UnCLe: Towards Scalable Dynamic Causal Discovery in Non-linear Temporal Systems

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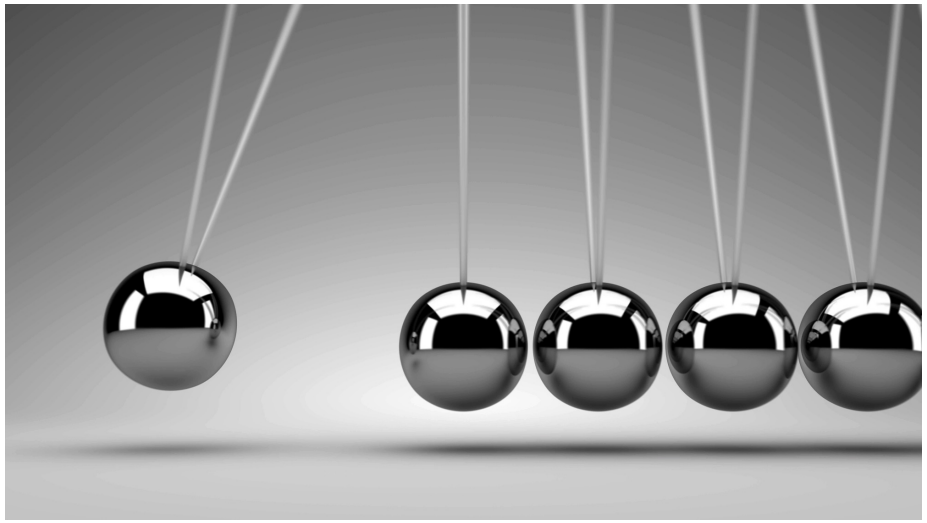
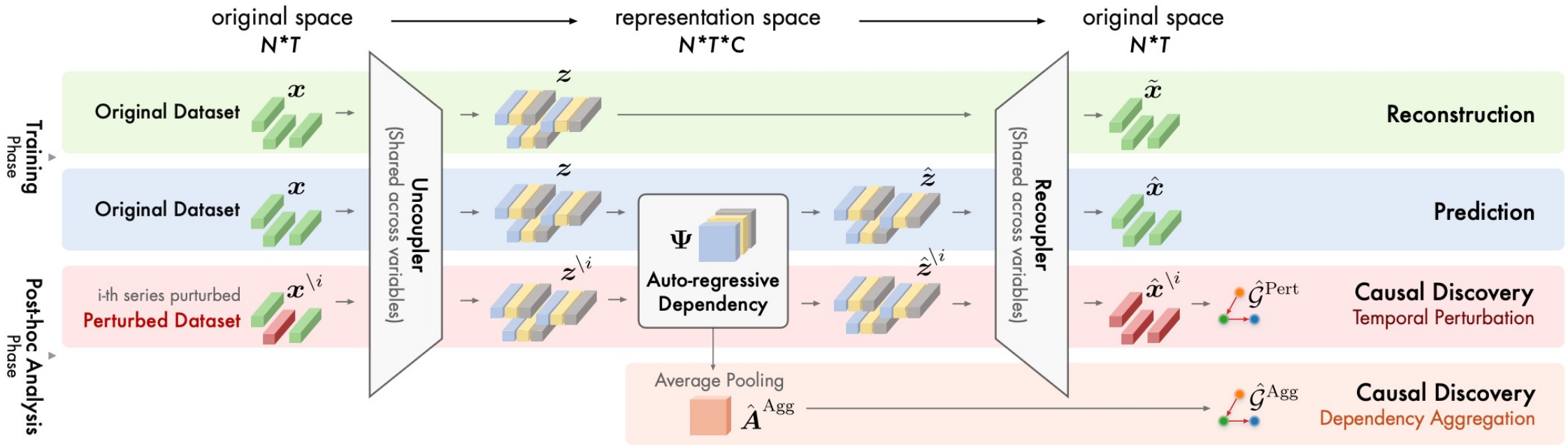
The Real World is Dynamic. Why Are Our Causal Graphs Static?

- In complex systems like transportation, human motion, climate, finance, cause-and-effect relationships evolve over time.
- However, most current methods for causal discovery only give us a single, static graph.
- Our goal was to create a method that could uncover these *time-resolved* causal graphs..



