Universal Physics Transformers (UPT)
A Framework For Efficiently Scaling Neural Operators

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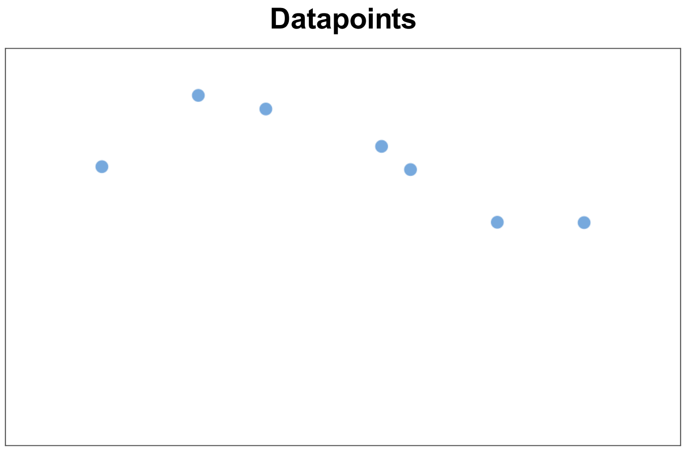
TLDR

- Current neural operators research largely focuses on small-scale problems (1K-10K inputs)
  - Interesting problems often have 100 thousands or millions of inputs

- We introduce a framework for efficient neural operators
  - Reduced latent space modeling
  - Applicable to Eulerian and Lagrangian data
  - Leverage scalability of transformers

Background: Neural Operators



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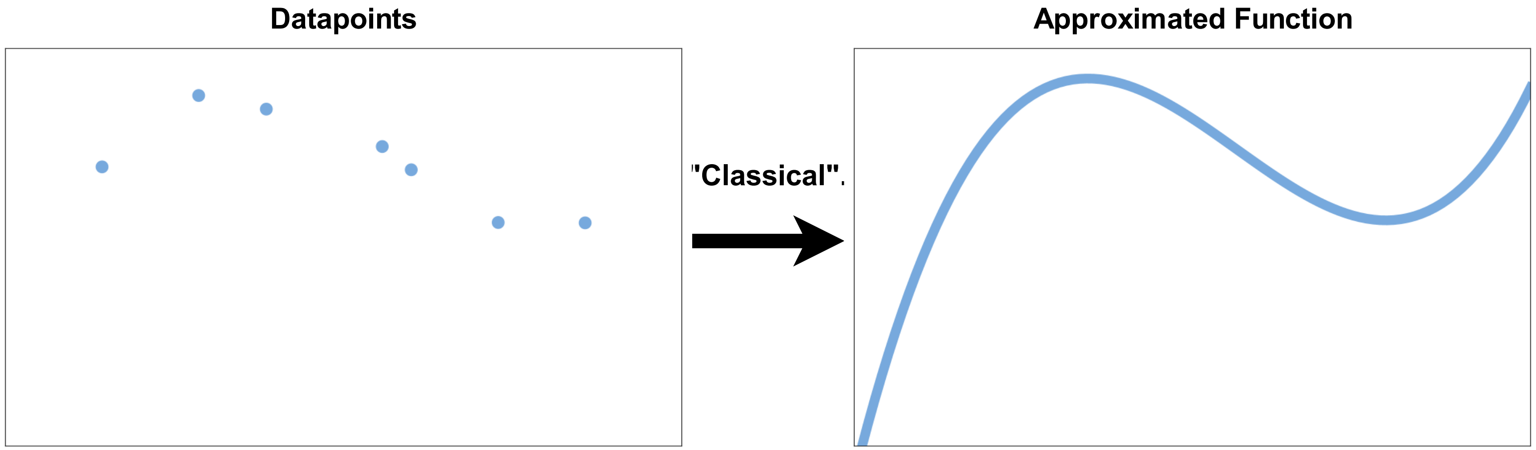

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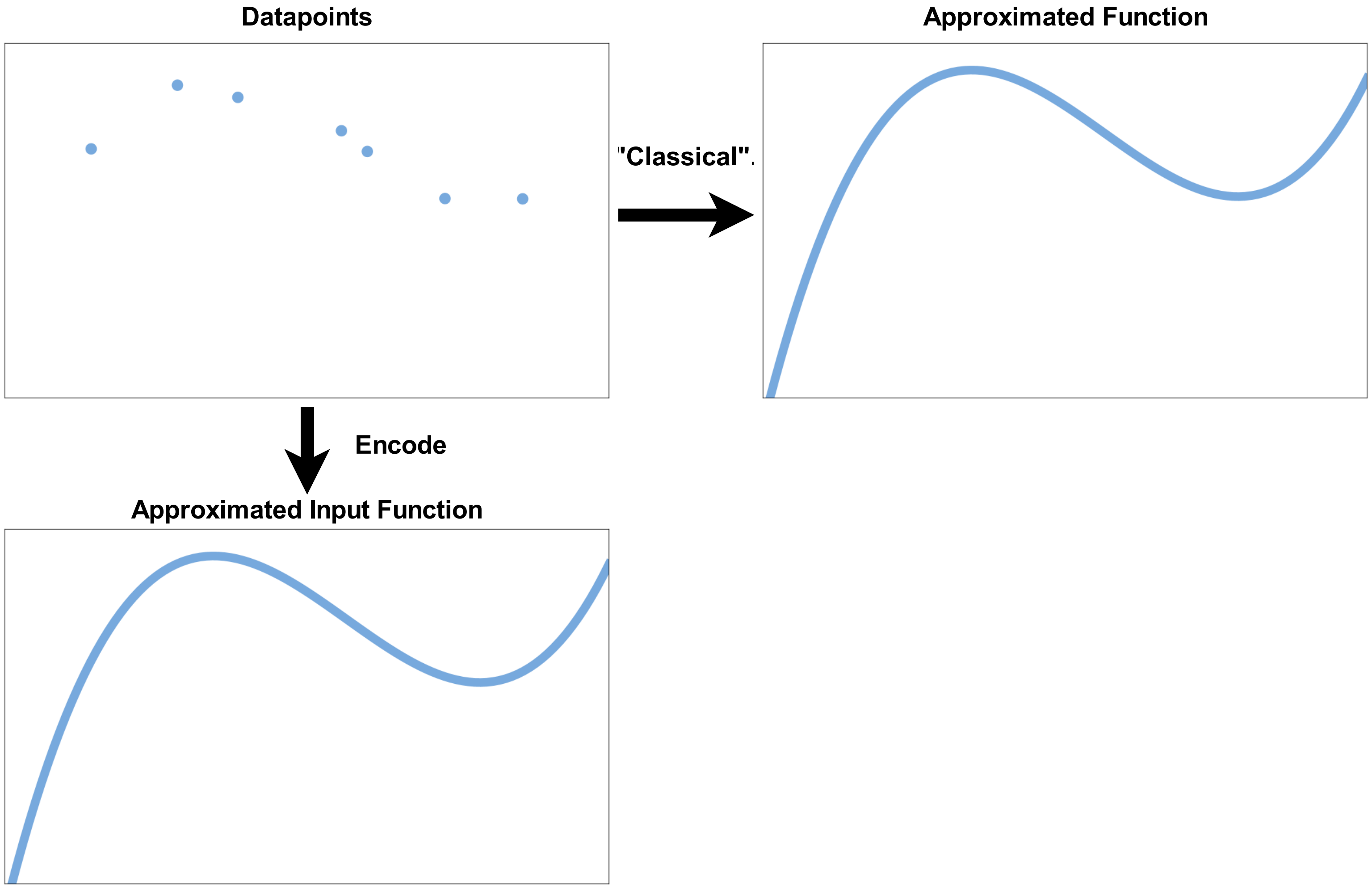

