Physics-Guided Inputs, Data and Representations

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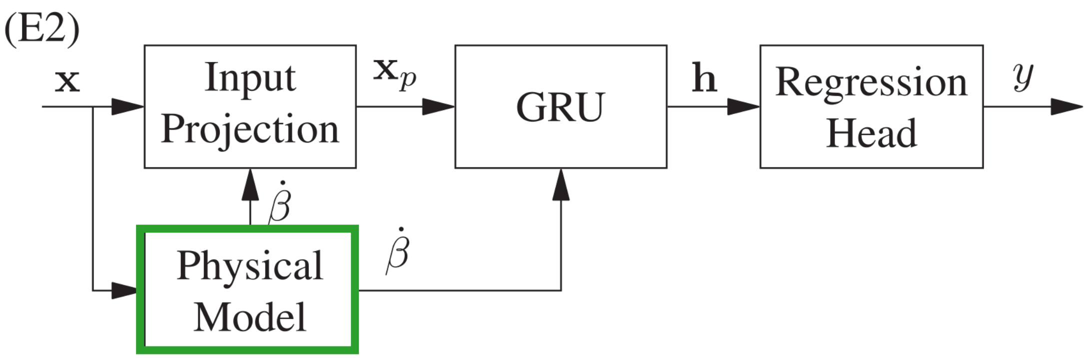
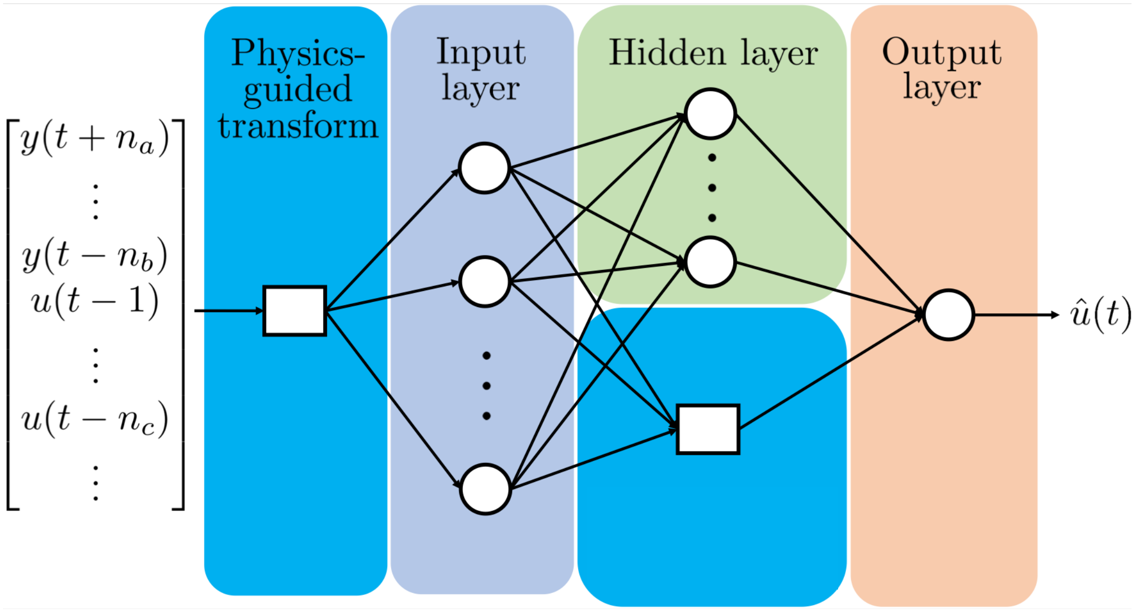
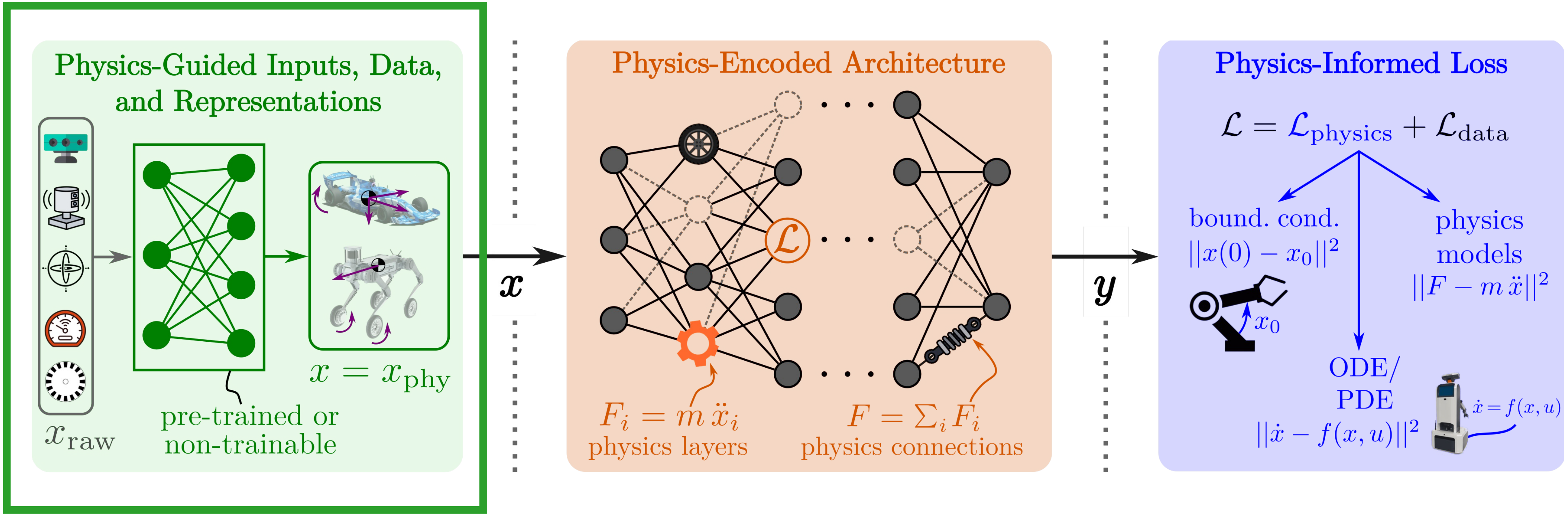




