# Neural Force Field : Few-shot Learning of Generalized Physical Reasoning

Shiqian Li*, Ruihong Shen*, Yaoyu Tao✉, Chi Zhang✉, Yixin Zhu✉
Peking University

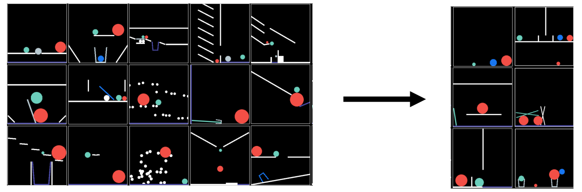
## Background

### Human intuitive physics vs. AI models

1. From infancy, humans develop robust intuitive physics understandings.
2. AI models struggle to achieve human-level few-shot learning and generalization ability in physical reasoning.

VoE paradigm  Object permanence  Gravity and support

### Goal: Achieve human-like few-shot learning and generalization in physical reasoning

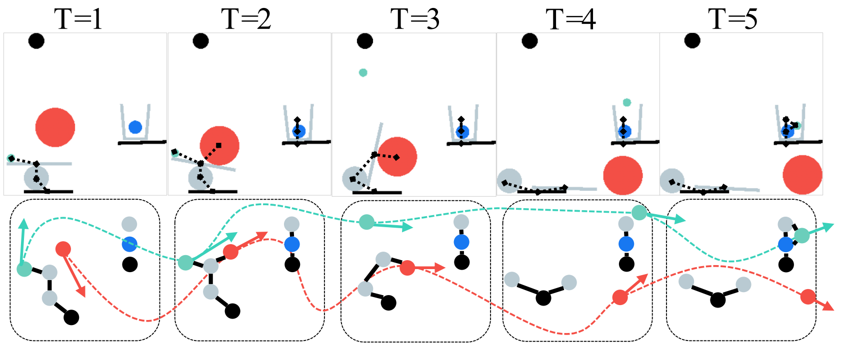


A few training examples  OOD templates

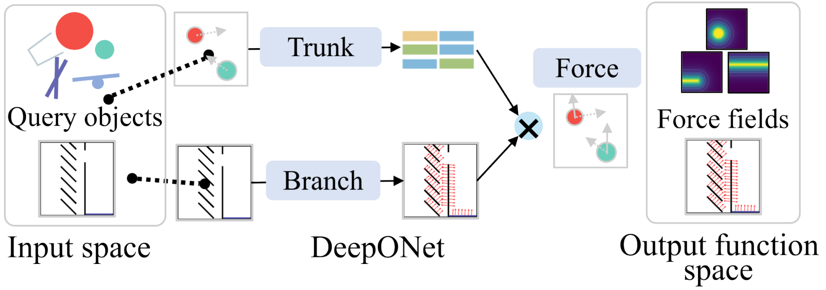
## Neural Force Field

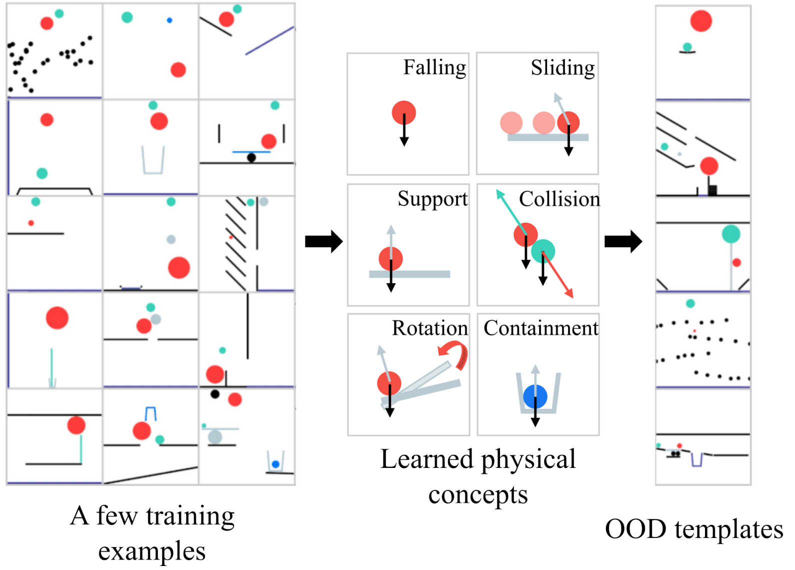
a neural function map from objects to forces for efficient interactive learning and reasoning.