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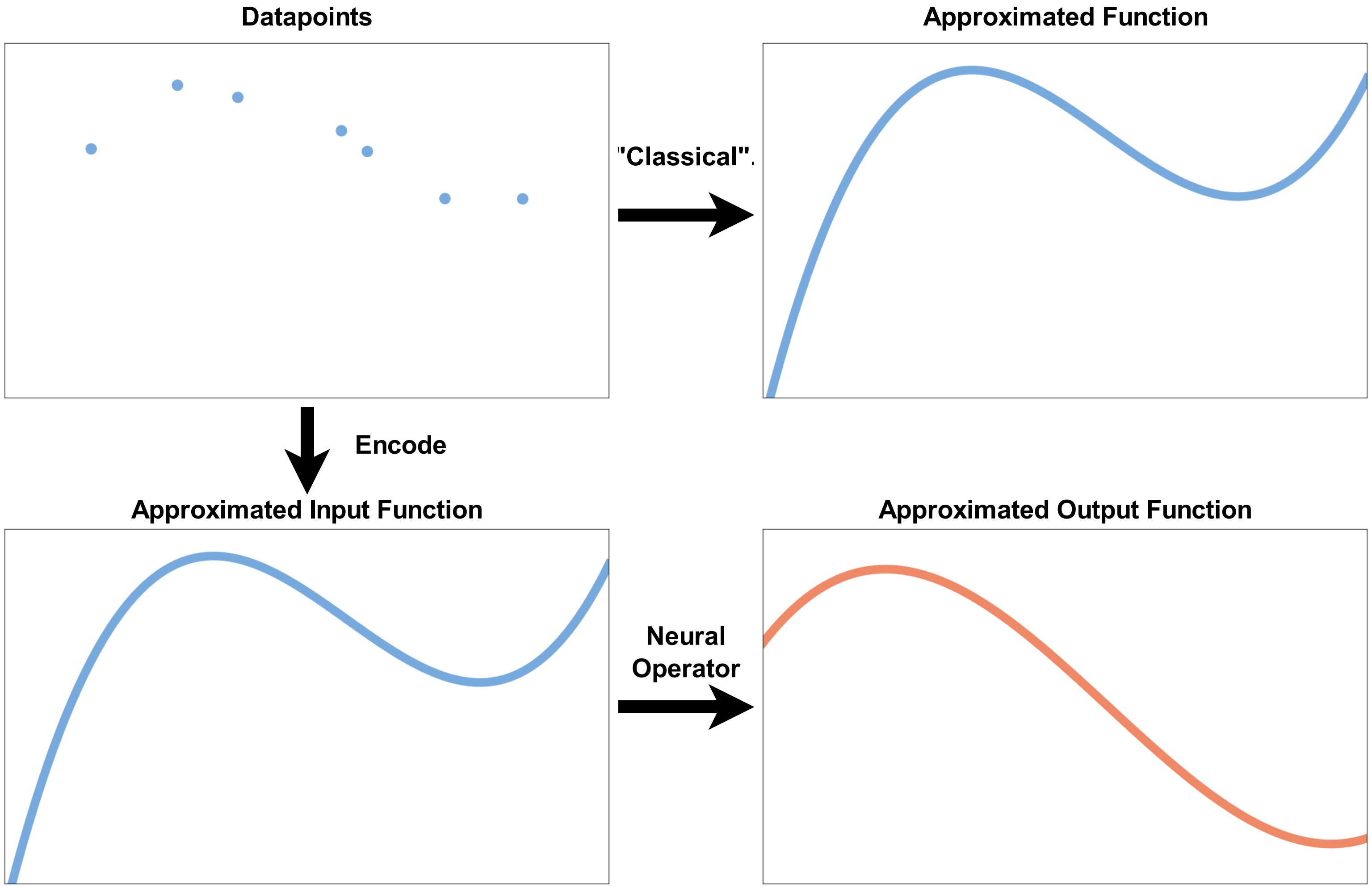