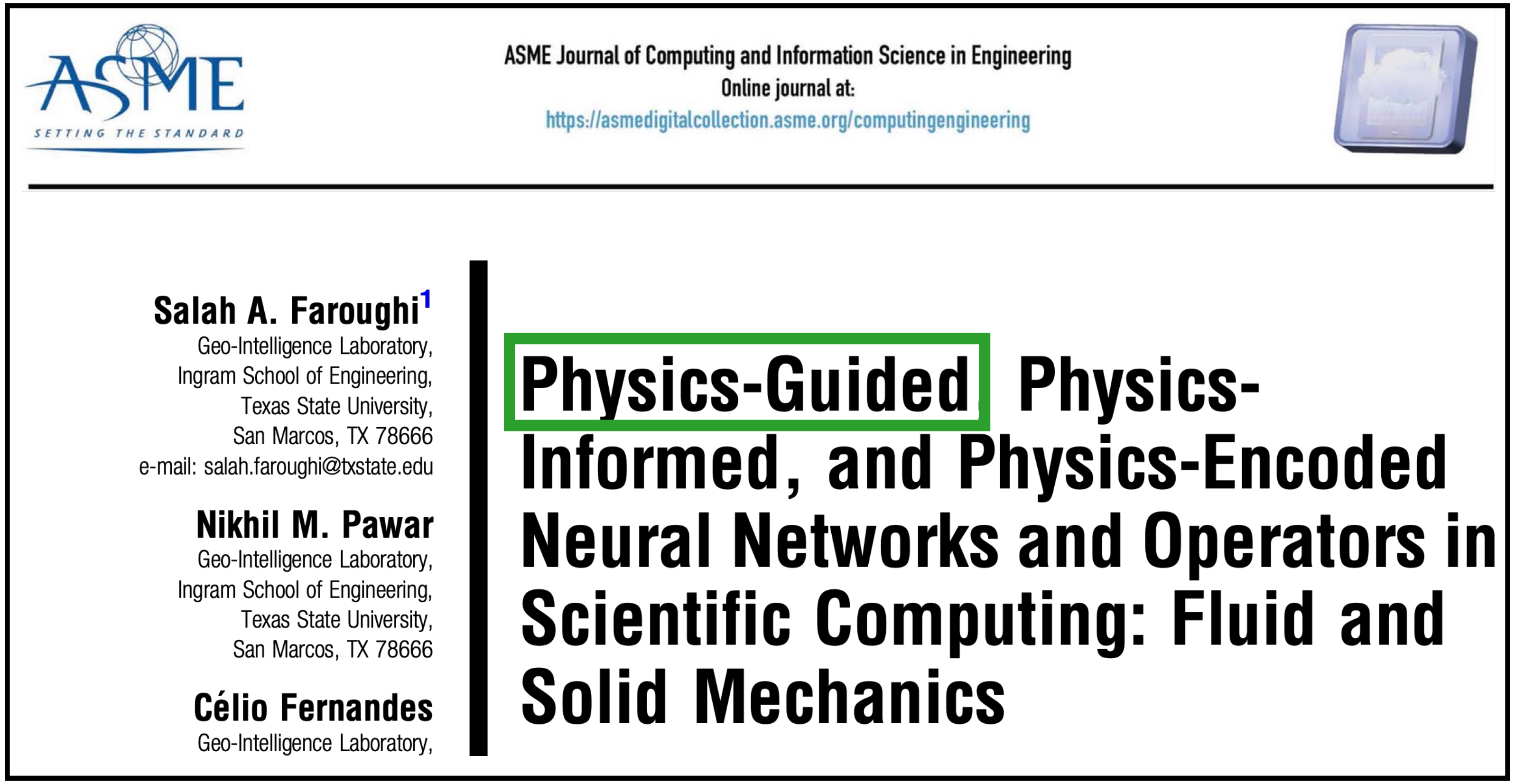
Physics-Guided Learning: Positioning



What Does Physics-Guided Learning Include?

Embedding **physics insights** into:

- Input features
- Data representations
- Training data selection / generation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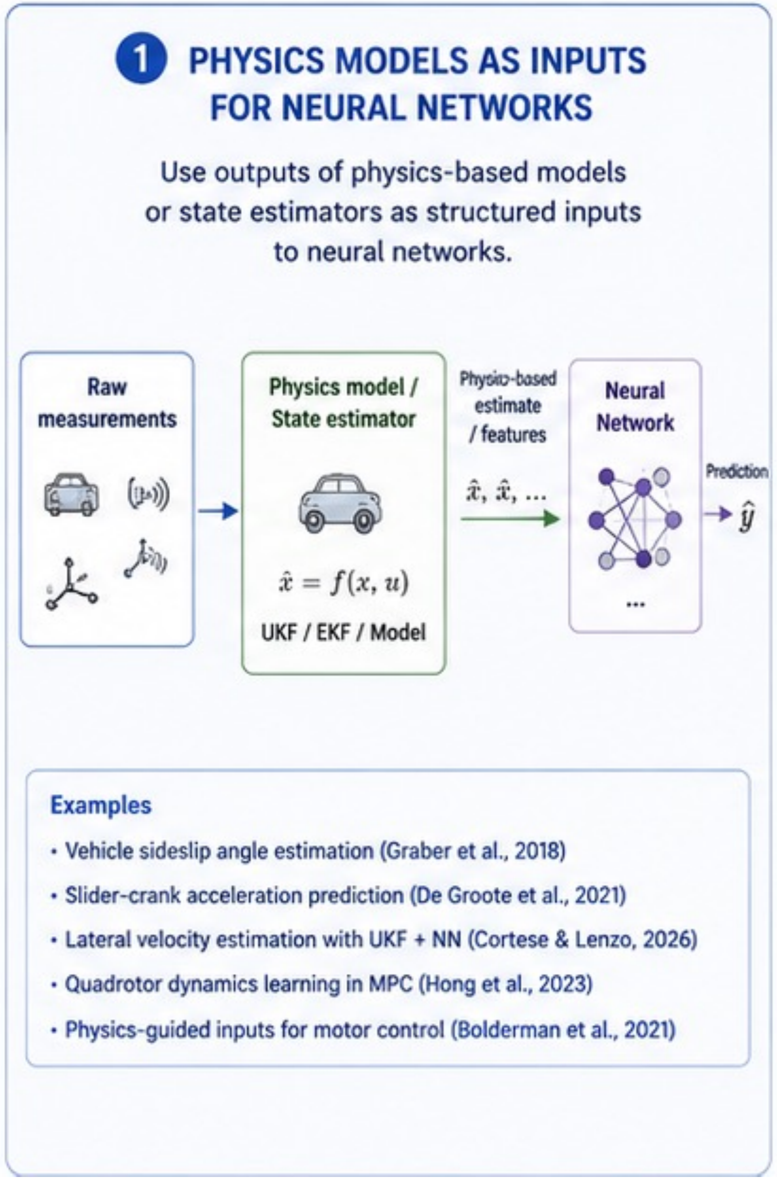
Physics-Guided, Physics-Informed, and Physics-Encoded Neural Networks and Operators in Scientific Computing: Fluid and Solid Mechanics

