Learning Identifiable Structures Helps Avoid Bias in DNN-based Supervised Causal Learning

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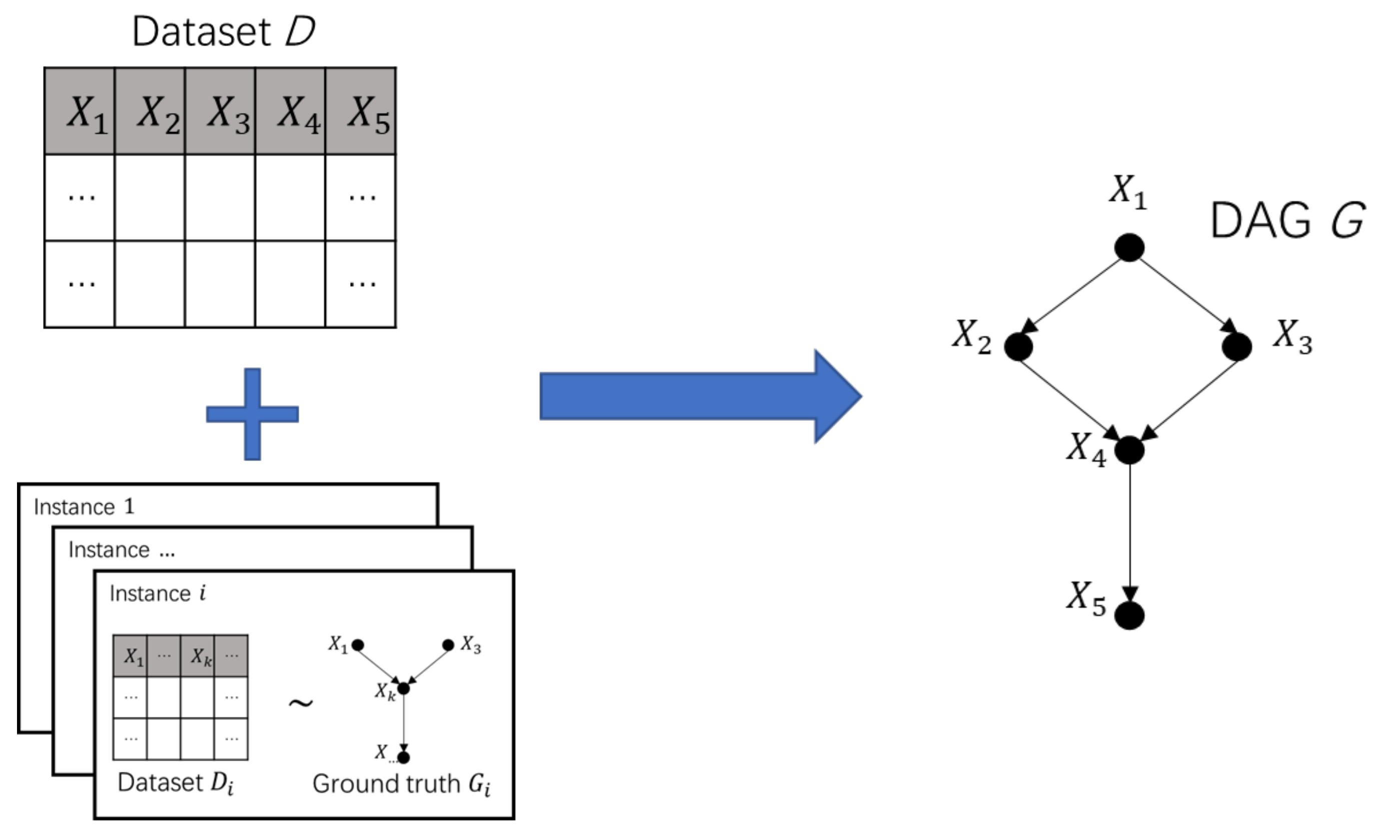
GitHub Repository: microsoft/reliableAI