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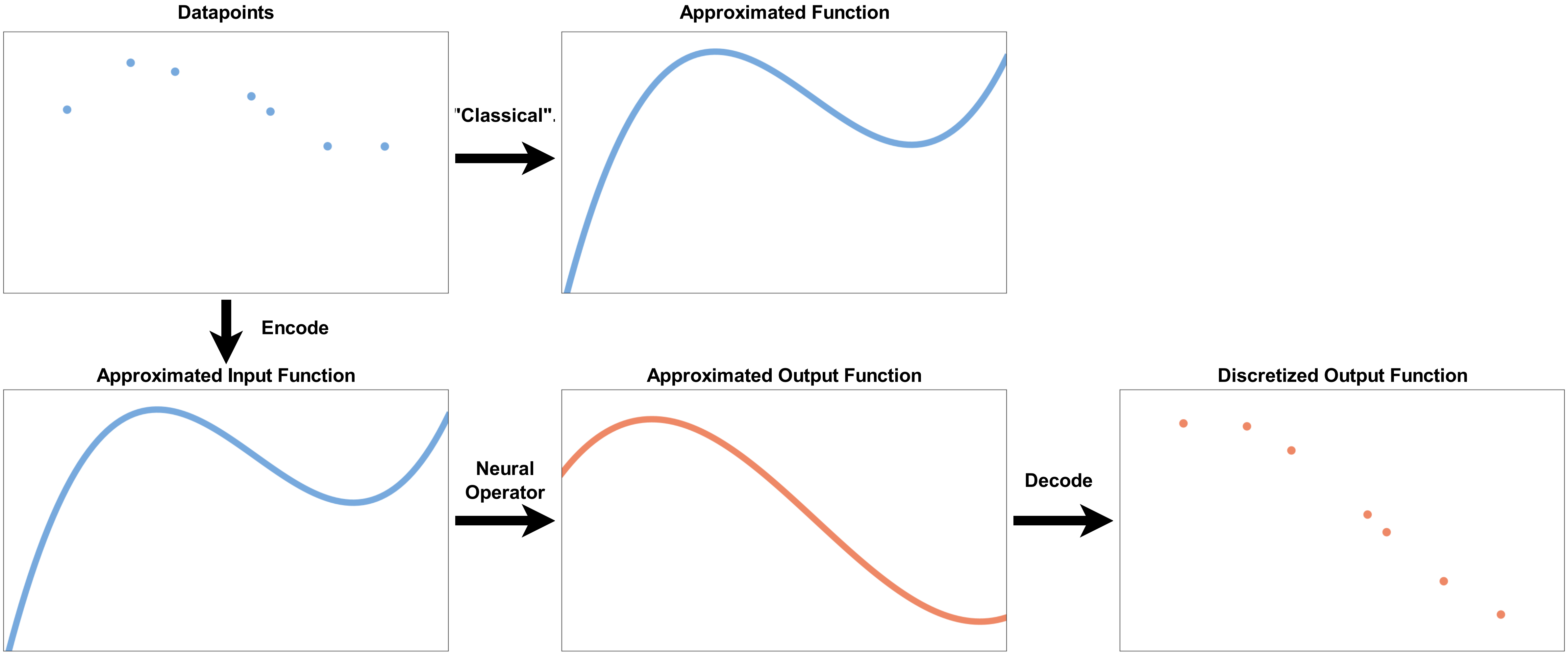
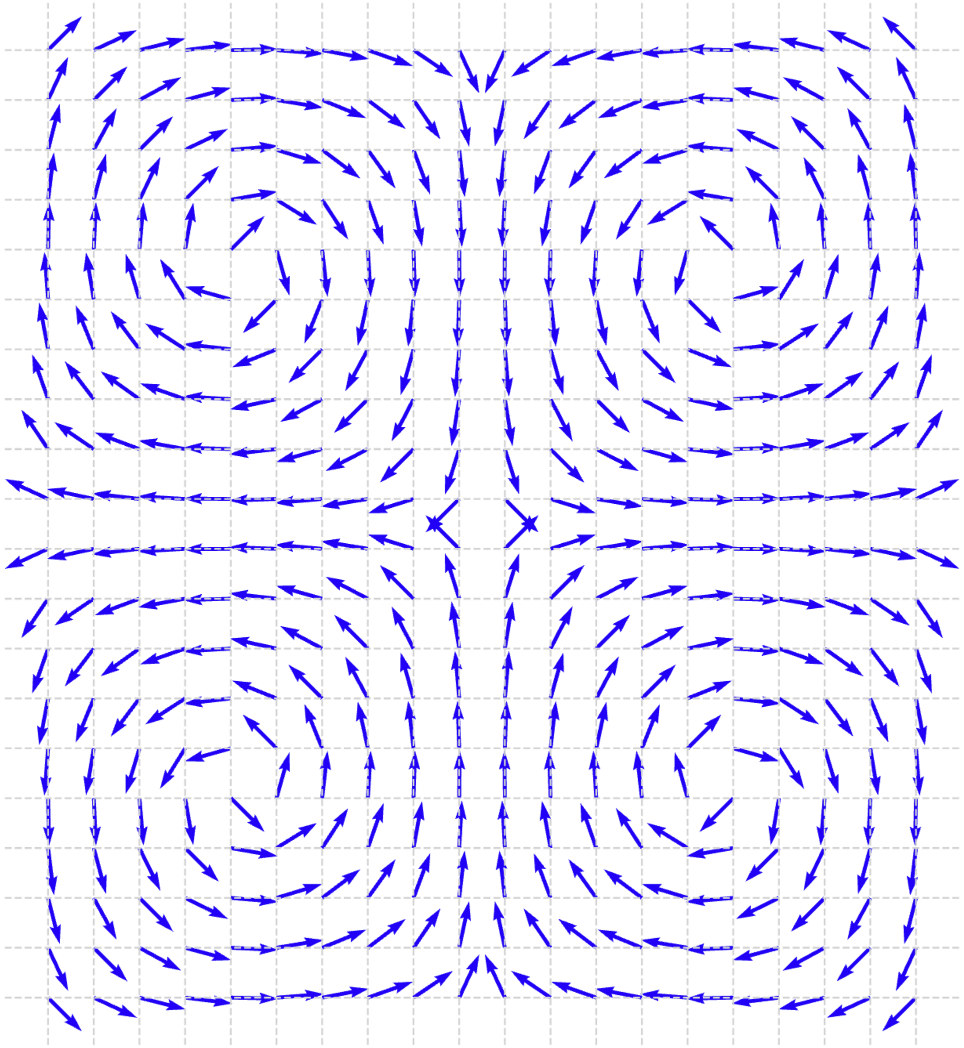
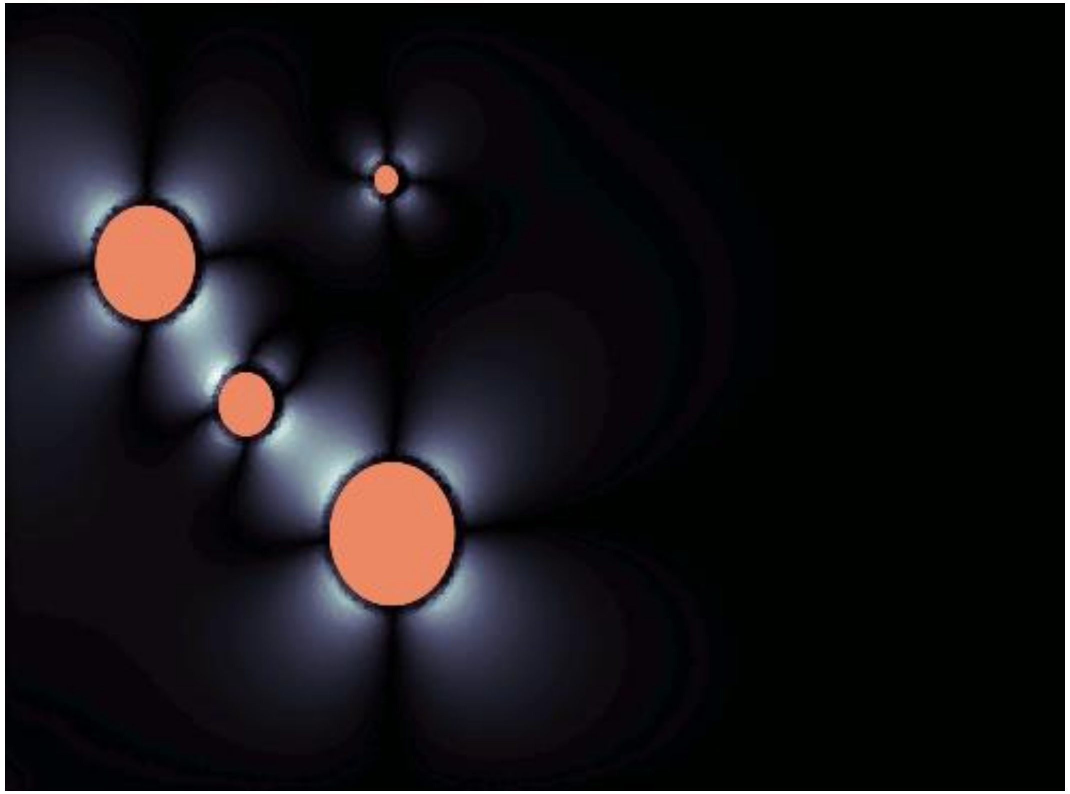


Background: Reduced Order Modeling

- Uncompressed representation: 400 2D vectors
- Abstract representation: “four swirls”