(a) NFF models complex physical interactions by constructing dynamic interaction graphs from scenes and performing continuous integration on force fields.




(b) The force fields are inferred by a neural operator that takes object interactions as input.



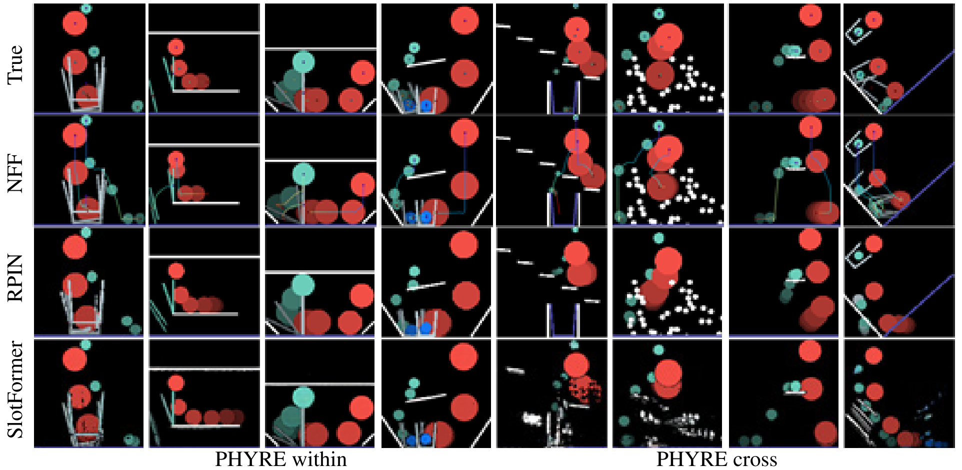



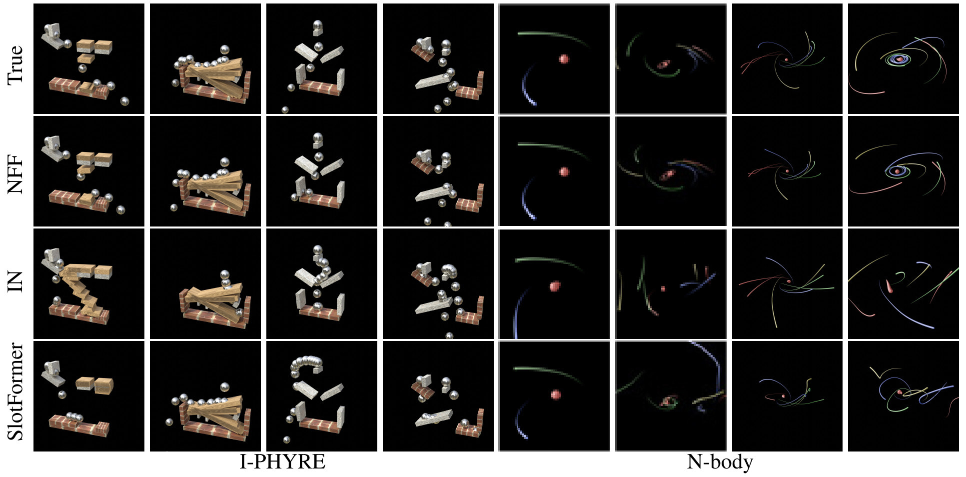

(c) After learning from a few examples, NFF can capture various physical concepts such as sliding, support and collision represented by force fields and generalize to unseen OOD scenarios.