Microsoft Sony Research

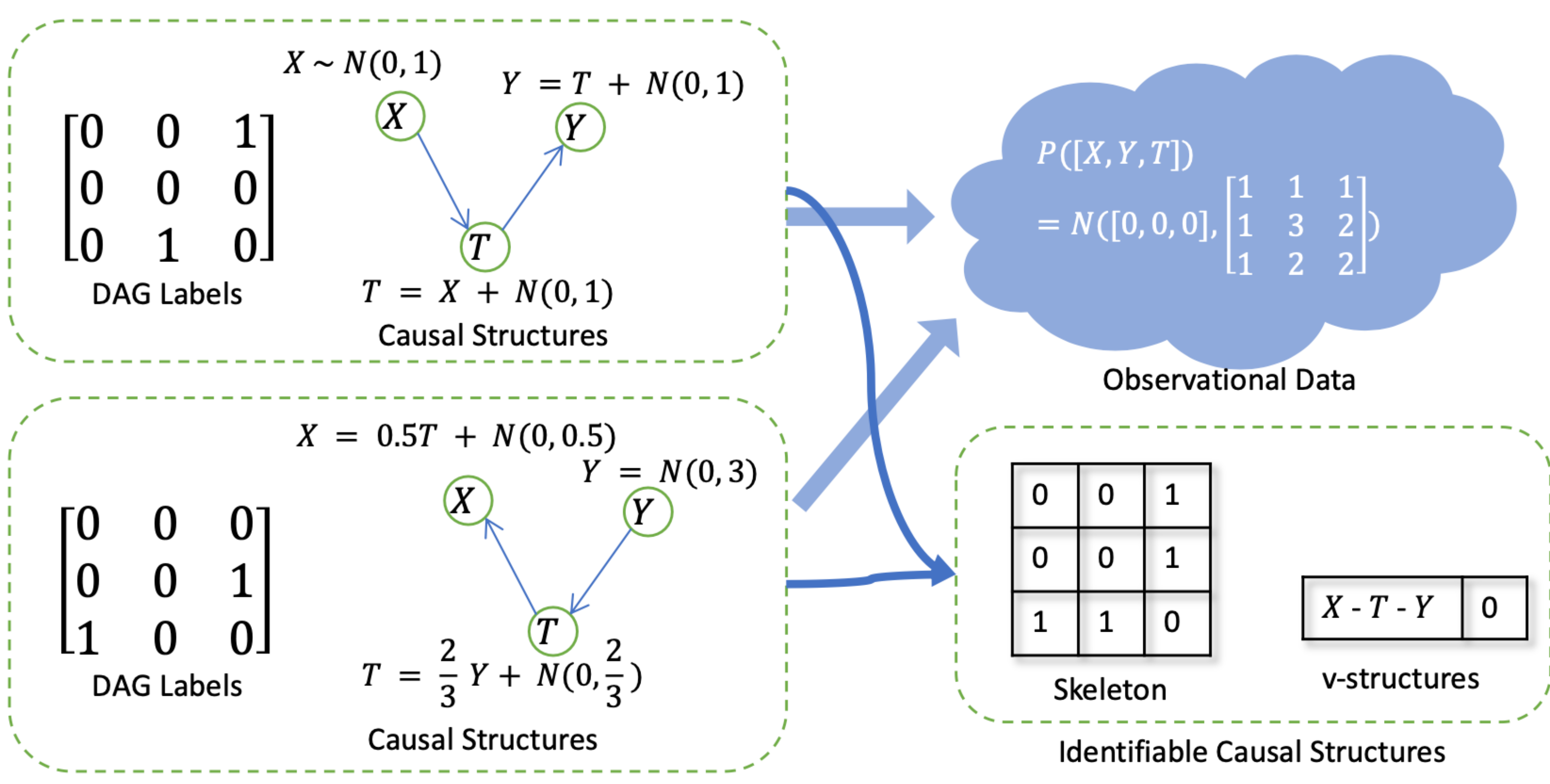
Background

- Supervised Causal Learning (SCL): learning causal relations from observational data by accessing previously seen datasets associated with ground truth causal relations.
- Existing Node-Edge model: node-wise feature + independent Bernoulli edge distribution