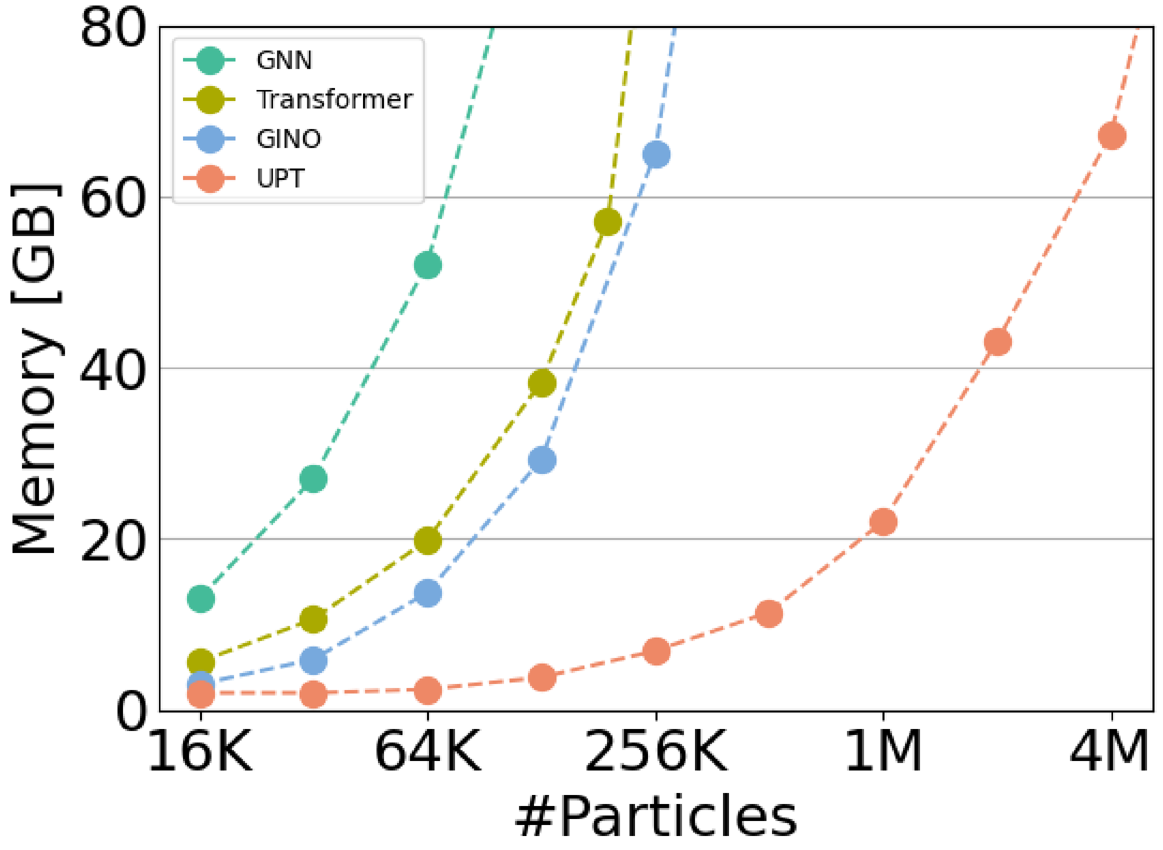


Transient Flow Simulations

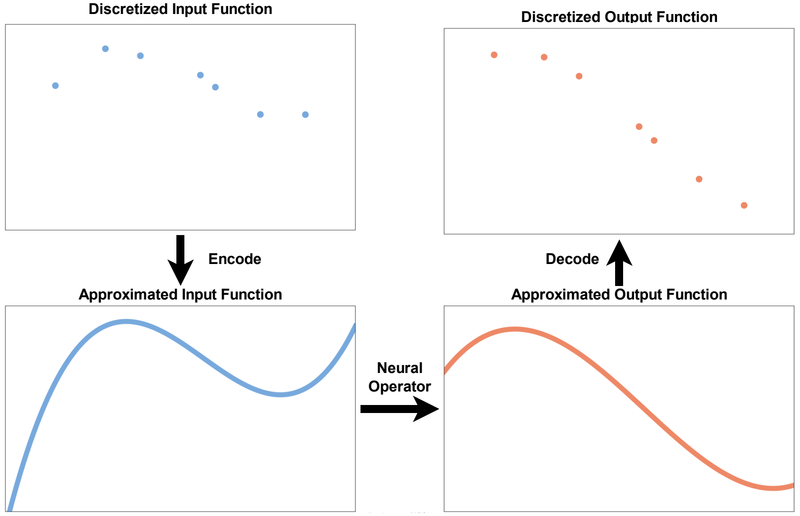


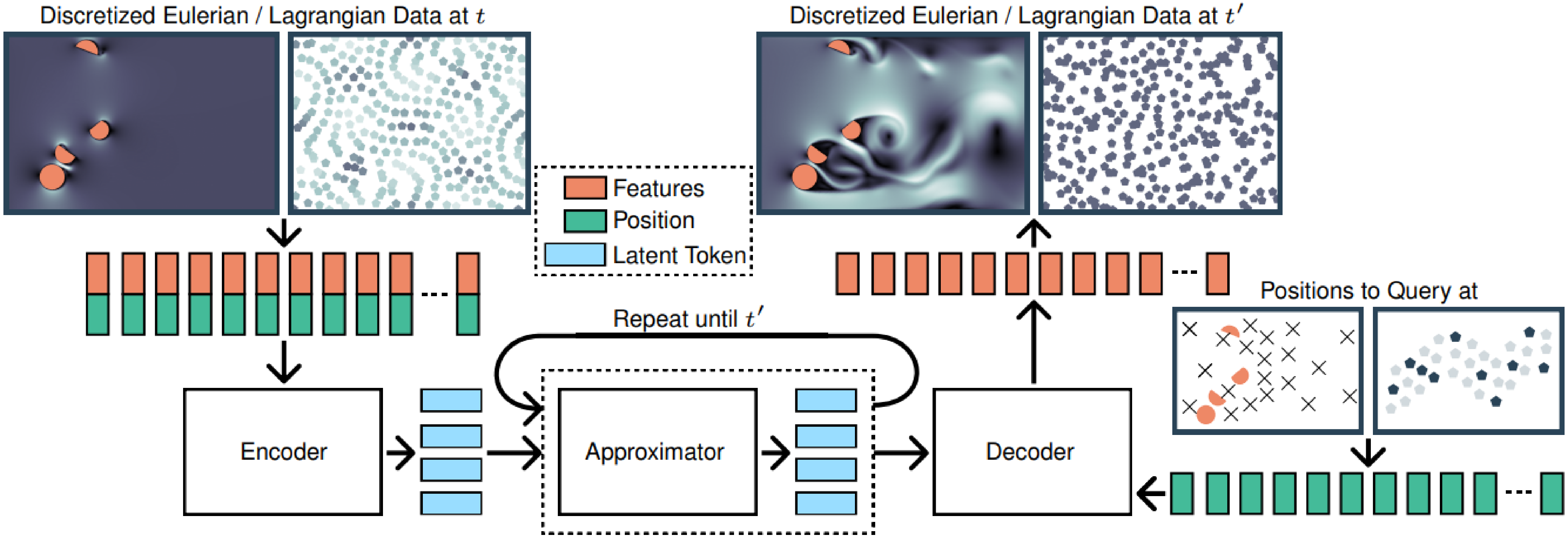
Current Landscape of Neural Operators

- Existing neural operator architectures don’t scale well
  - Architectures that can’t handle large inputs
  - No input compression



