Network Reconstruction Using Sensitivity Analysis

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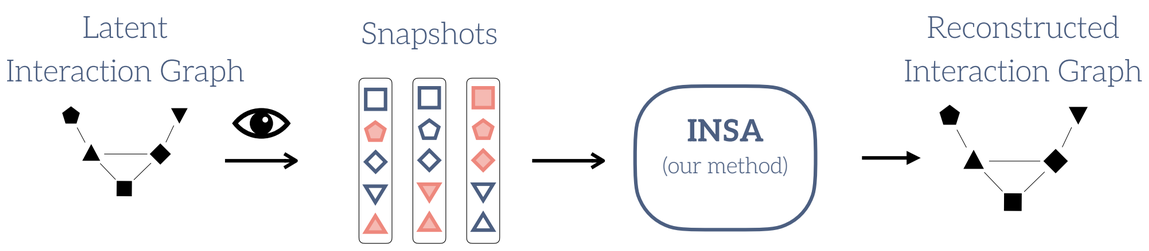
github.com/gerritgr/insa

Problem Setting



Unknown process generates data based on unknown network.

We want to reconstruct the network.

- Goal: Infer latent network structure of a system.
- Input: Large number of independent snapshots.
- Each snapshot measures state of each node/component.

Motivation

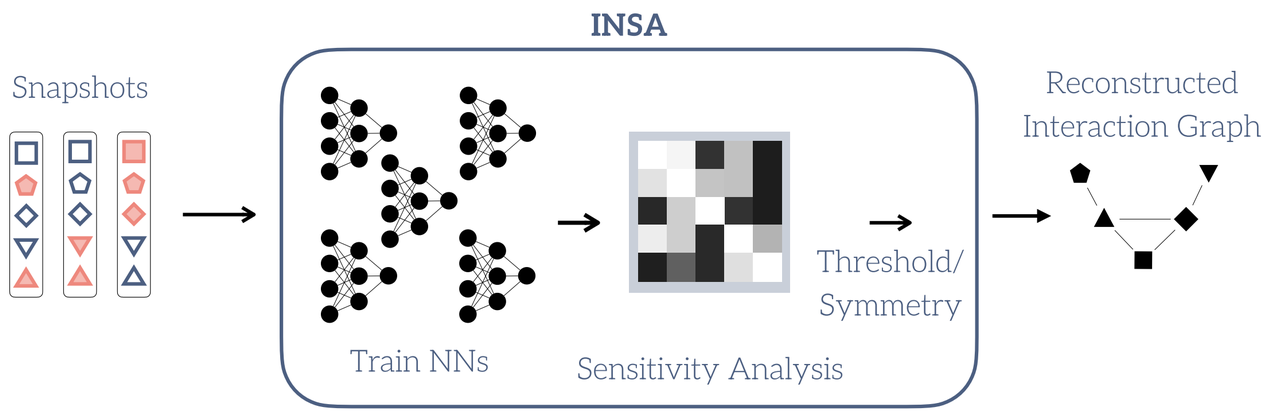
Measurement problem:

- Often limited to one measurement before needing to restart the system.
  - E.g., Cells, quantum states, brains
- Time-scales may not be adequate for detecting temporal correlations.

Prediction-based paradigm converts static snapshots into interactions.

Sensitivity analysis separates meaningful interactions from spurious correlations.

Method



- Step 1: Reconstruction task — train individual NN for each node:
  - Predict state/value of the node based on all other nodes.
- Step 2: Sensitivity analysis determines importance of each node.
- Step 3: Normalization + Thresholding + Symmetry leads to recovered interaction graph.

Sensitivity Analysis:

- **Masking**
  Obscure a node and evaluate the decrease in prediction accuracy for all remaining nodes.
- **Permutation**
  Distort a node and evaluate the decrease in prediction accuracy for all remaining nodes.
- **Saliency Values (Gradient)**
  Measure the extent of change in the prediction when altering the node value infinitesimally.

Results

Model	Graph	INSA (our method)	Corr	MI	ParCorr
Cascade	ER	**480** ± 41.8	697 ± 363.4	858 ± 482.1	717 ± 84.3
	Grid	**94** ± 10.3	149 ± 71.8	98 ± 11.3	169 ± 33.7
	WS	**125** ± 7.5	485 ± 240.4	325 ± 209.2	559 ± 117.1
Majority Vote	ER	755 ± 47.6	722 ± 80.3	**703** ± 78.2	721 ± 62.3
	Grid	**3** ± 3.9	44 ± 6.6	39 ± 7.3	10 ± 4.7
	WS	**31** ± 5.6	455 ± 112.1	455 ± 112.1	44 ± 5.9
Opinion	ER	**184** ± 10.2	684 ± 108.2	249 ± 18.3	761 ± 107.1
	Grid	**52** ± 20.5	158 ± 57.6	64 ± 11.9	155 ± 36.1
	WS	117 ± 18.7	653 ± 129.0	**127** ± 16.2	646 ± 152.9
SIS	ER	270 ± 41.4	830 ± 168.4	**225** ± 32.3	674 ± 211.3
	Grid	**18** ± 6.7	69 ± 61.2	27 ± 9.3	160 ± 70.8
	WS	78 ± 15.2	408 ± 341.0	**58** ± 15.7	563 ± 168.5

Conclusion: Sensitivity analysis can successfully differentiate between neighbors and non-neighbors.

Related Work

- GINA: Network inference for homogenous graphs without the need for thresholding. Großmann et al., 2023
- Neural Granger Causality: Measures how well a node can predict another node's state/value. Tank et al., 2021
- AIDD: Prediction-based network inference for time-series data. Zhang et al., 2019
- Netrd: Python library to compute baselines. Hartle et al., 2020

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