Physics-Guided Learning: Multiple Classes



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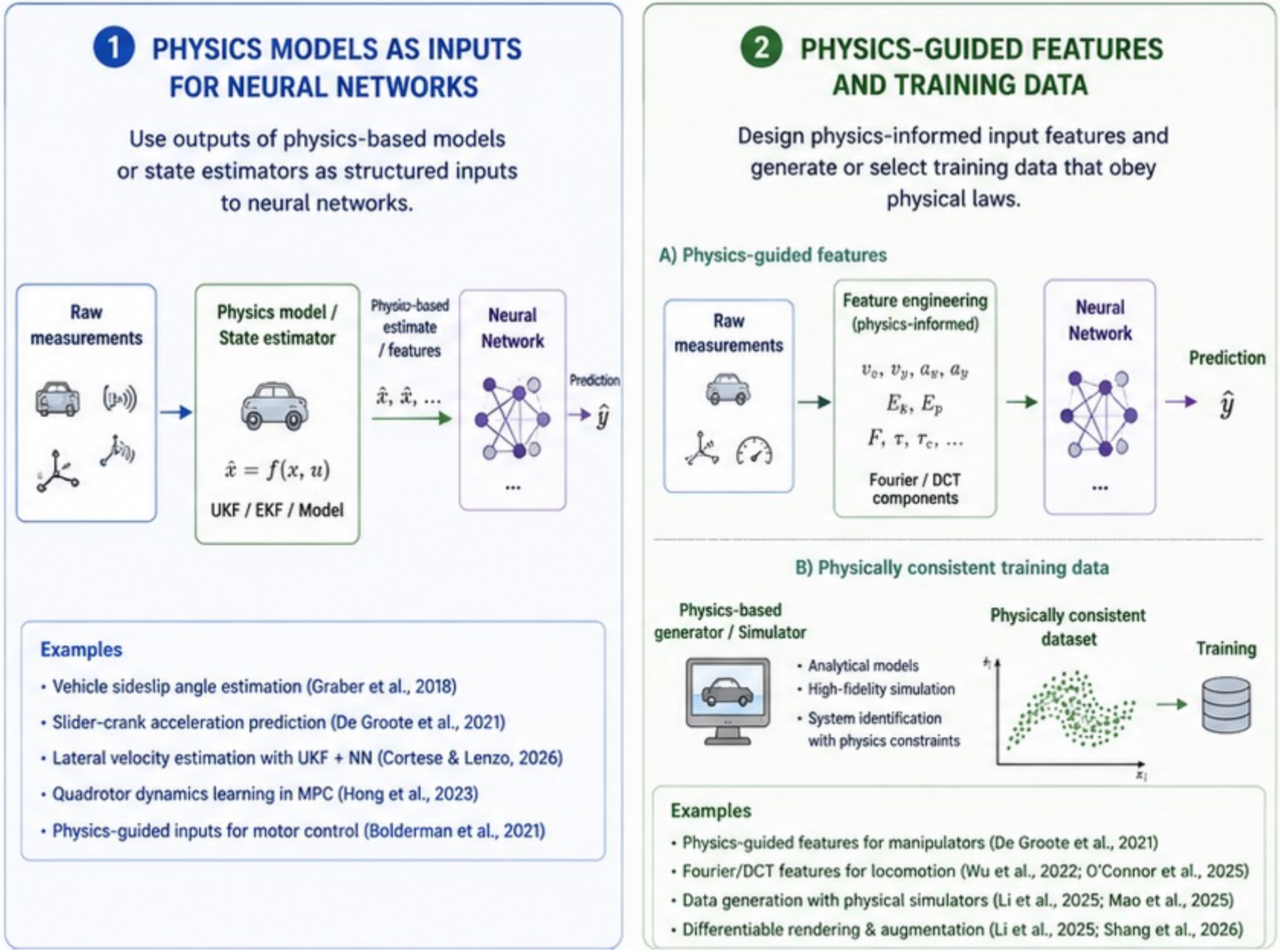

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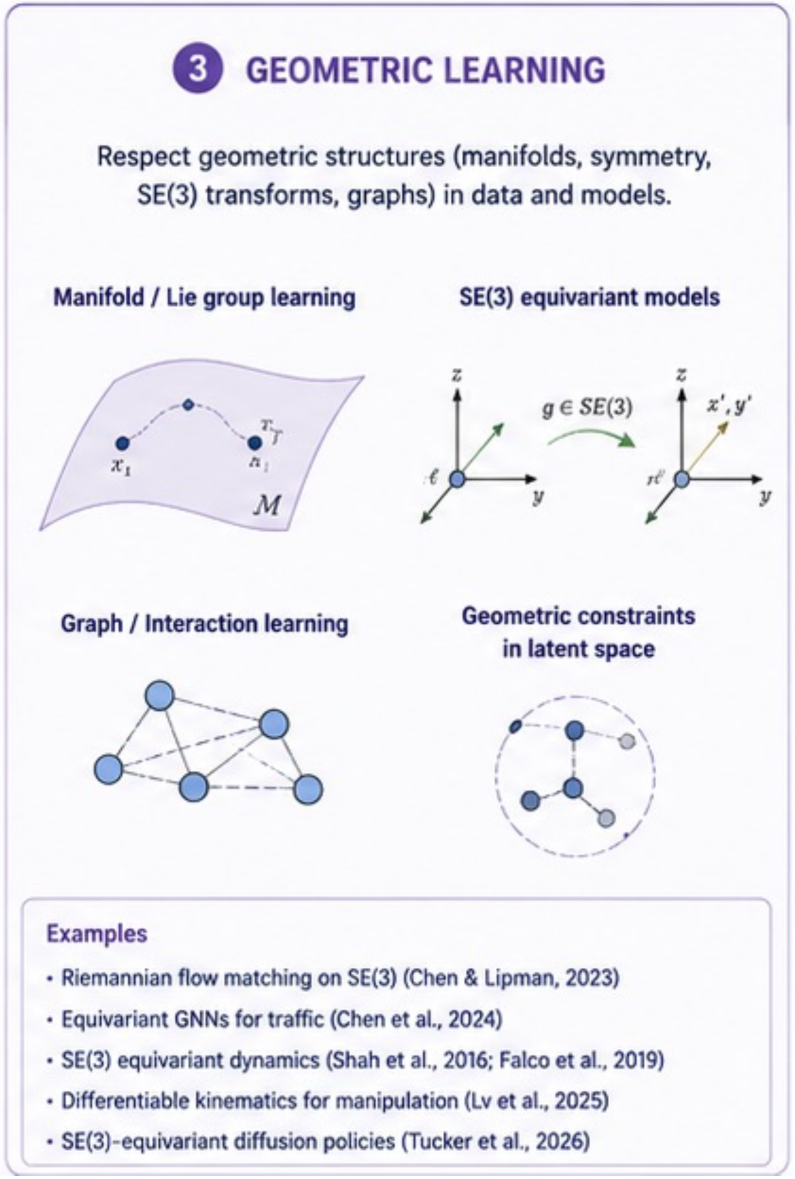

