Online Adaptation of Terrain-Aware Dynamics for Planning in Unstructured Environments

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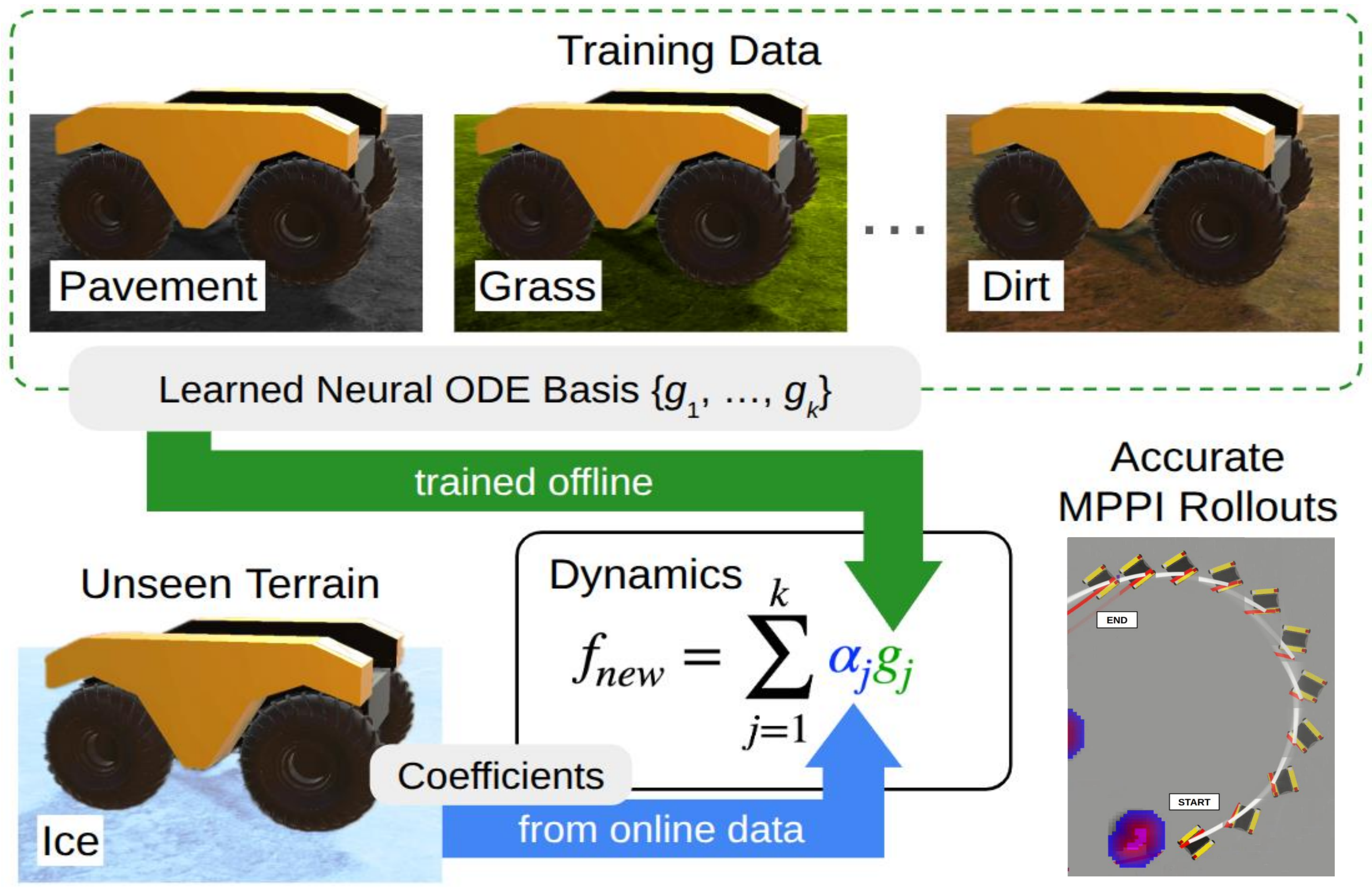
The Central Question

How can we estimate a robot's dynamics on unknown terrains and enable reliable, accurate navigation and planning?

