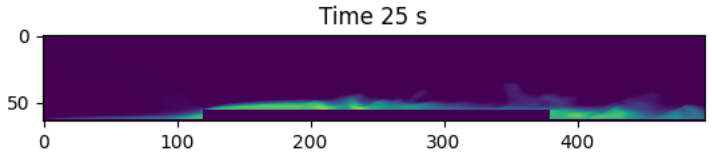
SCALED Result

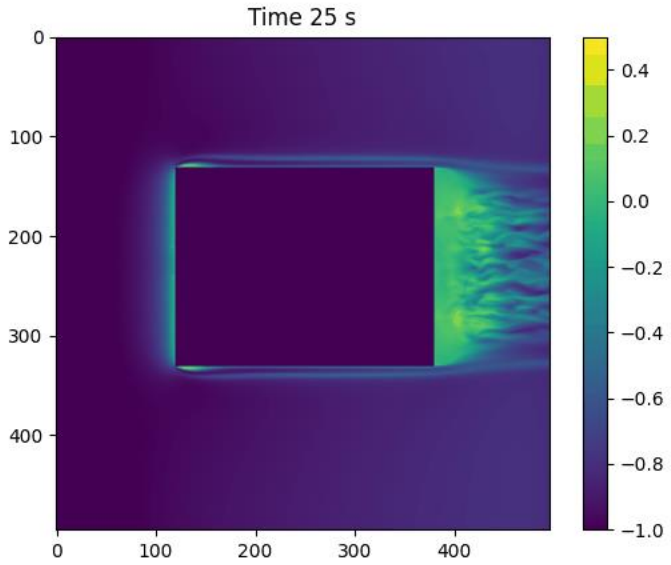
UNET Result

Model Result demonstration
Flow Past Large Square Area

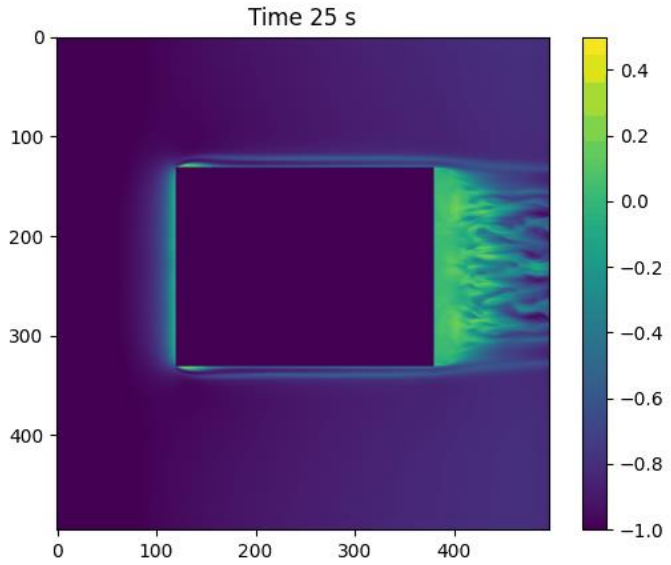




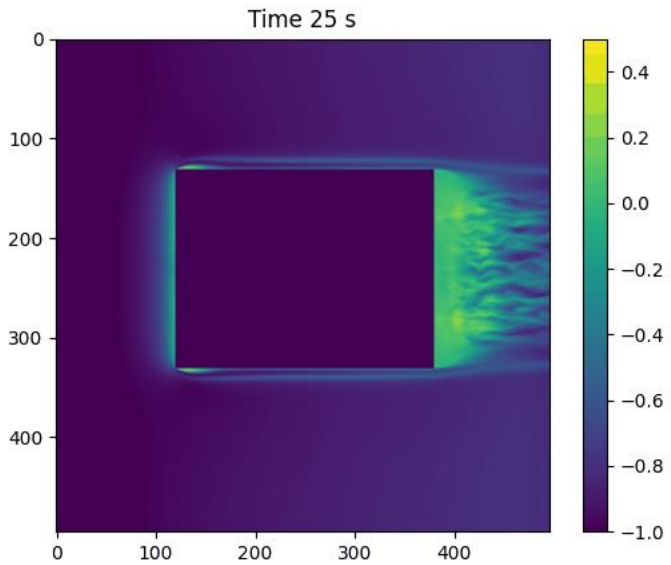




Gound Truth



SCALED Result



UNET Result

Conclusion and Future Work

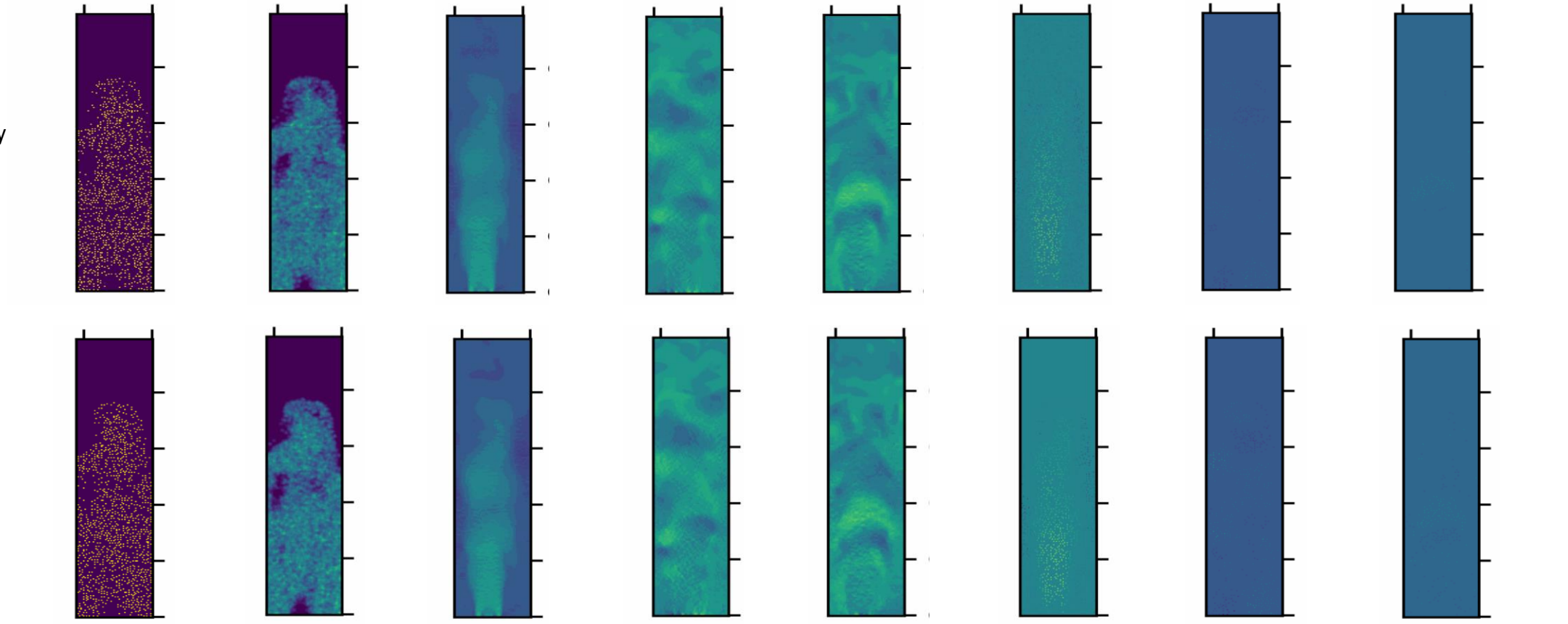
SCALED-X: extend scaled to multi-physics problems

SCALED-S: enhance scaled speed

SCALED-X: extend scaled to multi-physics problems

Result Generated by SCALED

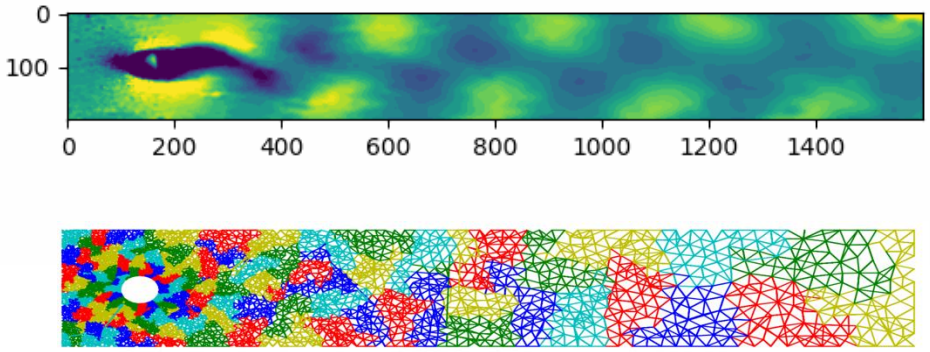
Result Generated by numerical solver

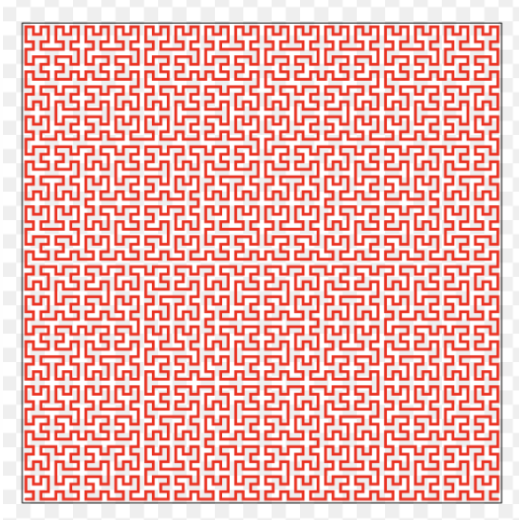