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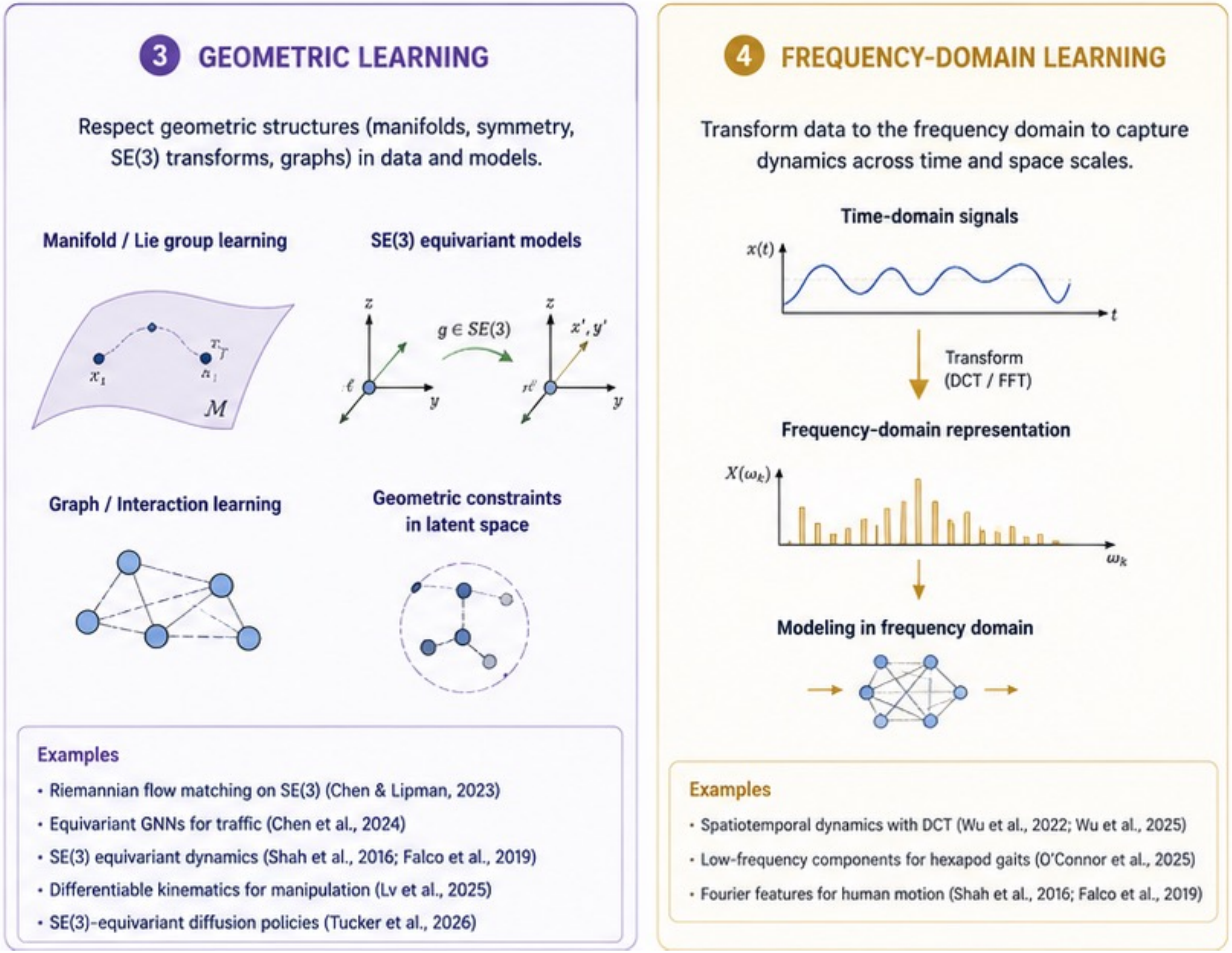
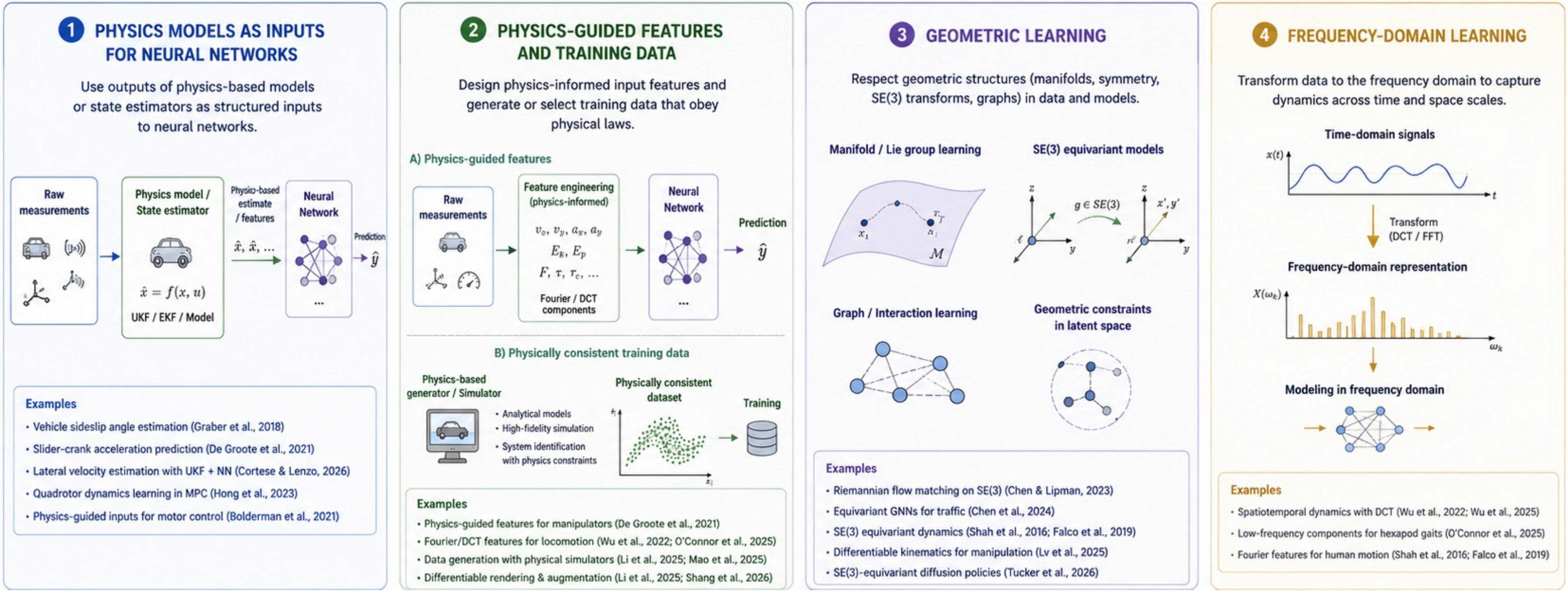
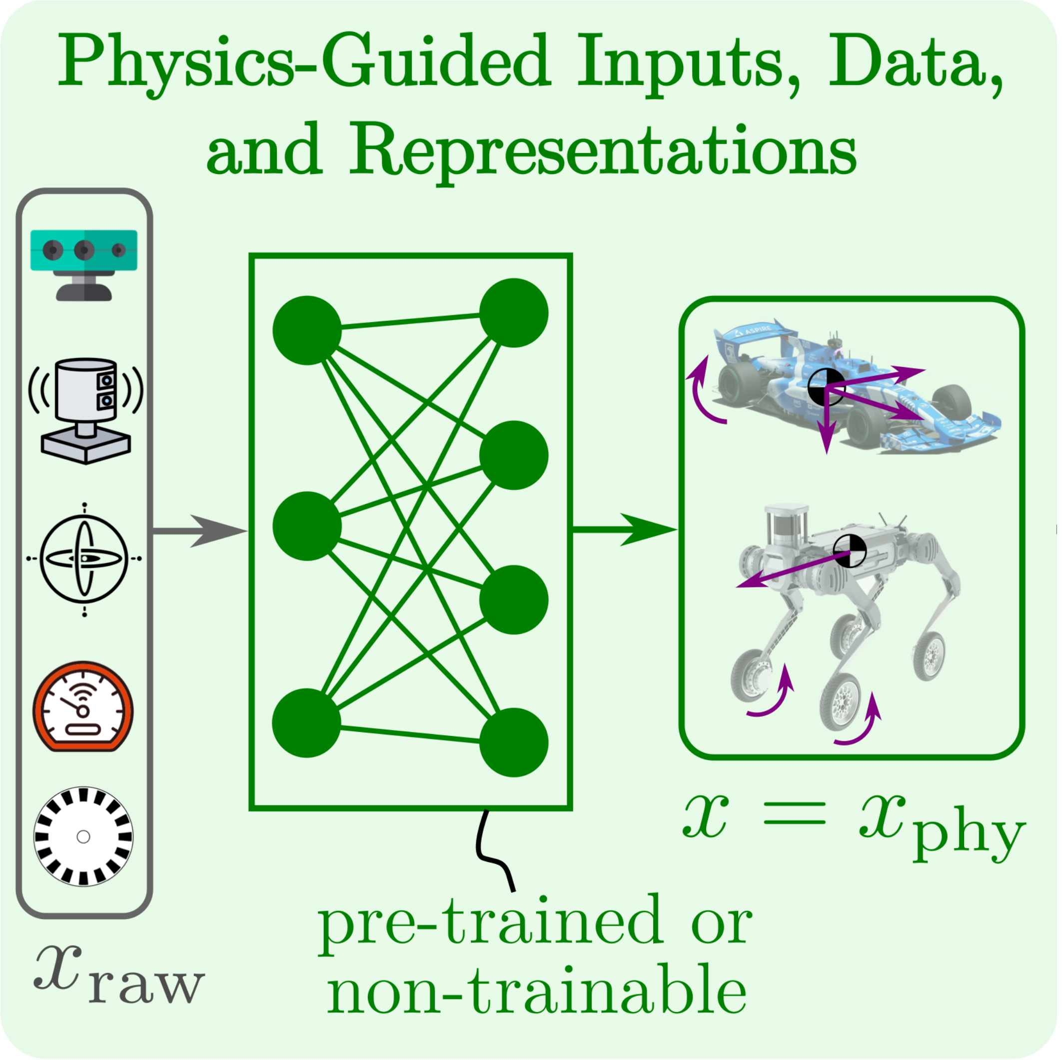