Goal: Develop a learned model that adapts to terrain online for reliable planning and control.

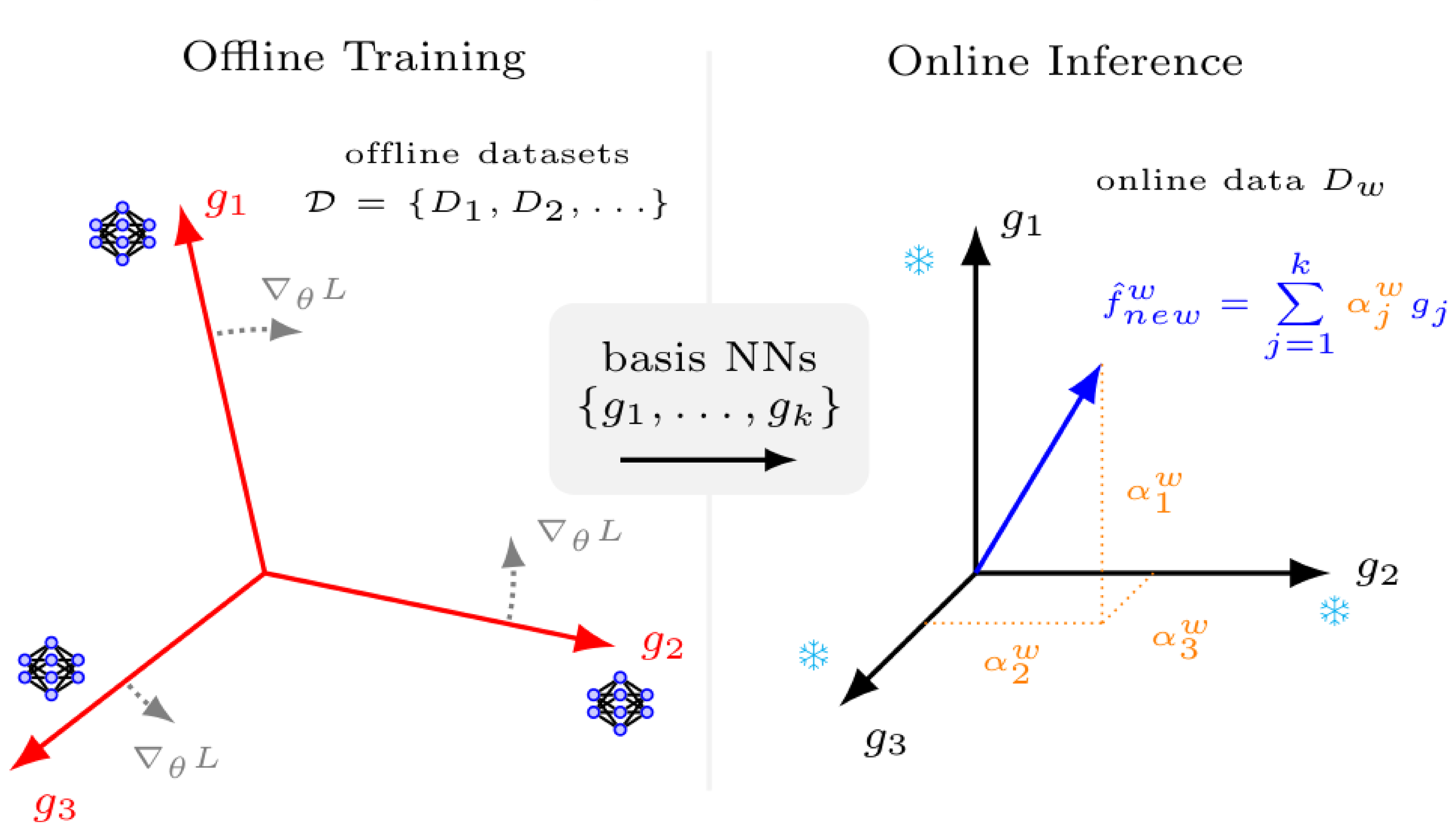
The Overall Framework



Stage 1 (Offline): Learn neural ODE basis functions from data on multiple terrains.

