A USER GUIDE FOR MORPH

Mahindra Singh Rautela
Los Alamos National Laboratory
mrautela@lanl.gov

ABSTRACT

(Work in Progress) This is user guide for "MORPH: Shape-agnostic PDE Foundational Models".
Paper: https://arxiv.org/abs/2509.21670.
Code: https://github.com/lanl/MORPH.
Models: https://huggingface.co/mahindrautela/MORPH.

1 WHAT IS MORPH?

MORPH (Shape-Agnostic PDE Foundation Model) is an autoregressive model designed for learning and predicting the behavior of physical systems governed by partial differential equations (PDEs). The model seamlessly accommodate datasets with different dimensions (1D–3D), resolutions, multiple fields with scalar/vector components.

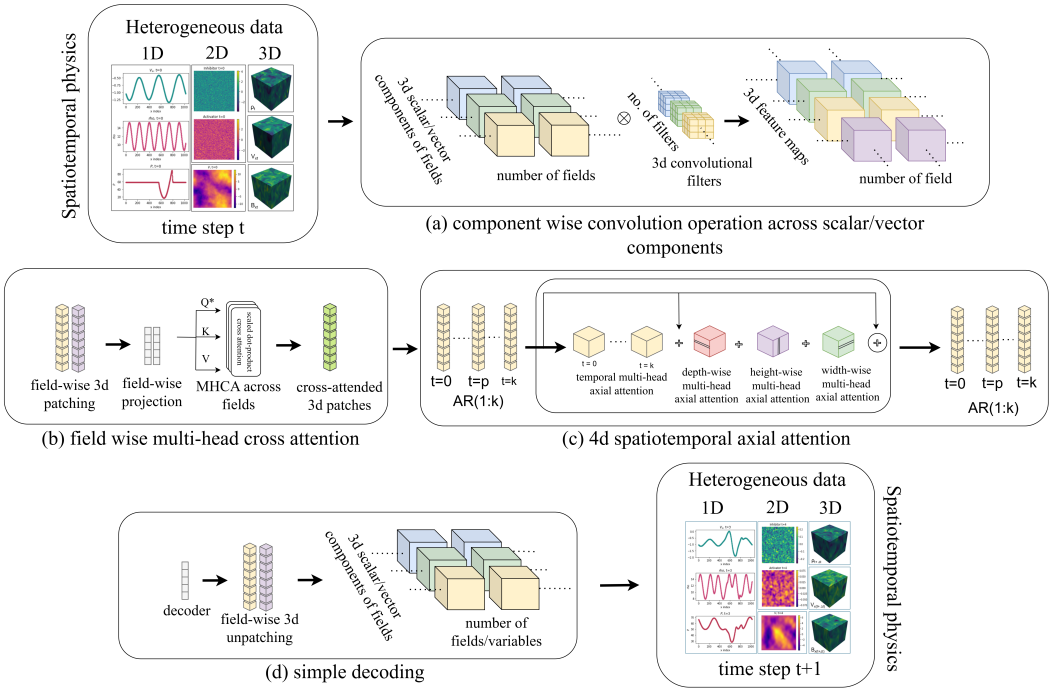

Figure 1: An illustration of the model architecture. MORPH is a shape-agnostic design that seamlessly handles heterogeneous datasets. The design consists of (a) 3D convolution operation is performed along the component (C) dimension providing filters$\times$ feature maps, (b) multi-head cross-attention is performed across fields (F) resulting in a fused field, (c) 4D factorized axial attention is performed along space-time dimension (T, D, H, W), (d) simple decoder maps back to the data space.

1.1 How MORPH is Different?

- **Shape-agnostic architecture:** Seamlessly operates across 1D–3D data without task-specific reconfiguration.
- **Unified data representation:** Uses UPTF-7 format to handle heterogeneous datasets consistently.
- **Cross-field learning:** Employs multi-head cross-attention to model interactions between coupled physical fields.
- **Efficient attention design:** Utilizes axial attention to reduce computational cost while preserving long-range dependencies.
- **Scalable variants:** Available in multiple model sizes (Tiny to Large) supporting diverse computational budgets.
- **Parameter-efficient adaptation:** Incorporates LoRA for fine-tuning with minimal additional parameters.
- **Superior generalization:** Outperforms existing PDE foundation models in zero-shot and fine-tuned settings.
- **Open and reproducible:** Publicly available datasets, code, and pretrained weights enable transparent benchmarking.

1.2 How MORPH can be used for Physics (PDE) datasets?

1. Standalone surrogate (SS): MORPH can be trained for PDE datasets as a task-specific ML model from scratch.
2. Foundation model (FM): Using open-sourced weights, MORPH can be finetuned on task-specific datasets.

2 Requirements

2.1 Datasets

2.2 Python environment

2.3 Computing resources

3 Installation