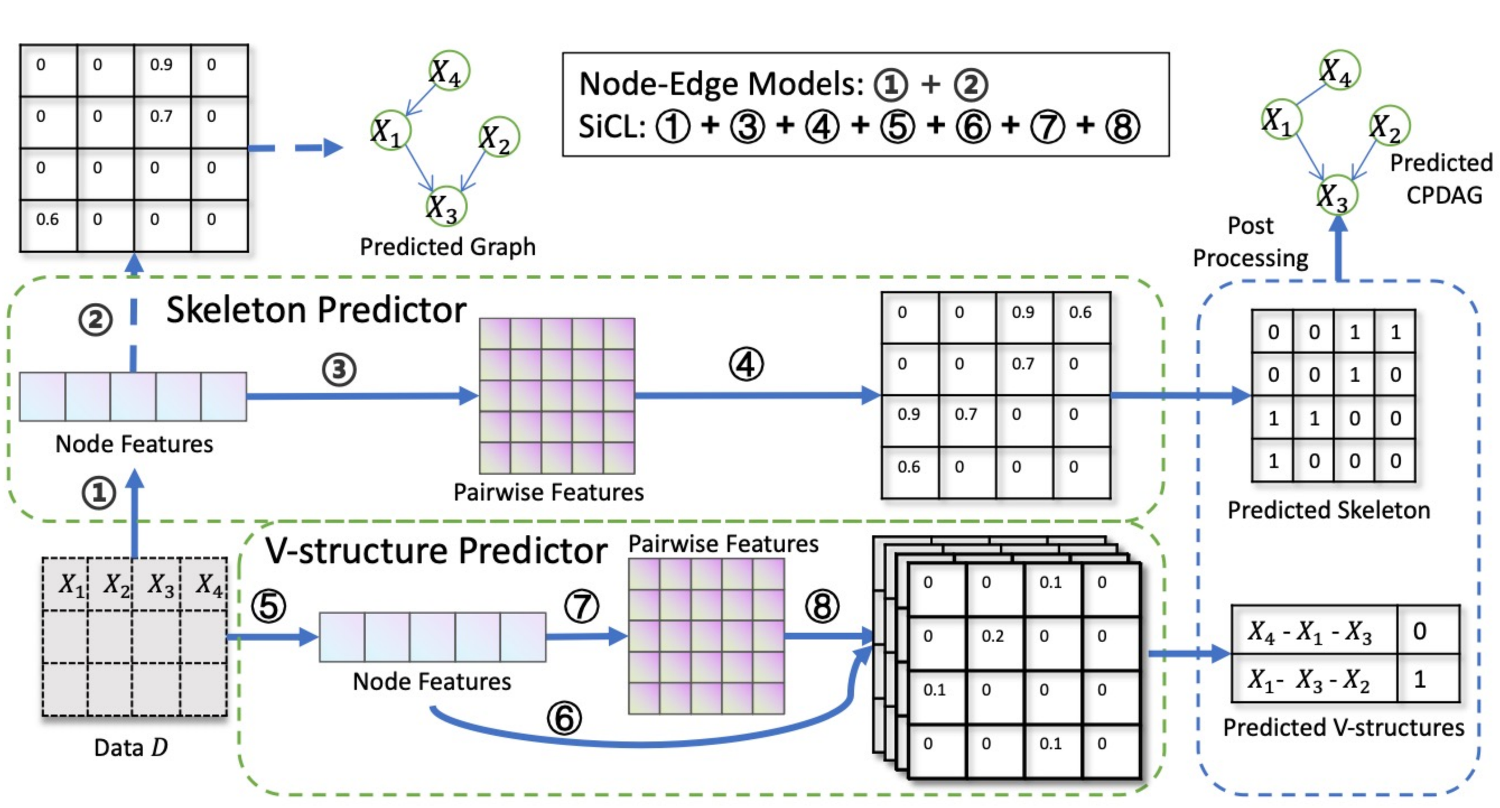
Limitations of Node-Edge Model

- It has an unavoidable error rate under a presented three-variable demo.
- It has a higher error rate of ~ 0.2642 under a more general scenario.
- It does not explicitly represent the essential features about node pairs.