Stage 2 (Online): On a new terrain, compute coefficients via least squares. No retraining required.

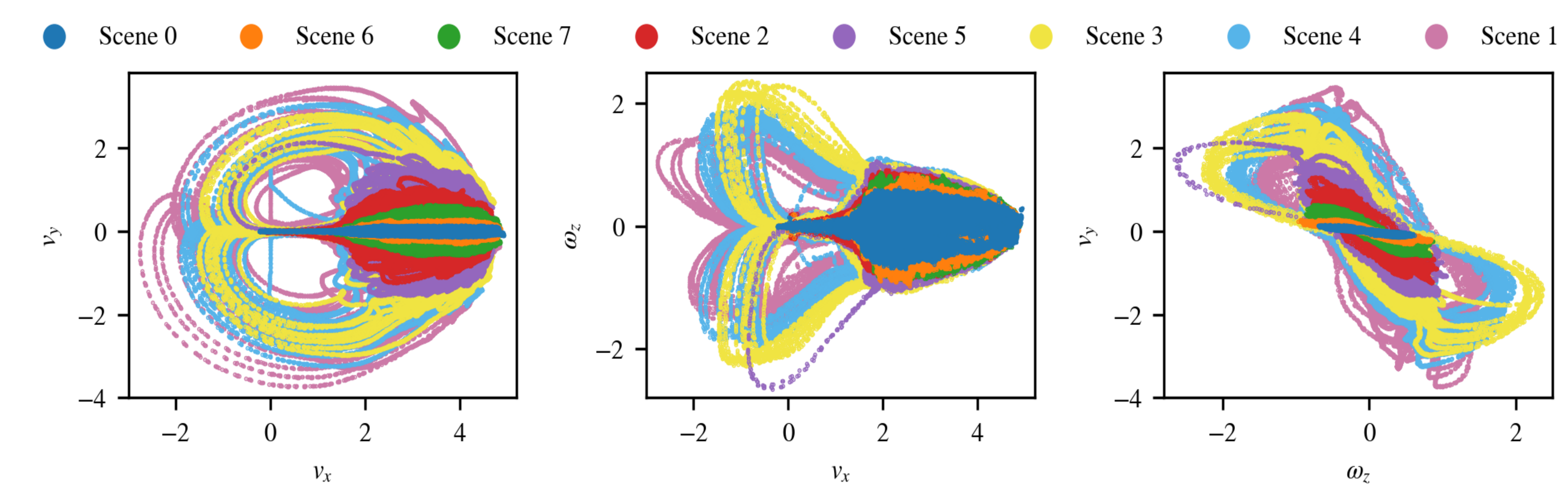
Function Encoder Dynamics Models



Stage 1 (Offline): Train neural ODE basis functions to "reorient" and span the space of terrain-induced dynamics.