Physics-Guided Learning: Multiple Classes

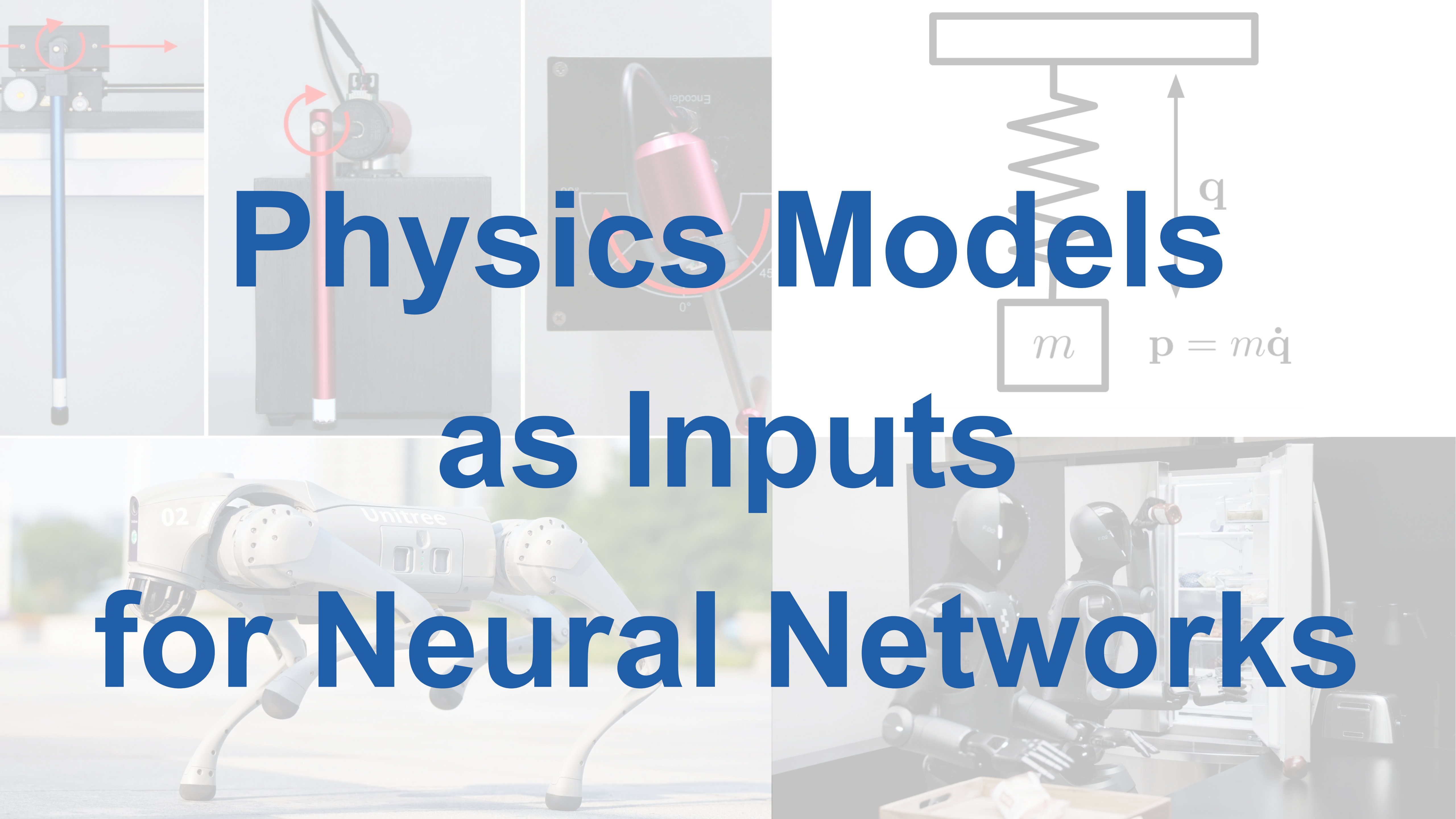


Physics-Guided Learning: Remark



Physics-guided operations are **pre-trained** or **non-trainable**:
if they contain NNs, these are ***not* trained** together with the main model

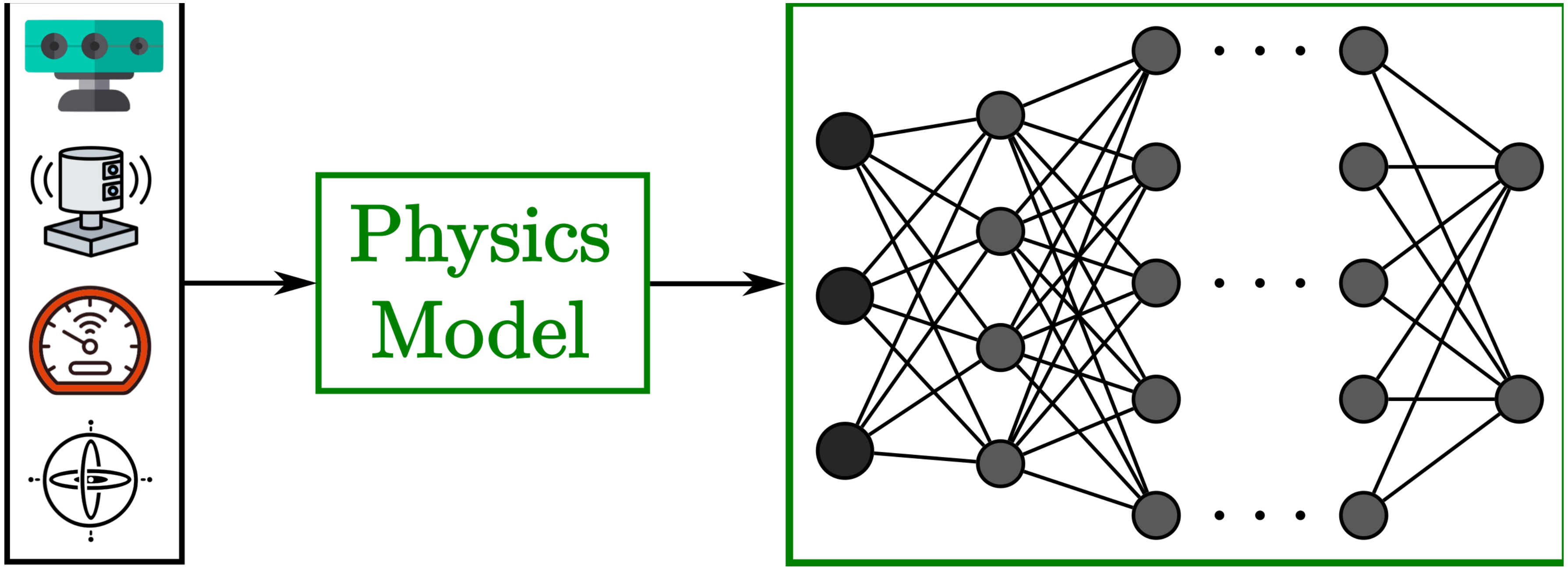
Physics Models as Inputs for Neural Networks