## Prediction results

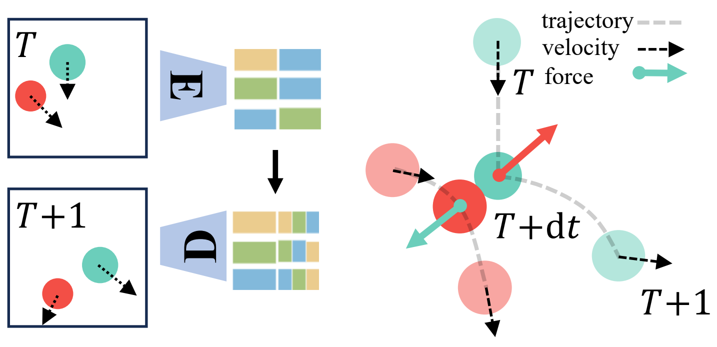
Superior OOD generalization.

| Metric | Model | I-PHYRE | | N-body | | |
|---|---|---|---|---|---|---|
| | | Within | Cross | Within [0,T] | Within [0,3T] | Cross [0,3T] |
| RMSE ↓ | IN | 0.12 | 0.19 | 0.20 | 0.75 | 6.94 |
| | Slotformer | 0.07 | 0.21 | 0.21 | 1.09 | 2.53 |
| | SEGNO | 0.20 | 0.31 | **0.08** | 0.69 | 2.76 |
| | NFF | **0.05** | **0.13** | 0.10 | **0.53** | **1.23** |



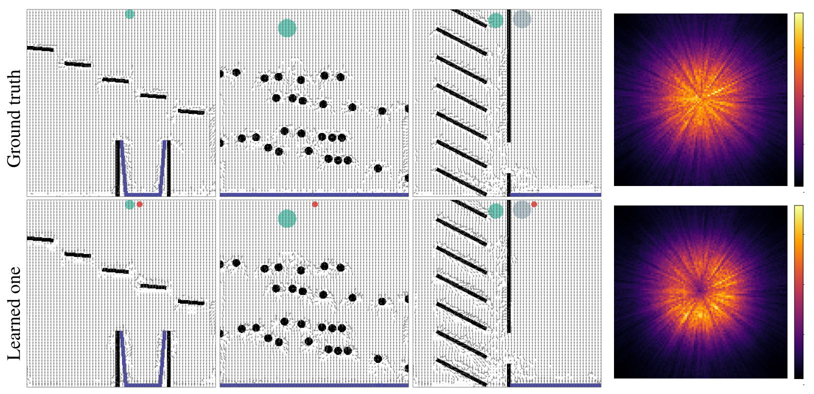




## Comparison of transition




Discrete prediction vs. NODE continous transition.

## Learned force fields




Invert underlying force fields using back-propagation.

## Planning results

Few-shot planning with minimal data.

| Method | Refine | Round 1 | Round 2 | Round 3 | Round 4 | Round 5 |
|---|---|---|---|---|---|---|
| Random | - | 0.24 | 0.37 | 0.45 | 0.51 | 0.56 |
| IN | × | 0.25 | 0.33 | 0.39 | 0.42 | 0.45 |
| IN | ✓ | 0.25 | 0.39 | 0.48 | 0.57 | 0.63 |
| SlotFormer | × | 0.30 | 0.36 | 0.39 | 0.41 | 0.43 |
| SlotFormer | ✓ | 0.30 | 0.42 | 0.49 | 0.55 | 0.60 |
| NFF | × | 0.51 | 0.55 | 0.58 | 0.60 | 0.62 |
| NFF | ✓ | 0.51 | 0.62 | 0.69 | 0.74 | 0.77 |
| Human | - | 0.52 | 0.70 | 0.79 | 0.83 | 0.86 |

| Metric | DQN | RPIN | SlotFormer | NFF |
|---|---|---|---|---|
| Sample (M) | 200.00 | 3.20 | 0.12 | 0.01 |
| AUCCESS | 30.96 | 36.58 | 21.04 | **49.22** |

## Contact

Paper  Website  Codebase  vimeo