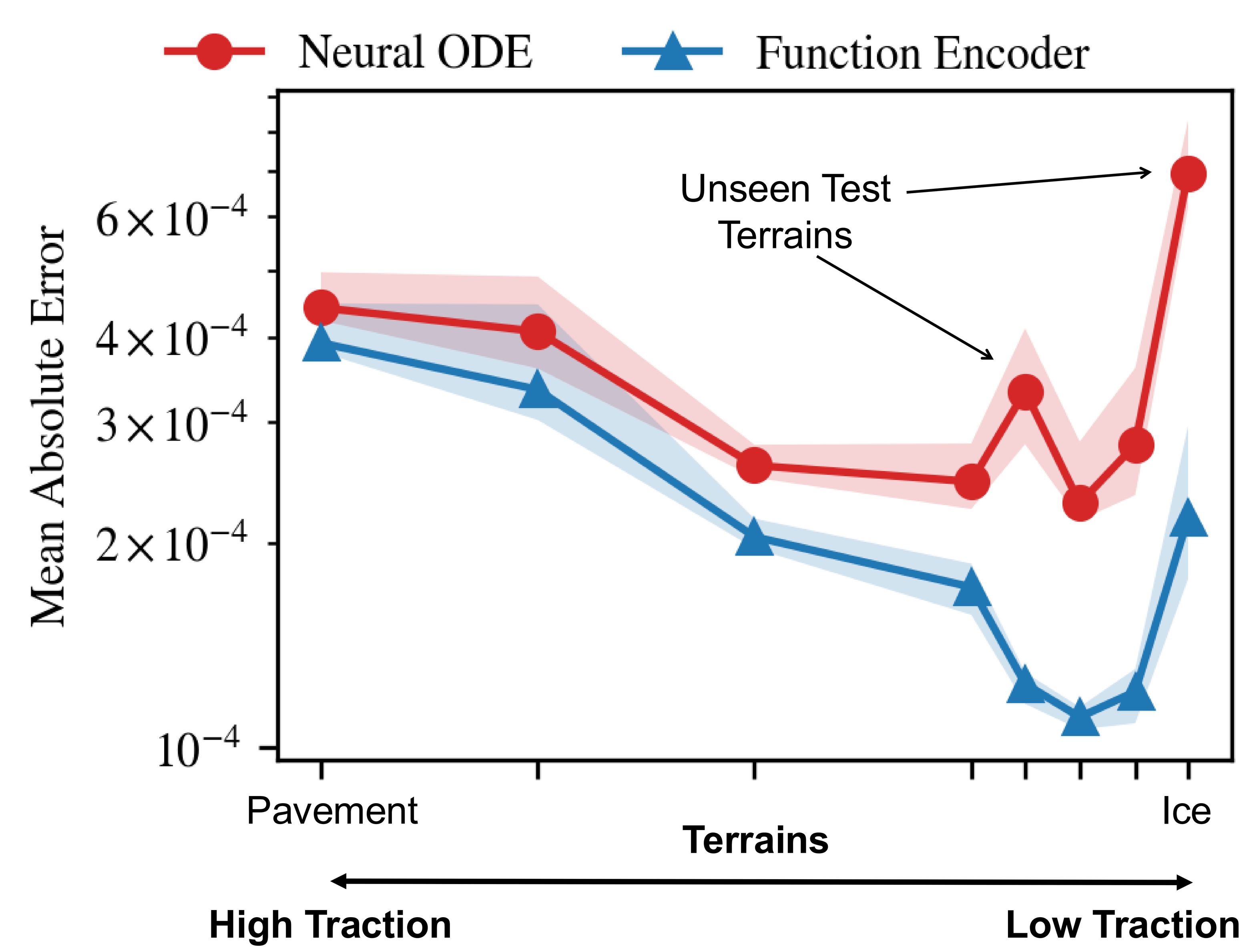
Stage 2 (Online): Keep the basis fixed. Use least squares to compute terrain-specific coefficients.