UPT





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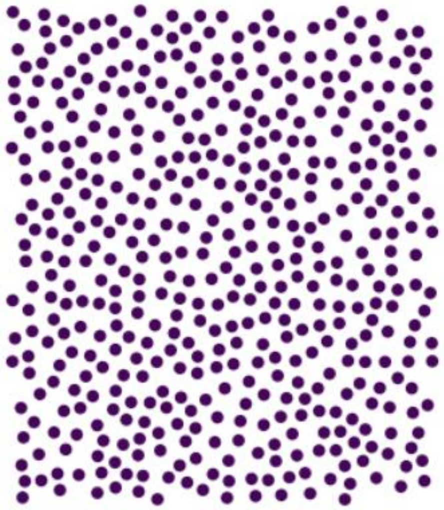
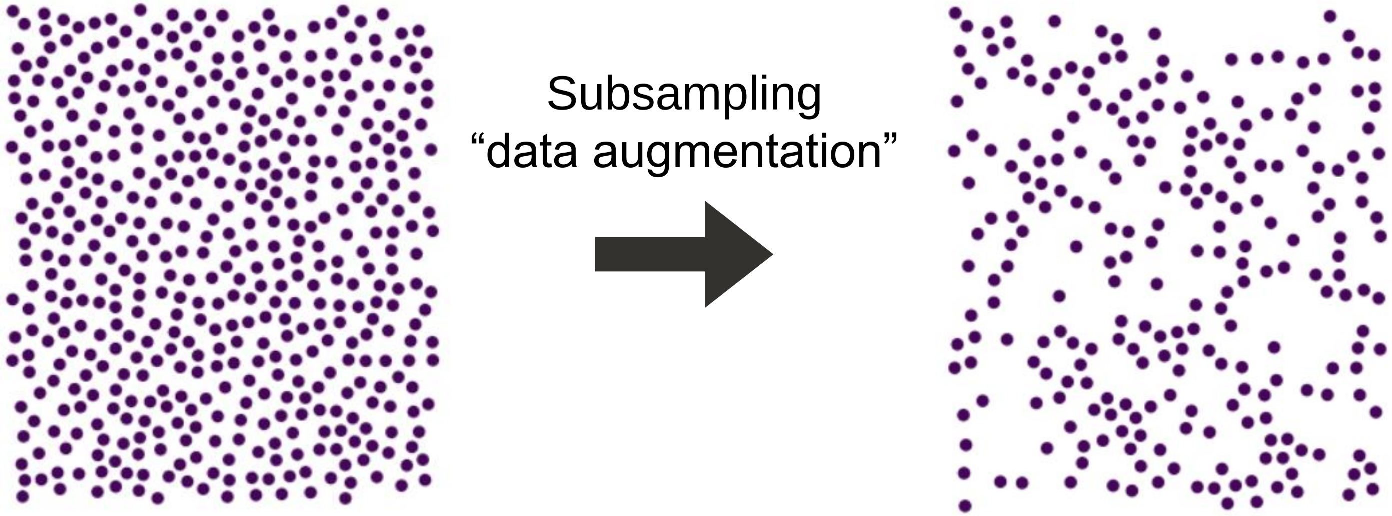
Encoding Physical Systems



Encoding Physical Systems



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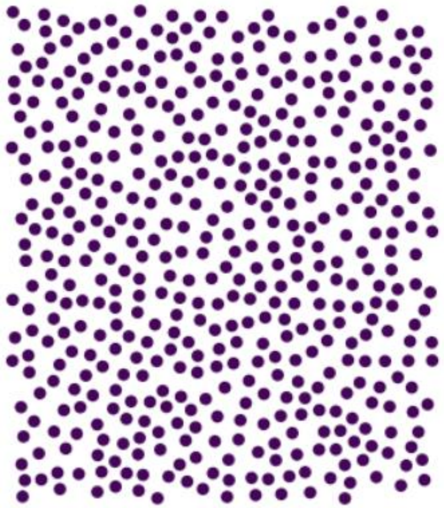
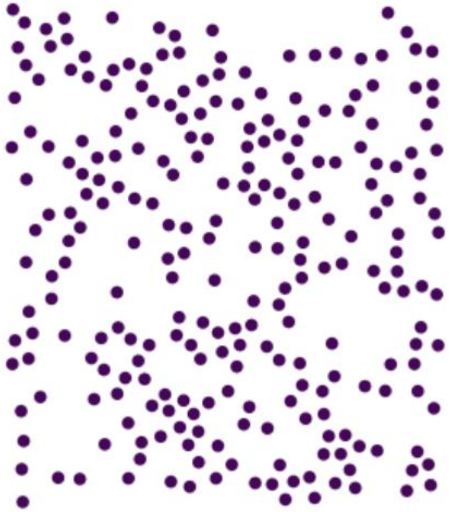
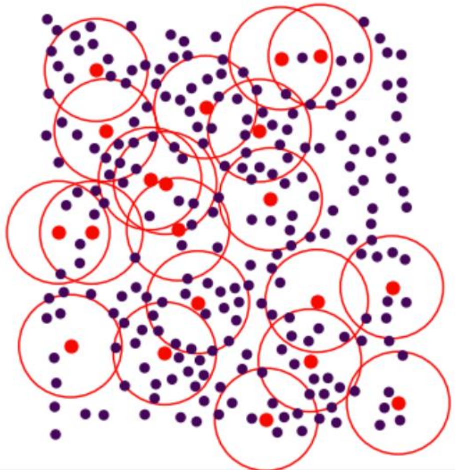


Subsampling
“data augmentation”



Select Supernodes



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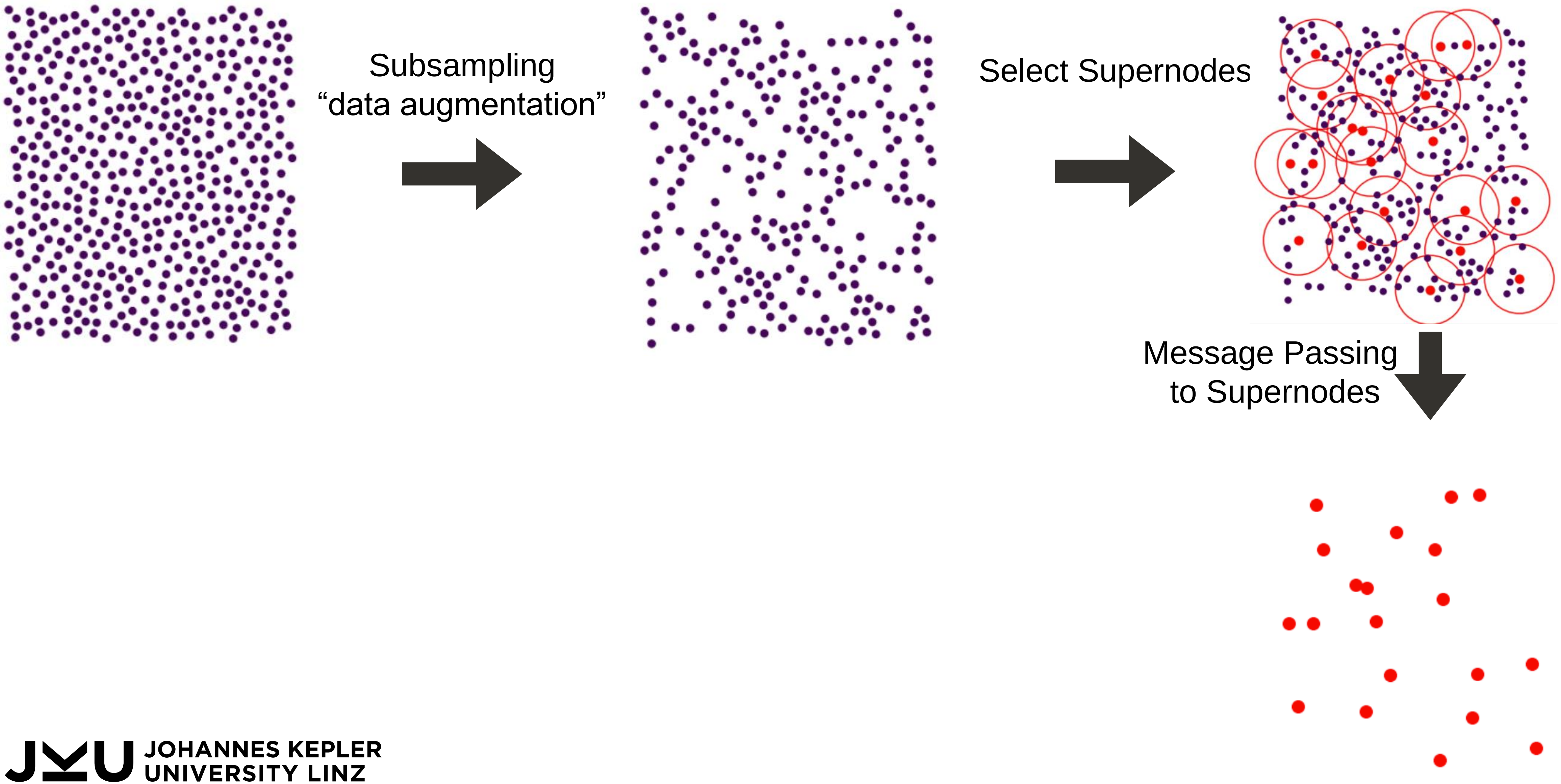

