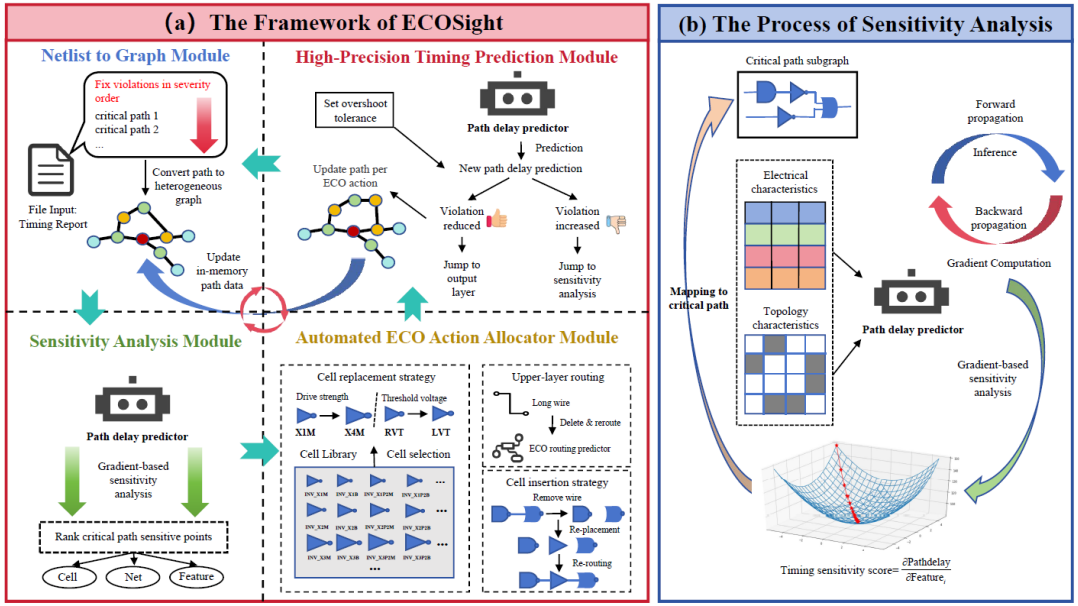
ECOSight: an explainable graph AI tool for automated decision-making in timing ECO

Huiqing YOU, Xiaowei HE, Wencheng JIANG, Bo HU, Peiyun BIAN, Zexiang CHENG, Chaochao FENG, Daheng LE, Pengcheng HUANG, Chiyuan MA, Zhenyu ZHAO

Frontiers of Computer Science, DOI: 10.1007/s11704-026-51891-6

Problems & Ideas

- Current Problem: Traditional ECO flow for IC timing closure is inefficient and experience-dependent, lacking automated, explainable decision-making.
- Ideas: We propose ECOSight, the first explainable graph AI tool that automates timing ECO decisions through transparent sensitivity analysis and action generation.



(a) Describe four core modules: the Netlist to Graph Module, High-Precision Timing Prediction Module, Sensitivity Analysis Module, and Automated ECO Action Allocator Module. These modules collaboratively form an automated decision-making workflow that translates timing reports into timing repair actions. (b)Describe the process of quantifying the timing sensitivity of critical path nodes. The timing sensitivity is represented by computing the squared values of the gradients with respect to the input features, which guides the backpropagation process.

Main Contributions

- Contributions:
  - Development of a high-fidelity, heterogeneous GNN for end-to-end path delay prediction, achieving exceptional accuracy R^2 = 0.9998 and serving as a fast, reliable substitute for static timing analysis. identification and localization of timing-critical points in critical paths.;
  - Introduction of a novel timing sensitivity analysis framework using explainable AI on the trained graph model, which quantifies the criticality of each cell and interconnects to generate a precise "timing sensitivity map" for decision-making.;
  - Design of an automated action allocation strategy that translates timing sensitivity scores into concrete ECO commands, establishing a closed-loop from analysis to implementation.
  - Introduction of the "explainable graph AI-driven decision-making" paradigm, which diverges from traditional black-box AI or heuristic methods, providing a novel and transparent solution for ECO challenges.

Comparison of Setup Time Repair Effectiveness Between ECOSight and Commercial Tools (ns)

		b12	b14	b15
Initial timing	WNS	-1.483	-5.61	-8.33
	TNS	-35.159	-635.831	-1335.772
	VM	44	188	387
Tool A	WNS	0	-2.708	-1.8561
	TNS	0	-206.1	-154.842
	VM	0	163	224
	ECOM	120	2551	3259
	TNSRE	0.293	0.168	0.362
Tool B	WNS	-0.496	-3.618	-4.003
	TNS	-2.897	-297.637	-643.992
	VM	13	170	352
	ECOM	134	1379	2063
	TNSRE	0.241	0.245	0.335
ECOSight	WNS	-0.318	-3.054	-4.913
	TNS	-2.237	-283.295	-636.426
	VM	16	165	358
	ECOM	41	478	622
	TNSRE	0.803	0.738	1.124

Comparison of average delay errors of different neural network models (ps)

	b12	b14	b15
SAGEConv	12.621	8.721	7.928
GraphConv	10.636	7.357	8.416
RGCNConv	10.689	7.593	8.275
Ours	1.257	2.38	2.29

Comparison of Runtime Between ECO Sight and Commercial Tools (s)

		b12	b14	b15
Tool A	Data loading	5.37	9.02	9.24
	Timing repair	46.46	102.16	104.85
	Total time	51.83	118.18	114.09
Tool B	Data loading	12.15	35.28	53.28
	Timing repair	1.05	69.32	82.62
	Total time	13.2	104.6	135.9
ECOSight	Data loading	4.39	4.71	5.3
	Timing repair	4.92	34.97	58.2
	Total time	9.31	39.68	63.5