Diverse Phoenix Simulation Data

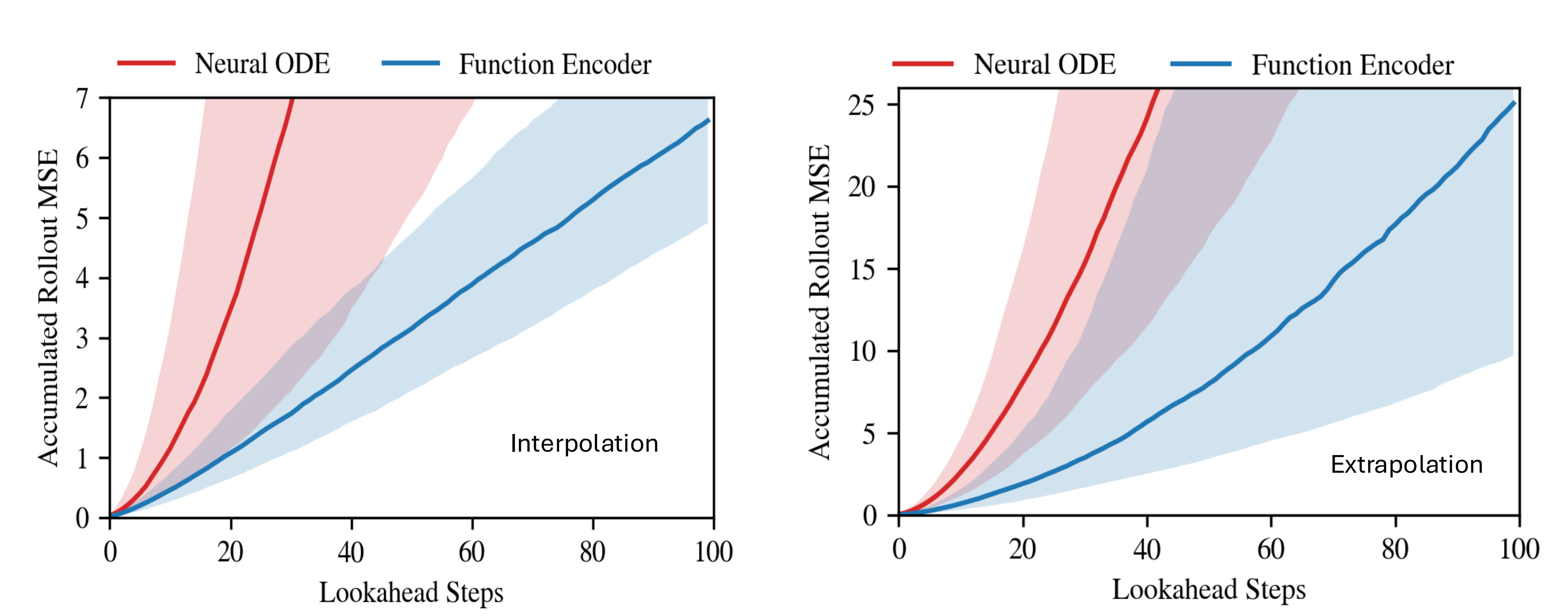


- Data shows significant variation in the dynamics.
- Low friction causes high lateral velocity (drifting).