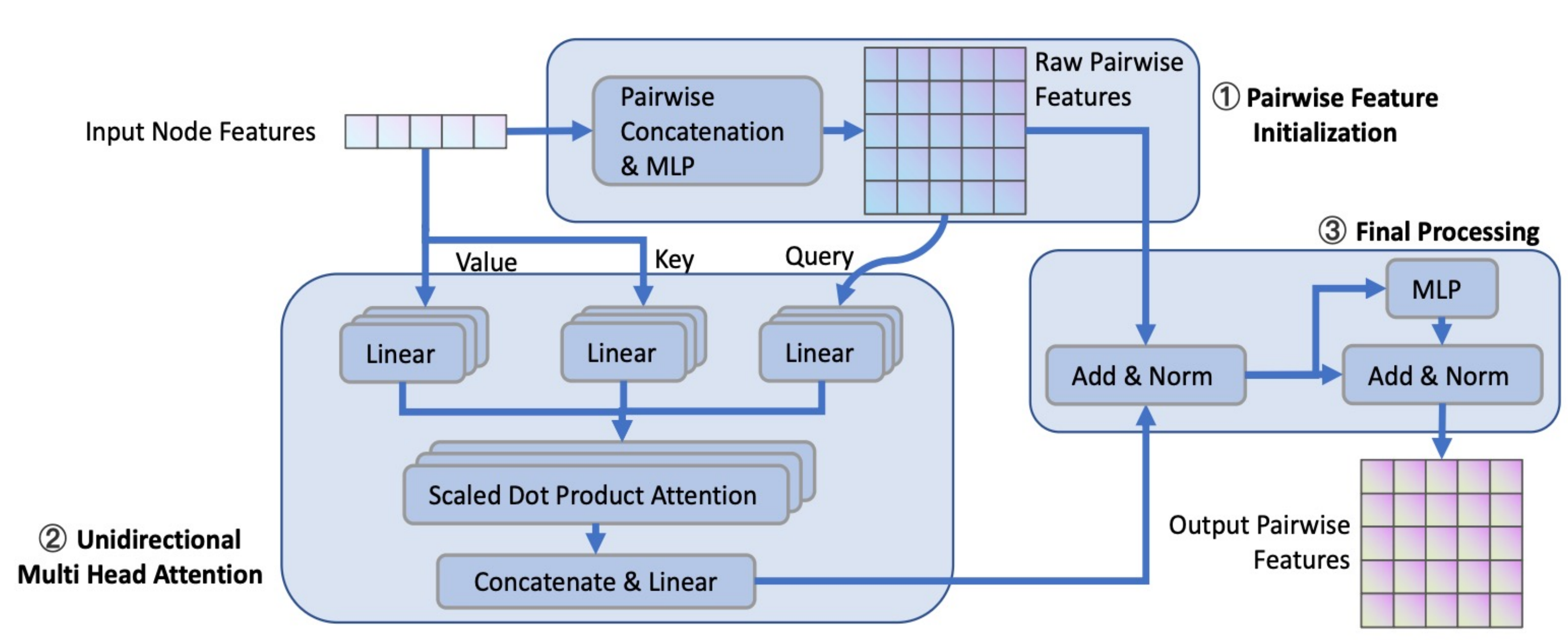


Our SiCL Approach

- Learning *identifiable* causal structure: skeleton + v-structures with two separate DNNs.
- Utilizing a pairwise encoder to encode pairwise features explicitly.
- Theoretical guarantee: DNNs with our learning targets have a theoretical guarantee for correctness in asymptotic sense.