Our Solution: The UnCLe Framework



UnCLe uses a pair of neural networks we call an *Uncoupler and Recoupler* to disentangle the complex signals and learnable *auto-regressive dependency* matrices to capture the interplay between different series.

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How We Find Dynamic Causality: The Perturbation Principle

Original prediction error: $\epsilon_{i,t} = (\hat{x}_{i,t} - x_{i,t})^2$

Perturbed prediction error: $\epsilon_{i,t}^{\setminus j} = (\hat{x}_{i,t}^{\setminus j} - x_{i,t})^2$

Error gain: $\Delta\epsilon_{i,t}^{\setminus j} = \max(0, \epsilon_{i,t}^{\setminus j} - \epsilon_{i,t})$

By measuring the increase in prediction error–'error gain'–at every single time step, we can precisely quantify the strength of the causal link dynamically

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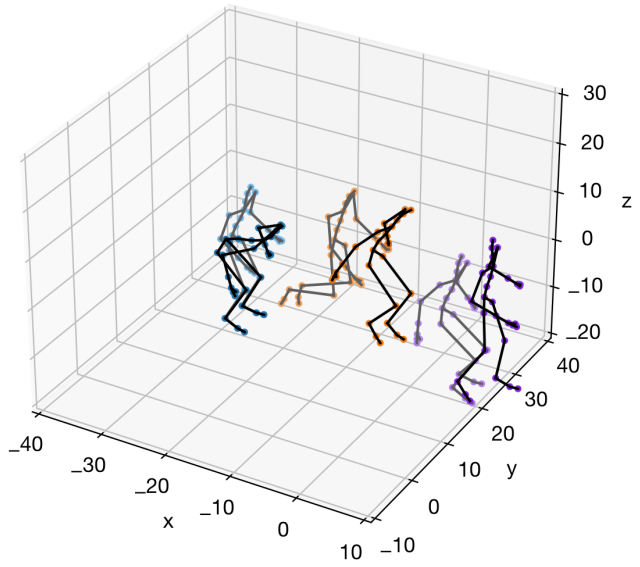
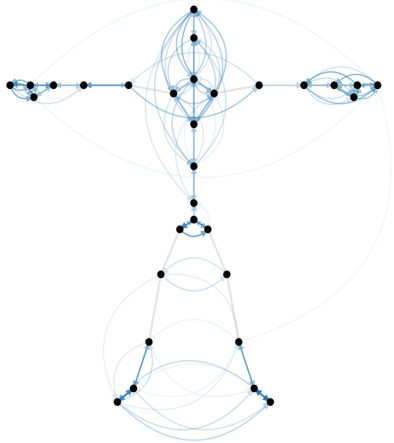
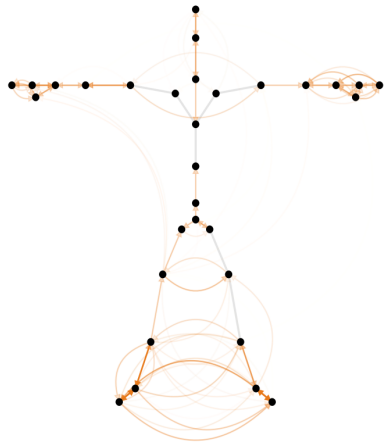
Case Study: Uncovering the Biomechanics of a Forward Jump



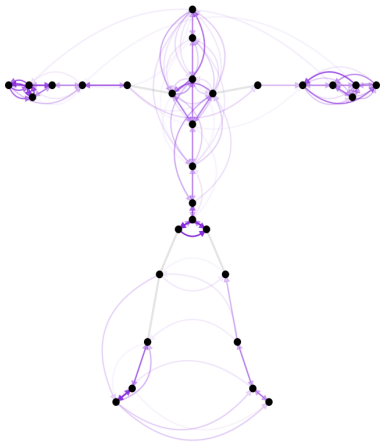
Forward jump motion in MoCap Dataset



Crouch phase



Flight phase



Touchdown phase

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Conclusion & Find Out More

- **UnCLe** is a novel and scalable framework for dynamic causal discovery.
- It provides interpretable, time-evolving insights into complex systems.
- Find me at *Fri 5 Dec 2025 4:30 p.m. PST – 7:30 p.m. PST*, Exhibit Hall C,D,E, San Diego Convention Center

Paper (arXiv)

Code (GitHub)

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