Adaptation Improves Dynamics Prediction

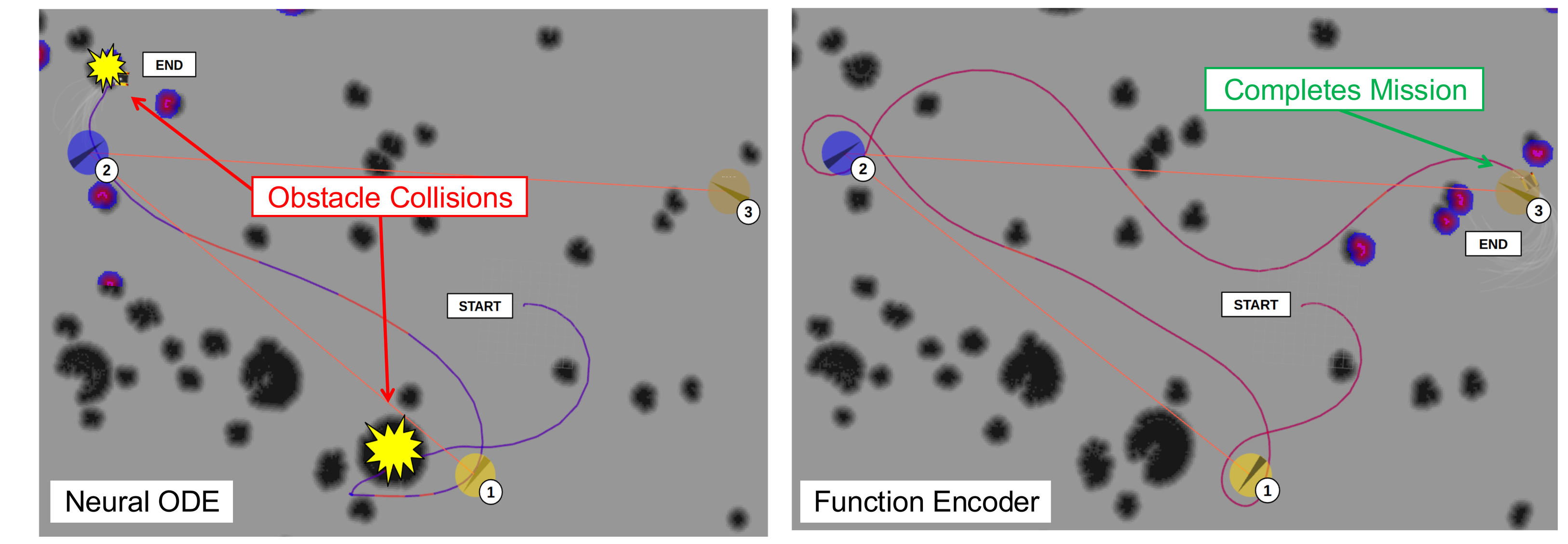


The function encoder achieves low error across all scenes.