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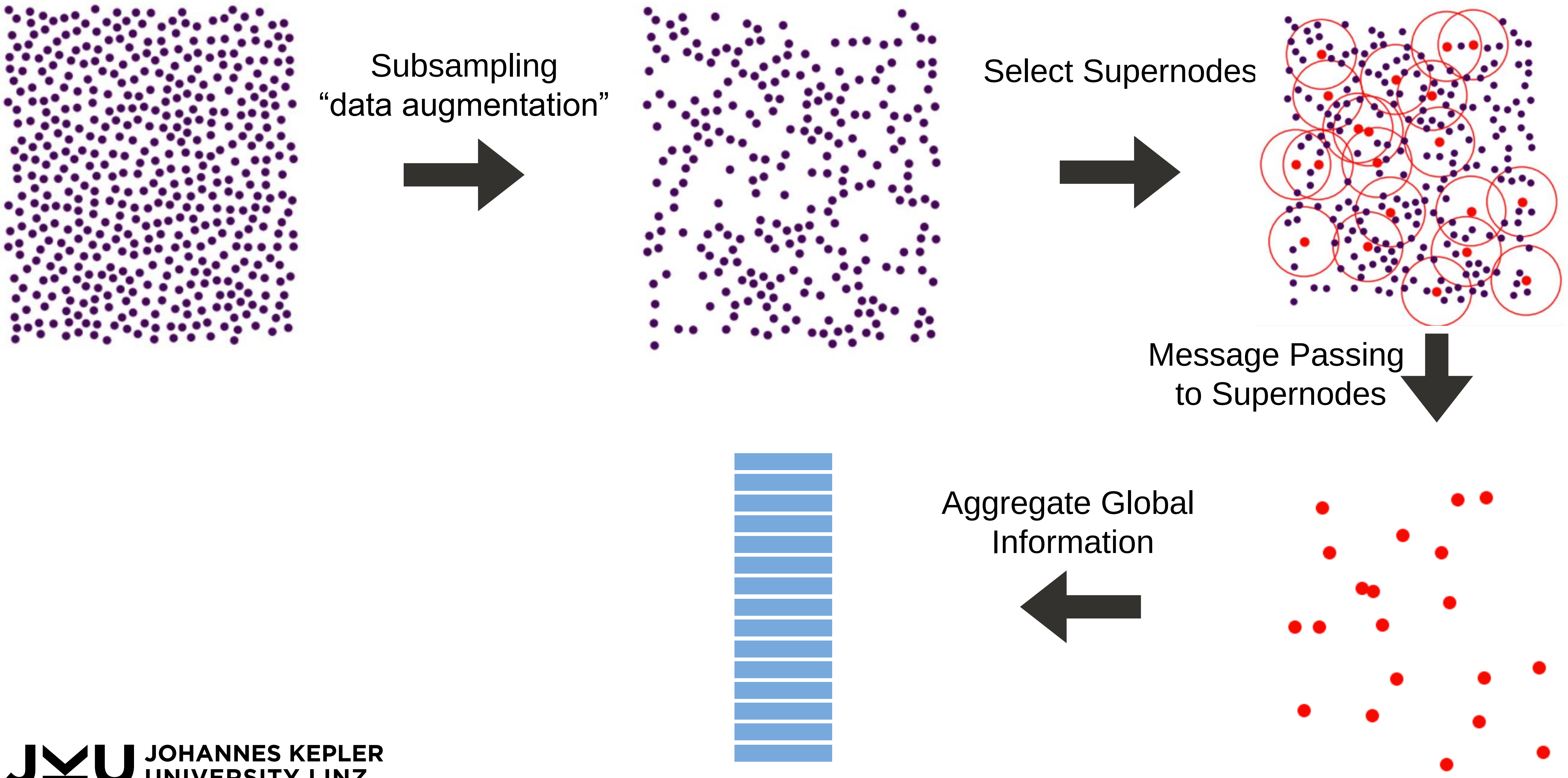