Physics Models as Inputs for Neural Networks

Idea: Use **physics-based modes** to generate input features for machine learning models

➔ Constrain learning to a **physically consistent** space

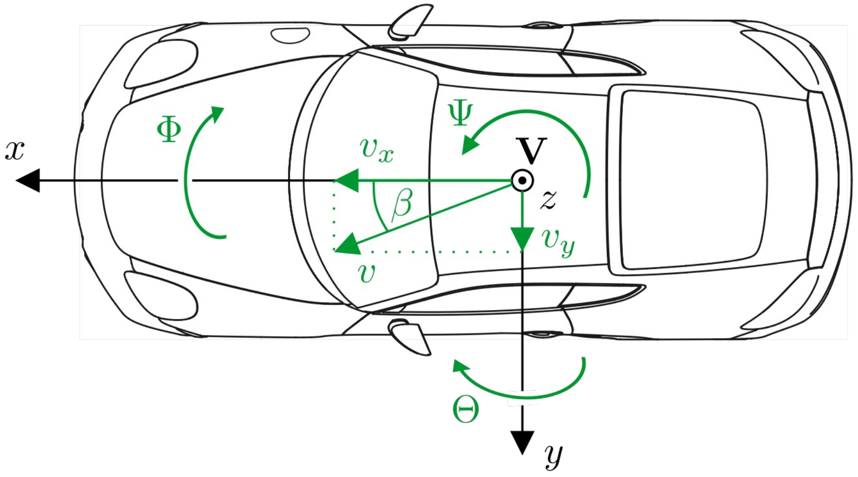


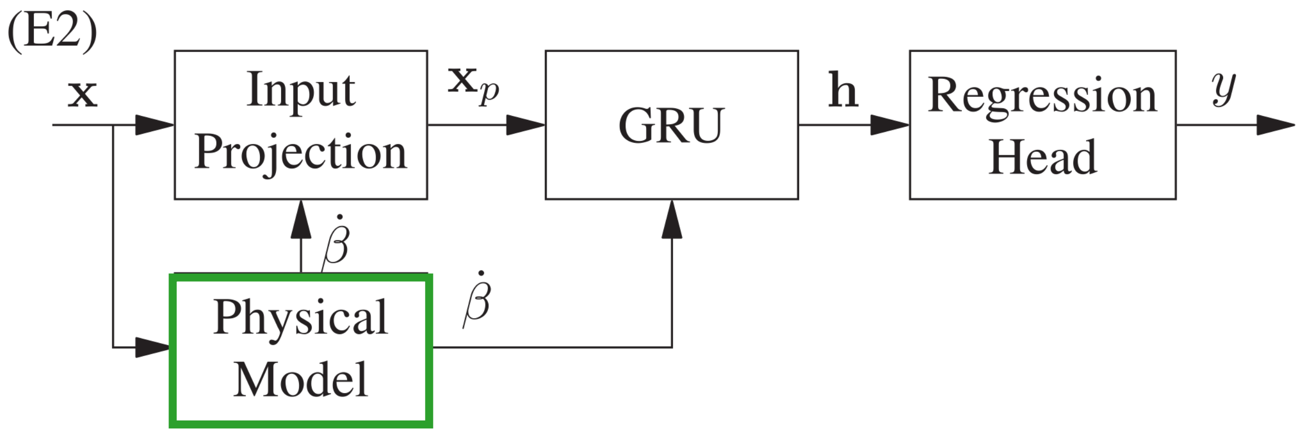
Physics Models as Inputs for Neural Networks - Examples

Vehicle **sideslip angle** (β) **estimation**

Physics-guided NN design:

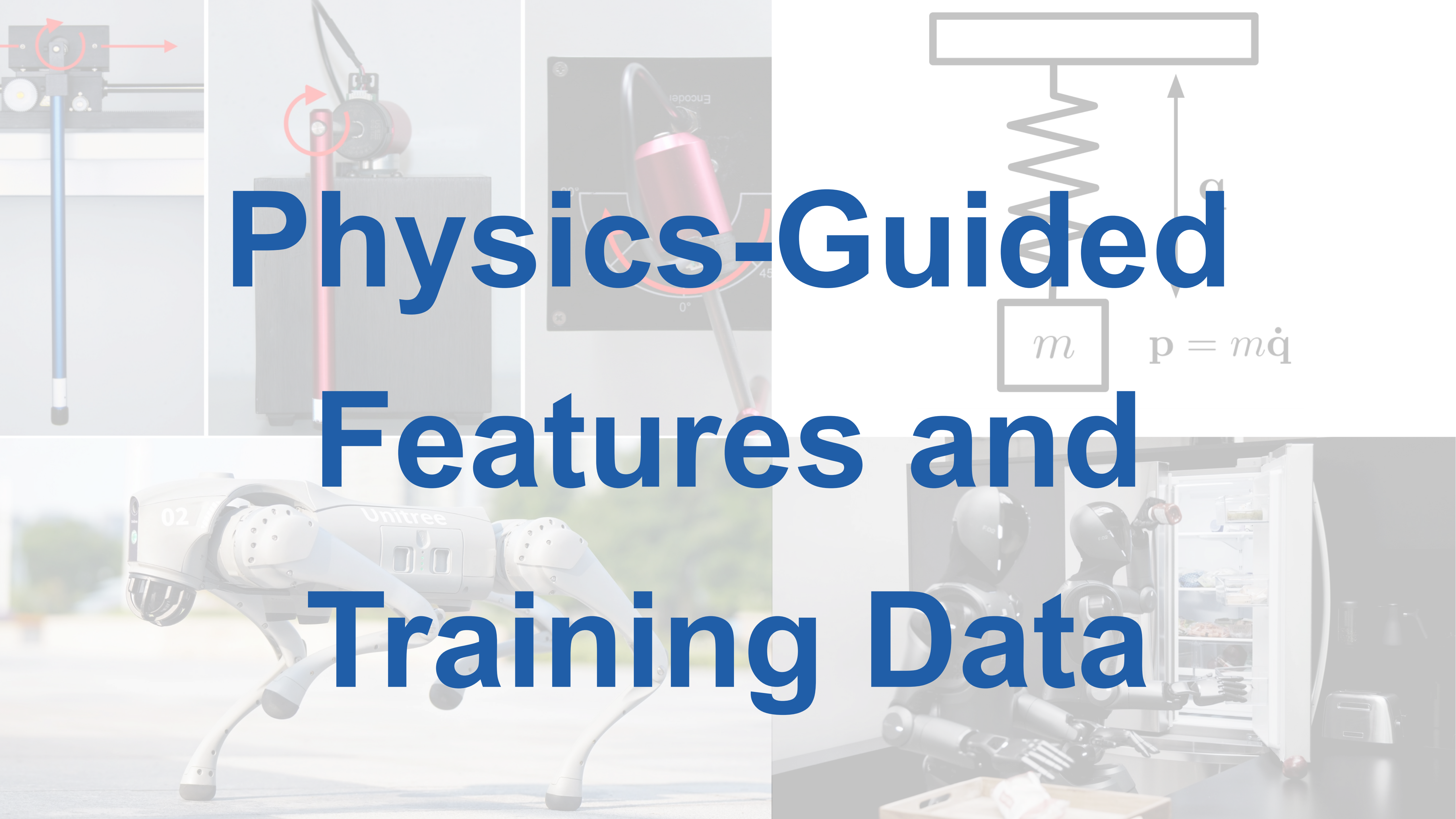
- **Physics-based estimator** of $\dot{\beta}$, then fed to a Gated Recurrent Unit (**GRU**) NN
- **Outperforming** the same NN without physics-guided inputs
- **Outperforming** a purely physics-based model