Inference workflow of SiCL



Structure of the proposed pairwise encoder

Experimental Results

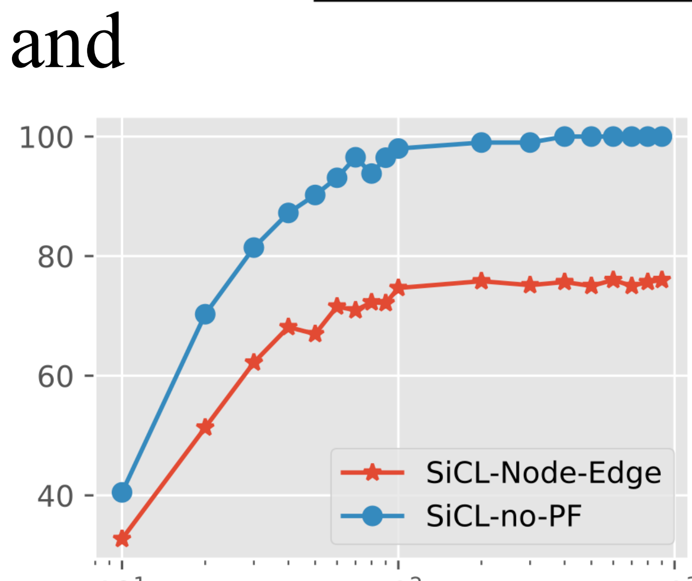
- SiCL outperforms various baselines on both synthetic datasets and real-world Sachs dataset.
- Ablation study confirms the effectiveness of learning identifiable structures and using pairwise representation.

Comparison on synthetic datasets

Method	WS-L-G		SBM-L-G		WS-RFF-G		SBM-RFF-G		ER-CPT-MC	
	s-F1↑	o-F1↑	s-F1↑	o-F1↑	s-F1↑	o-F1↑	s-F1↑	o-F1↑	s-F1↑	o-F1↑
PC	30.4	16.0	58.8	35.9	36.1	16.1	57.5	34.2	82.2	40.6
GES	*	*	70.8	55.0	41.7	23.6	56.5	38.0	82.1	42.4
NOTEARS	33.3	31.5	80.1	77.8	37.7	33.4	55.6	48.5	16.7	0.6
DAG-GNN	35.5	32.7	66.2	62.5	33.2	28.9	47.1	40.6	24.8	3.7
GRAN-DAG	16.6	11.7	22.6	14.4	4.7	1.1	17.4	3.8	40.8	7.3
GOLEM	30.0	19.3	68.5	65.2	27.6	17.7	41.1	24.8	37.6	9.3
AVICI	39.9	35.8	84.3	81.6	47.7	45.2	76.6	72.7	76.9	57.6
SiCL	**44.7**	**38.5**	**85.8**	**82.7**	**51.8**	**46.3**	**82.1**	**78.0**	**84.2**	**59.9**

A part of ablation study results

Method	WS-L-G		SBM-L-G	
	s-F1↑	o-F1↑	s-F1↑	o-F1↑
SiCL-Node-Edge	39.9	35.8	84.3	81.6
SiCL-no-PF	42.4	37.9	85.5	82.2
SiCL	**44.7**	**38.5**	**85.8**	**82.7**



Verification of learning identifiable structures on a constructed dataset

Comparison on Sachs dataset

Method	Skeleton Prediction		CPDAG Prediction	
	s-F1↑	s-Acc.↑	SHD↓	#v-struc.↓
PC	68.6	80.0	19	12
GES	70.6	81.8	19	8
DAG-GNN	21.1	72.7	15	**0**
NOTEARS	11.1	70.9	16	**0**
GRAN-DAG	45.5	78.2	12	**0**
GOLEM	36.4	74.5	14	**0**
AVICI	66.7	83.5	18	14
SiCL	**71.4**	**86.8**	**6**	**0**