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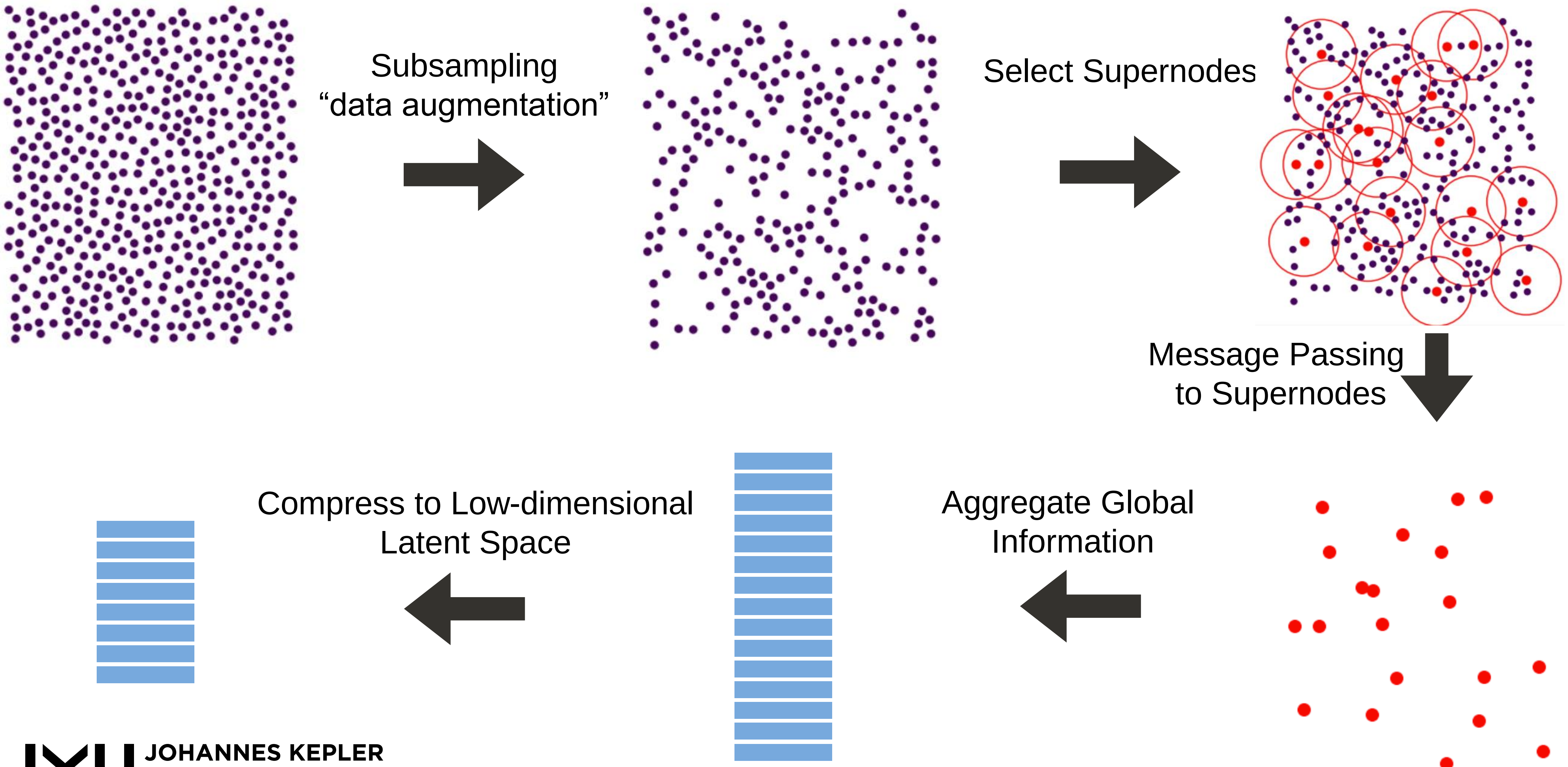
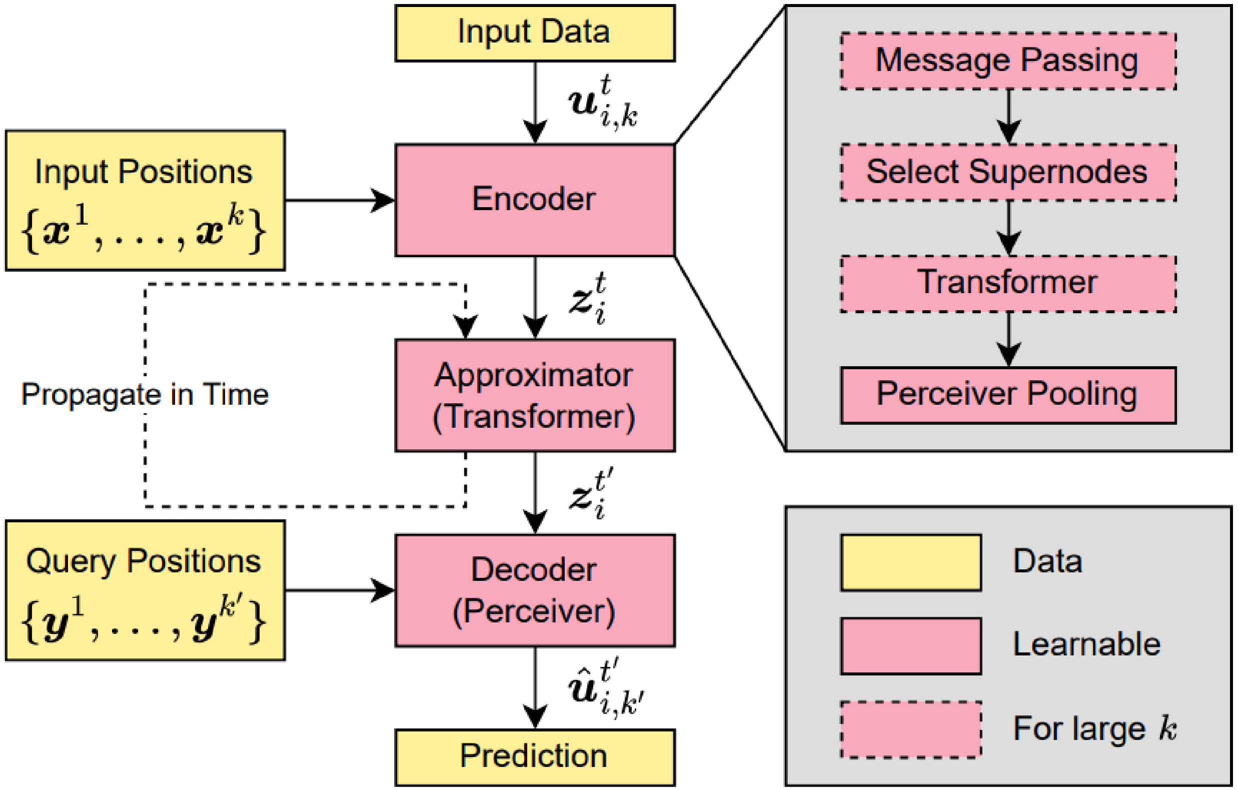


Architecture

- Encoder
  - Aggregate information into supernodes
  - Exchange global information
  - Reduce into a small latent space
- Approximator
  - Propagate latent space forward in time
- Decoder
  - Decode the latent space at arbitrary query positions