T. Gräber, S. Lupberger, M. Unterreiner, D. Schramm,
"A Hybrid Approach to Side-Slip Angle Estimation With Recurrent Neural Networks and Kinematic Vehicle Models", *IEEE T-IV*, 2019

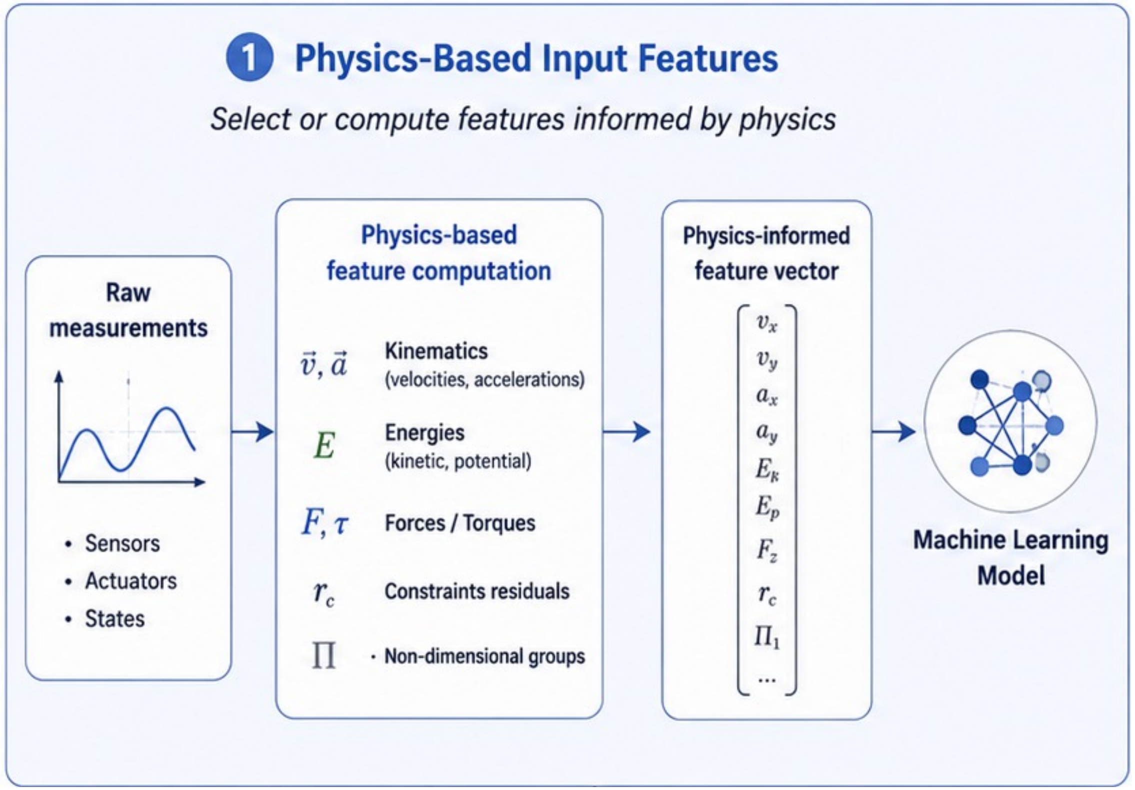
Physics-Guided Features and Training Data



Physics-Guided Features and Training Data

Idea:

- Select / compute **physics-based input features** for machine learning models

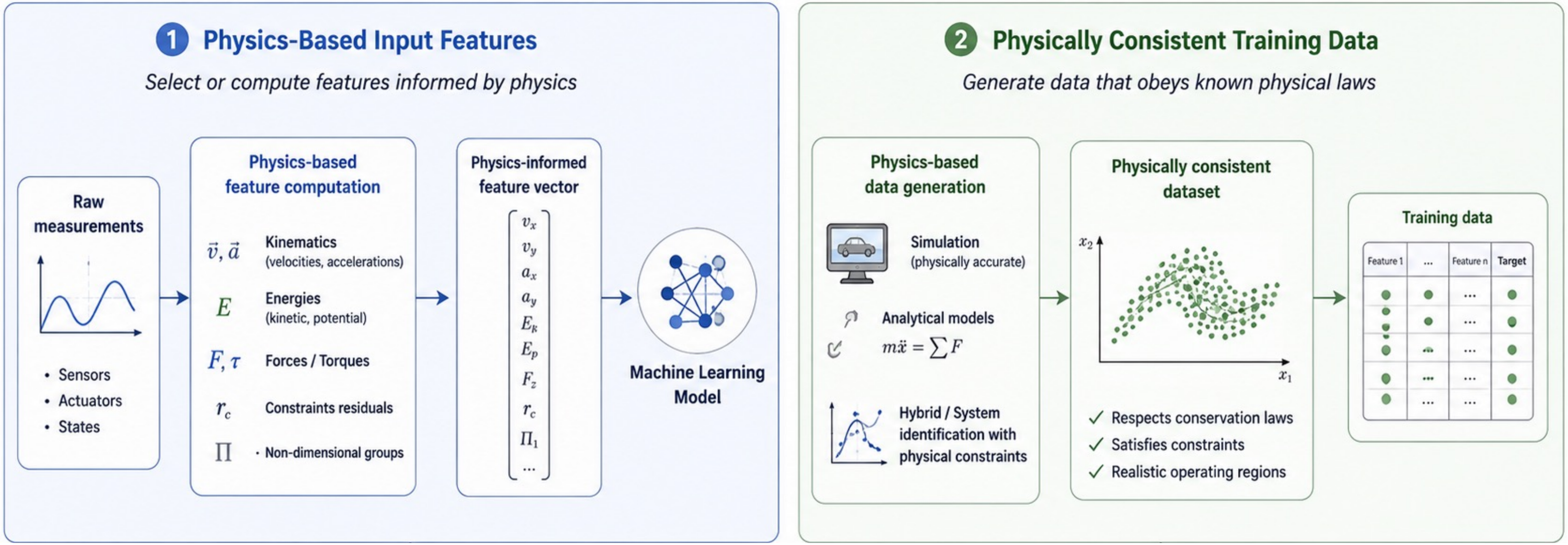


M. Bolderman, M. Lazar, H. Butler, "Physics–Guided Neural Networks for Inversion–based Feedforward Control applied to Linear Motors", *IEEE CCTA*, 2021

Physics-Guided Features and Training Data

Idea:

- Select / compute **physics-based input features** for machine learning models
- Generate physically consistent **training data**