Particle Position | Particle Volume | flow velocity on z direction | flow velocity on y direction | flow velocity on x direction | Particle velocity on z direction | Particle velocity on y direction | Particle velocity on x direction

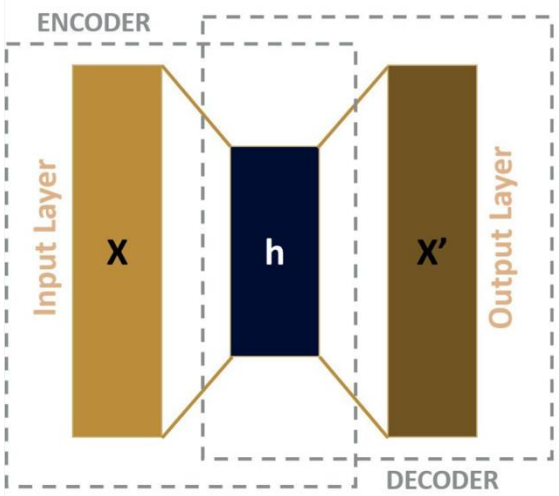
Particle on fluidized bed problems

SCALED-X: extend SCALED to multi-physics problems





Space filling curve method:
Using adoptive mesh method and unstructured mesh method for acceleration.



Auto-encoder compression method: compress the primitive variable into latent space and inference on the latent space. Could accelerate 100x.

IMPERIAL

Thank You

SCALED-SCALable gEnerative founDational model for Computational Physics

25/03/2025