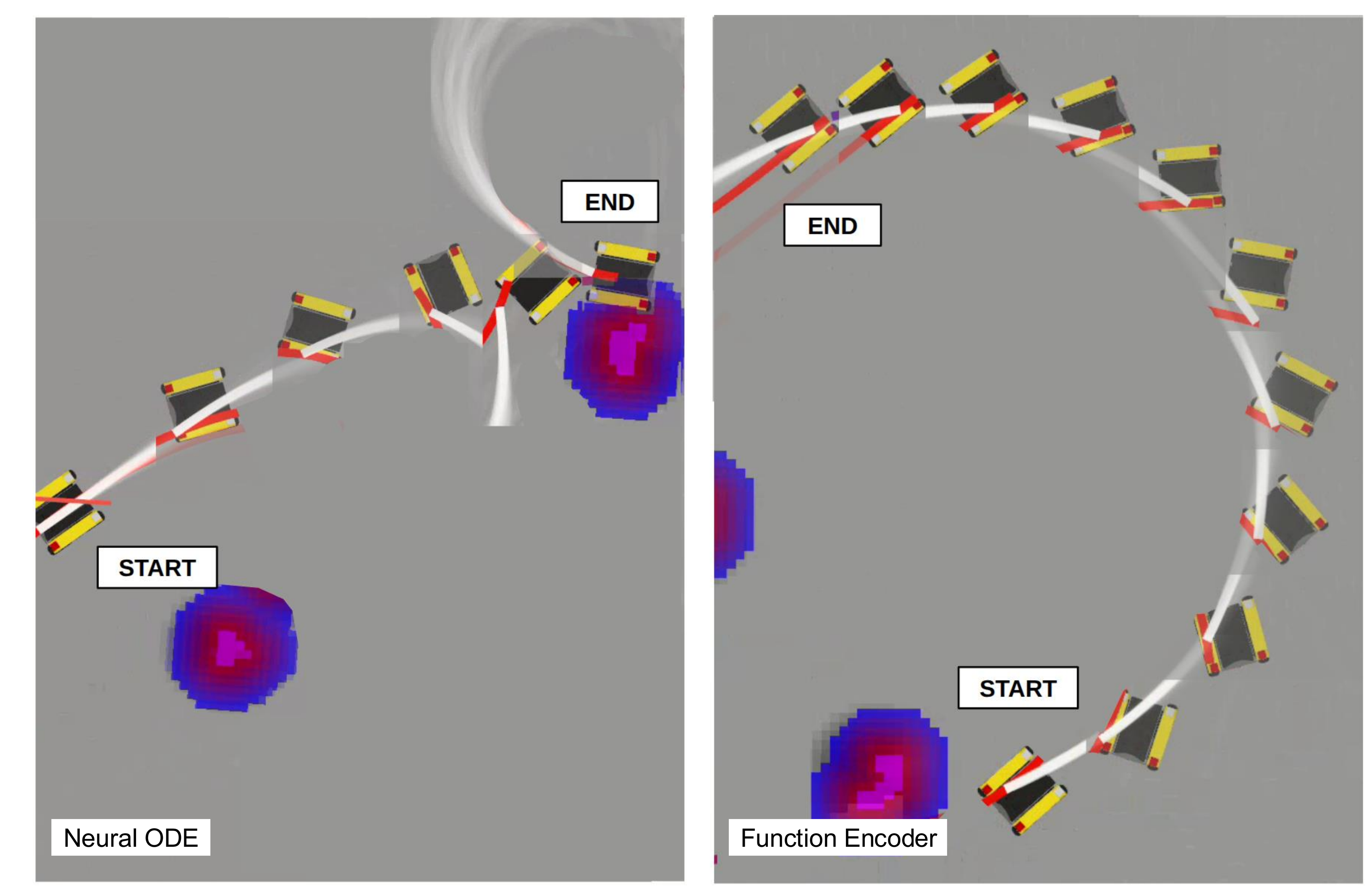


Our approach:
- Reduces error on individual terrains.
- **Adapts** to unseen terrains.
- Maintains **low error** over long horizons—critical for control.

Better Models Enable Safer MPPI Control



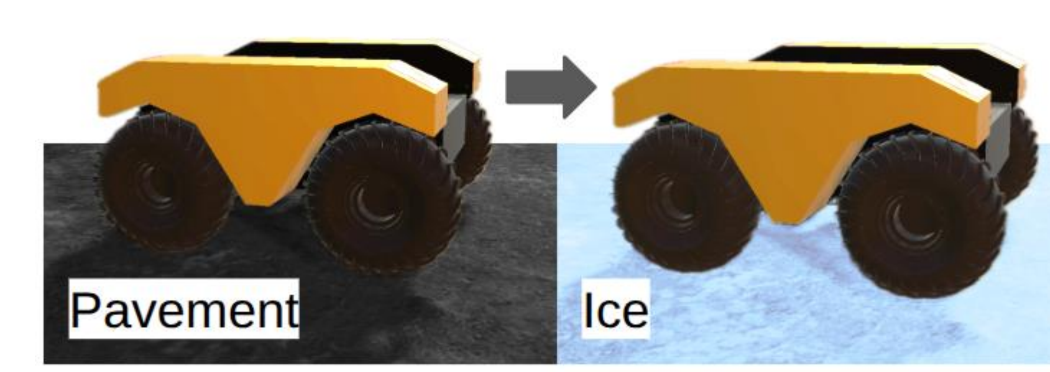
The function encoder successfully adapts to an unknown icy terrain, while the neural ODE collides with trees and fails the task.



Baseline (no adaptation): Controller uses a mismatched model → inaccurate predictions → obstacle collisions → task failure.

Our Approach: Adapts to the terrain → better predictions → obstacle avoidance → successful goal completion.

Future Work: Real-time Online Adaptation



- In realistic deployments, terrain can change rapidly.
- Use recursive least squares to update the coefficients in real time.

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