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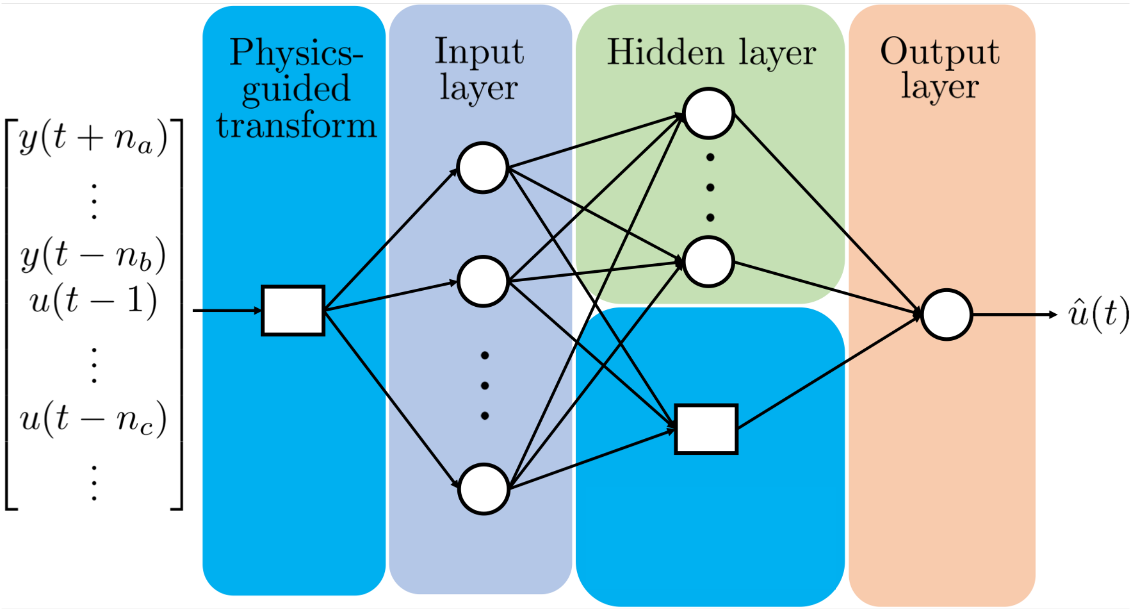
Physics-Guided Features and Training Data - Examples

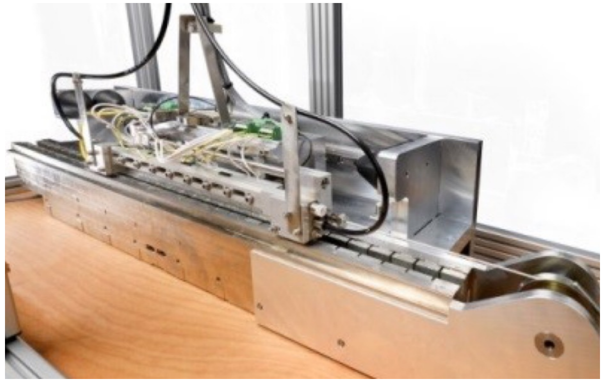
Feedforward control of linear motors: Compute force $\hat{u}(t)$ to track a desired position y

Physics-guided NN design:

- Linear friction depends on position y, velocity $\dot{y}$, sign($\dot{y}$) → use them as **additional NN inputs**
- **Outperforming** the same NN without physics-guided input features



$$\hat{u}(t) = f_{\text{PGNN-I}}\Big(\theta, \ddot{y}(t), u(t-1), y(t), y(t-1), \dot{y}(t), \boxed{\dot{y}(t-1), \text{sign}(\dot{y}(t)), \text{sign}(\dot{y}(t-1))}\Big).$$



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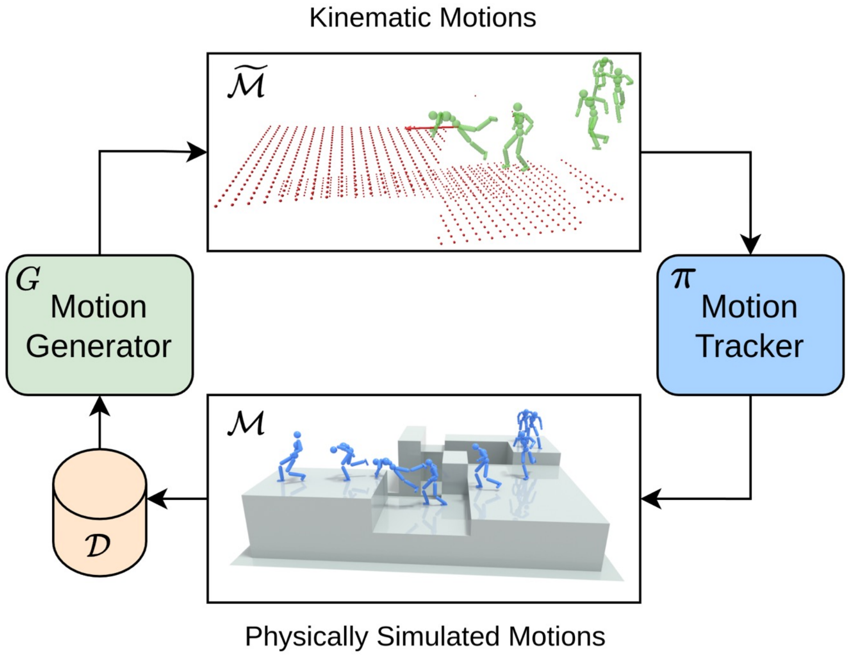
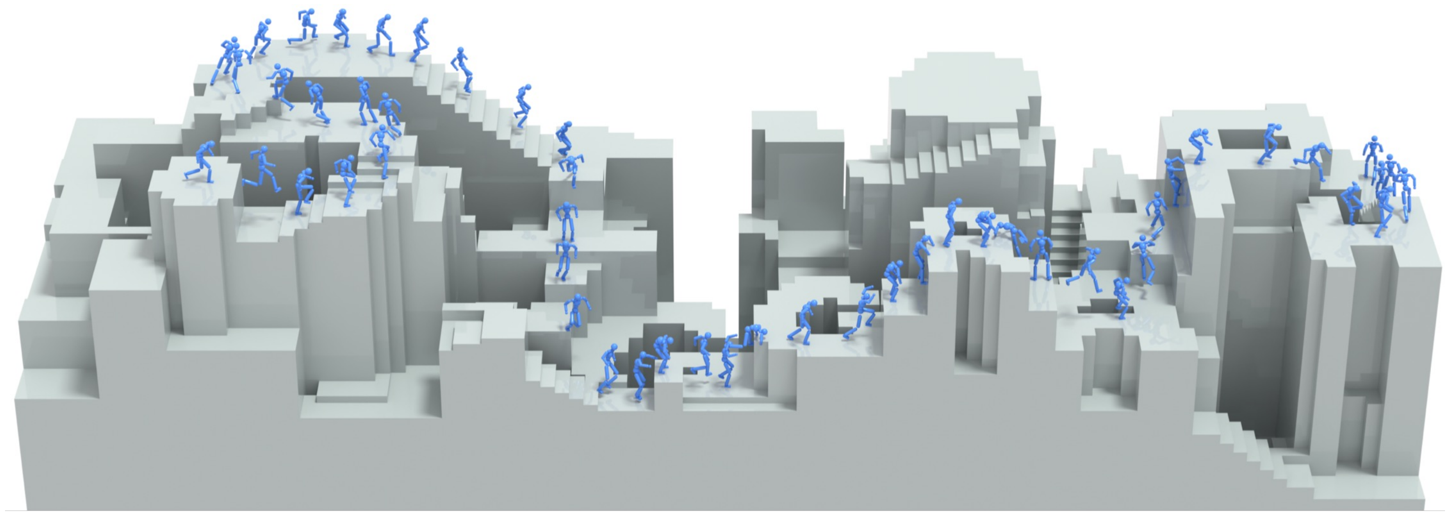
Physics-Guided Features and Training Data - Examples

Generating human motions in **parkour** scenarios in Isaac Gym

- **Diffusion model** to generate motions
- **Physics-based tracking controller** to make the motions physically consistent
- The corrected motions are recycled as **training data** for the **diffusion model**





M. Xu, Y. Shi, K. Yin, X. Peng, "Parc: Physics-based augmentation with reinforcement learning for character controllers", *Proceedings of the Special Interest Group on Computer Graphics and Interactive Techniques Conference Conference Papers*, 2025

Questions & Discussion

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