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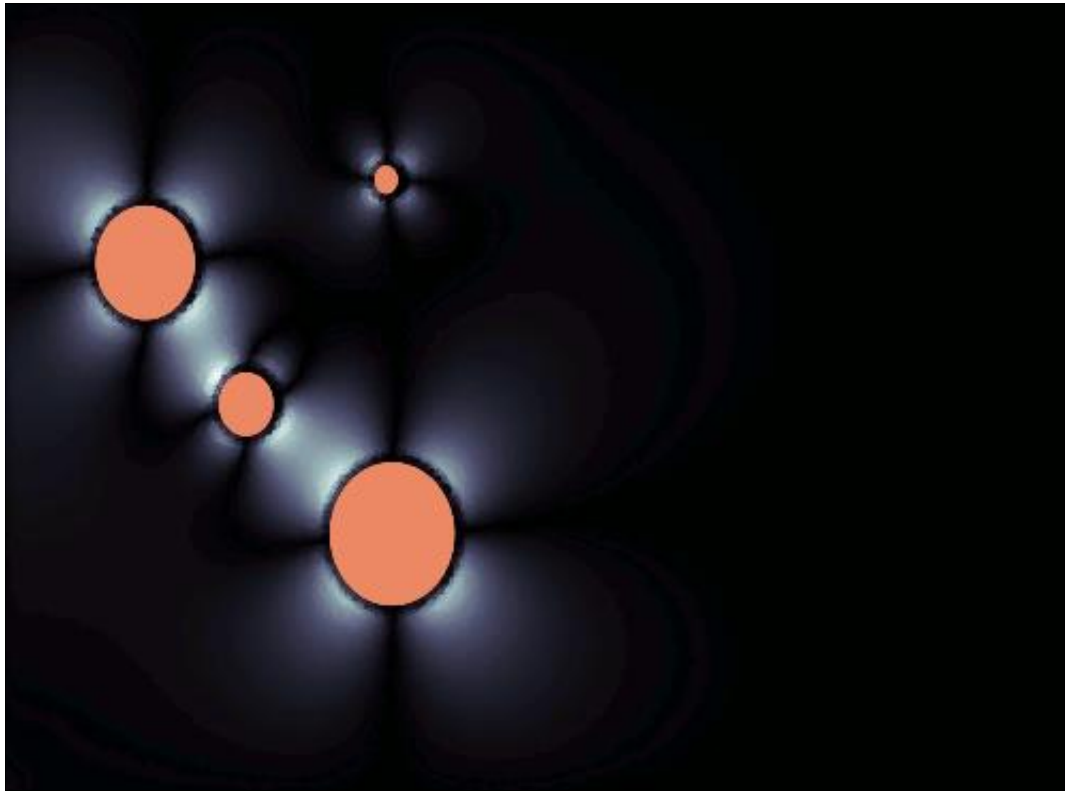
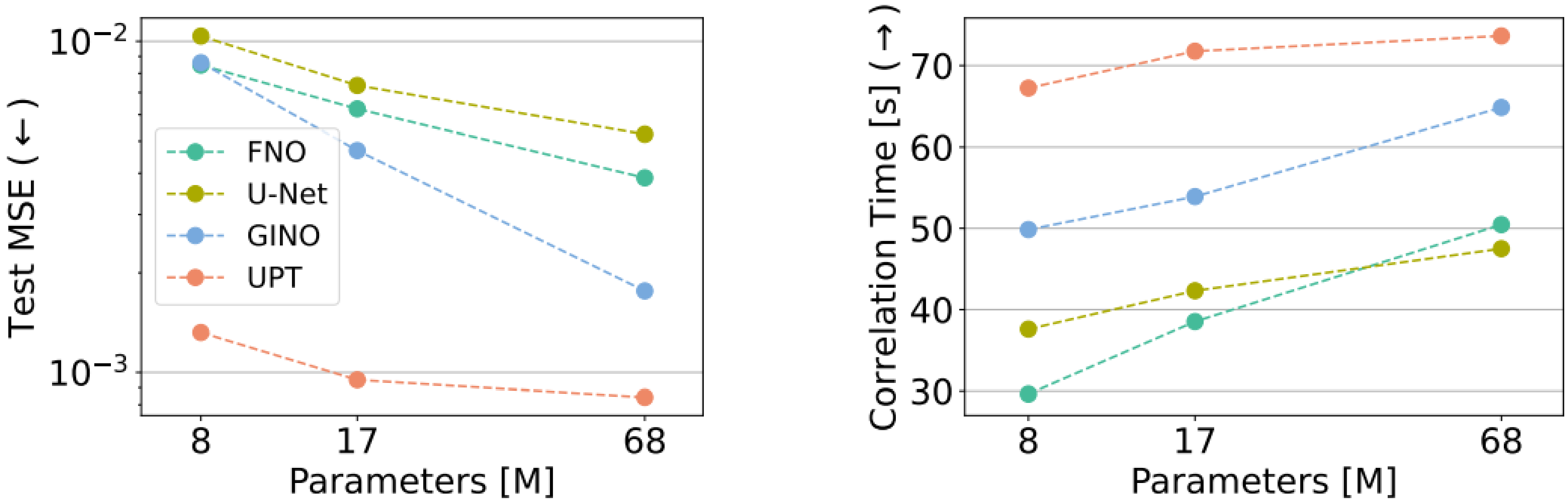
Results: Transient Flow Simulations

- Self-generated computational fluid dynamics (CFD) dataset
- 10K simulations (8K train, 1K validation, 1K test)
- Adaptive meshing (between 29K and 59K mesh points)
- 2D problem

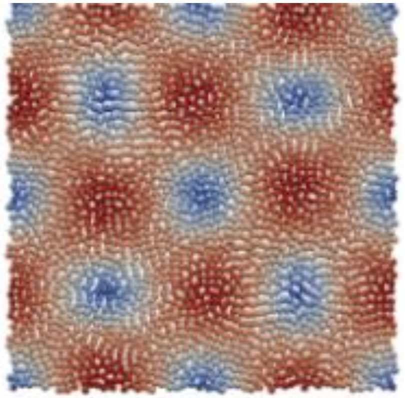


Results: Transient Flow Simulations

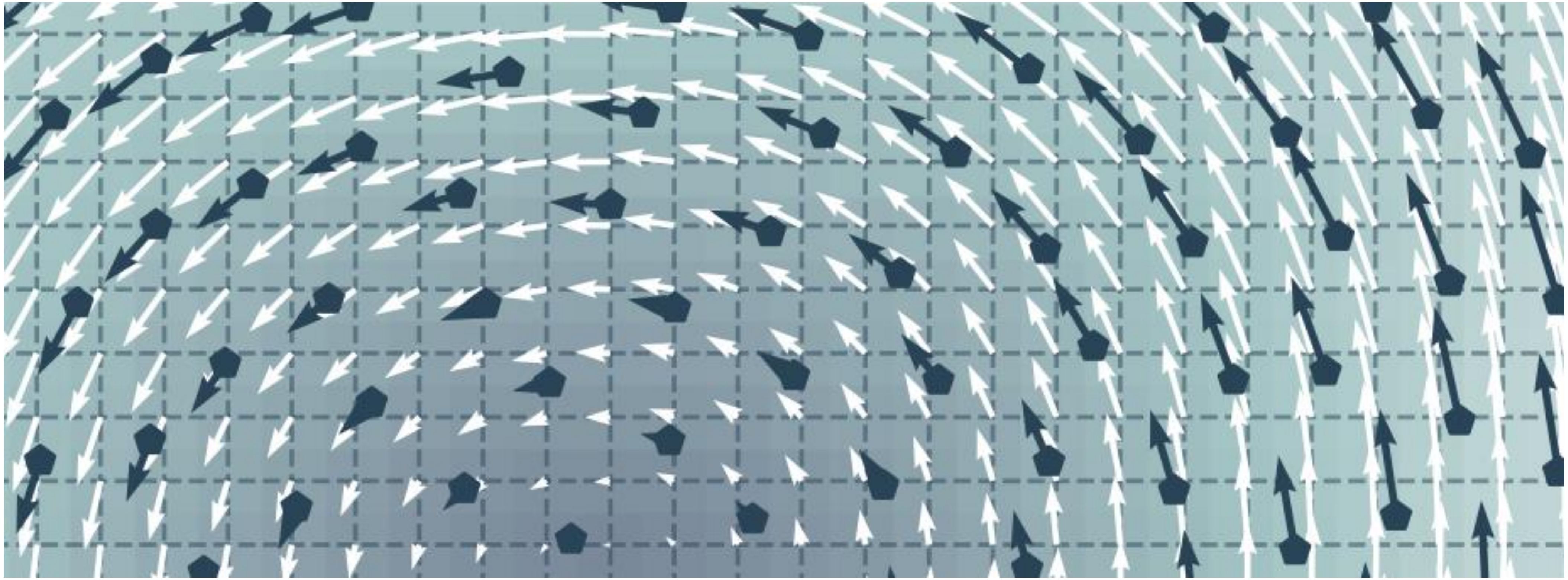
- UPTs easily outperform competition



UPTs for Lagrangian Simulations



- UPTs can model the underlying velocity field extremely well



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Thanks for your attention!

Project Page + Code	Paper	Tutorial
https://ml-jku.github.io/UPT	https://arxiv.org/abs/2402.12365	https://github.com/BenediktAlkin/upt-tutorial

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