

OmniArch: Building Foundation Model for Scientific Computing

Unified 1D-2D-3D PDE Solver with Physics Alignment

Tianyu Chen¹ Haoyi Zhou¹ Ying Li² Hao Wang² Chonghan Gao¹ Rongye Shi¹
Shanghang Zhang² Jianxin Li¹

¹Beihang University ²Peking University

ICML 2025

From Specialized to Universal: A Paradigm Shift

Traditional Approach

Navier-Stokes → CFD Solver

Heat Equation → FEM Solver

Maxwell's Eqs → FDTD Solver

⚠ One solver per PDE type

Foundation Model Approach

Any PDE → **OmniArch**

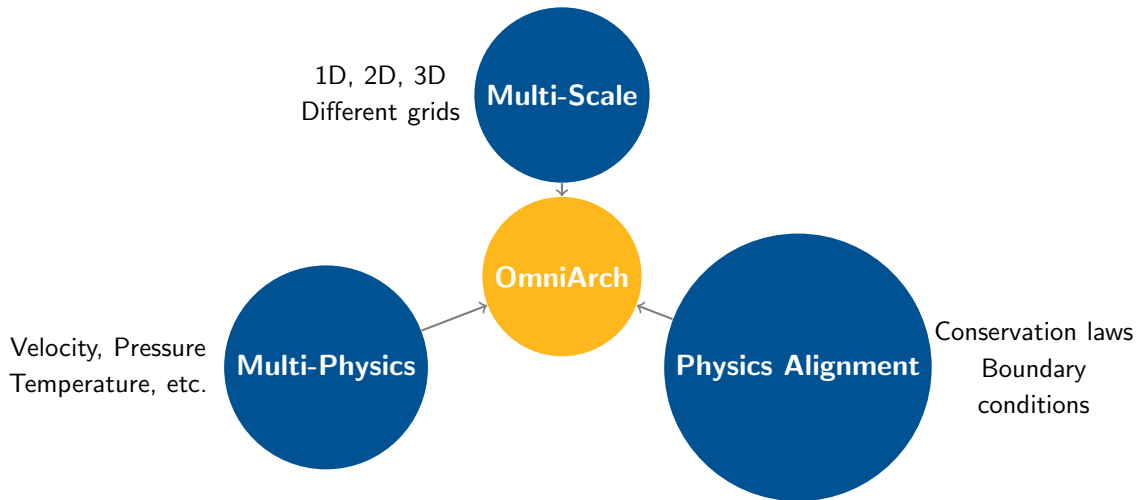
1D/2D/3D → **Unified**

Multi-physics → **One Model**

✓ Universal PDE solver

*"Like Newton's laws unifying celestial and terrestrial mechanics,
OmniArch unifies PDE solving across scales and physics"*

The Triple Challenge in Scientific Computing



OmniArch Architecture: Unified Multi-Scale Processing

1 Fourier Encoder/Decoder

- Grid-agnostic representation
- Handles 1D/2D/3D uniformly
- Frequency domain truncation

2 Transformer Backbone

- Temporal Mask for multi-physics
- Shared layers across dimensions
- Autoregressive prediction

3 PDE-Aligner

- Physics-informed fine-tuning
- Equation text embedding
- Energy conservation constraints

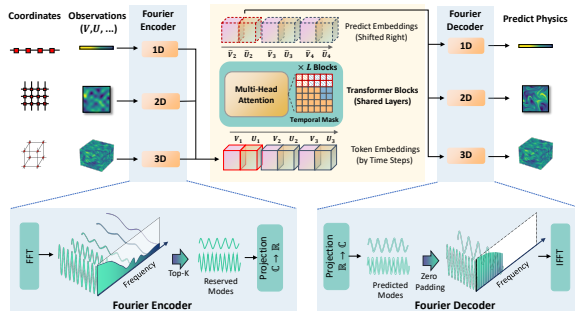


Figure: The framework of OmniArch

State-of-the-Art Performance on PDEBench

Table: nRMSE comparison across 1D, 2D, and 3D PDEs

Method	1D CFD	2D CFD	2D SWE	3D CFD	Avg. Improve.
U-Net	2.6700	1.0700	0.0830	0.7989	Baseline
FNO	1.4100	0.2060	0.0044	0.3052	68.7%
MPP-L	–	0.0178	0.0022	–	87.2%
DPOT-L	–	0.0112	0.0451	0.4321	–
OmniArch-L	0.0200	0.0125	0.0012	0.0827	98.7%

Emergent Capabilities: Beyond Traditional Solvers

Zero-Shot Generalization

- KH, Shock, OTV Fluids

4-7 $\times$ error reduction vs. MPP
without any fine-tuning!

In-Context Learning

- No explicit time encoding
- learning from context

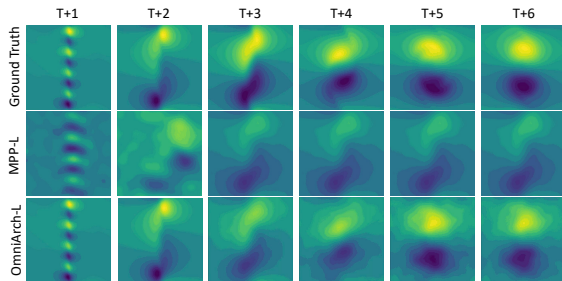


Figure: Zero-shot predictions on unseen PDEs

Impact: Accelerating Scientific Discovery

Application Domains

- ✈️ **Aircraft Design**: Real-time CFD simulations
- ☁️ **Weather Forecasting**: Multi-scale dynamics
- 🏭 **Semiconductor Manufacturing**: Complex physics
- ⚙️ **Materials Science**: Property prediction

Key Advantages

- ✅ 155× speedup vs. traditional FDM
- ✅ Resolution-invariant inference
- ✅ Unified framework for all PDEs
- ✅ Physics-consistent predictions

Computational Efficiency

Resolution	Speedup
128 ²	0.6×
256 ²	10.6×
384 ²	48.2×
512 ²	155.4×

OmniArch: Three Breakthroughs

Multi-Scale



Unified 1D-2D-3D
Grid-agnostic
Fourier domain

Multi-Physics



Single model
All PDE types
Temporal attention

Physics Alignment



PDE-Aligner
Conservation laws
Equation guidance

*"First foundation model to successfully conduct
1D-2D-3D united pre-training for scientific computing"*

Thank You!

Questions?

✉ tianyuc@buaa.edu.cn

🔗 <https://openi.pcl.ac.cn/cty315/OmniArch>



Scan for paper & code