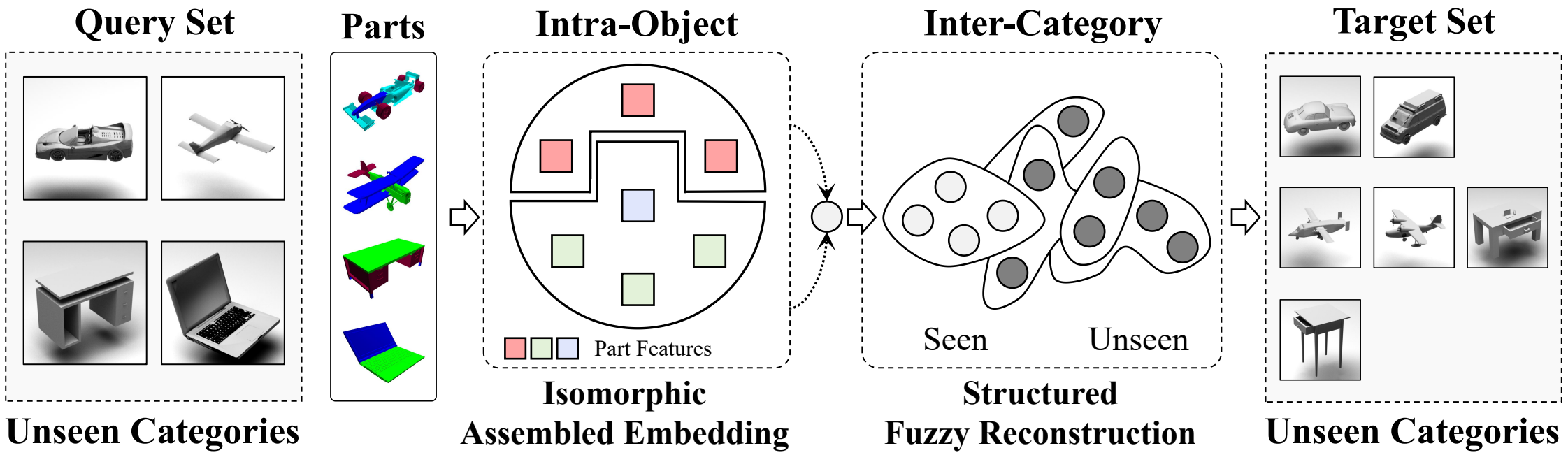
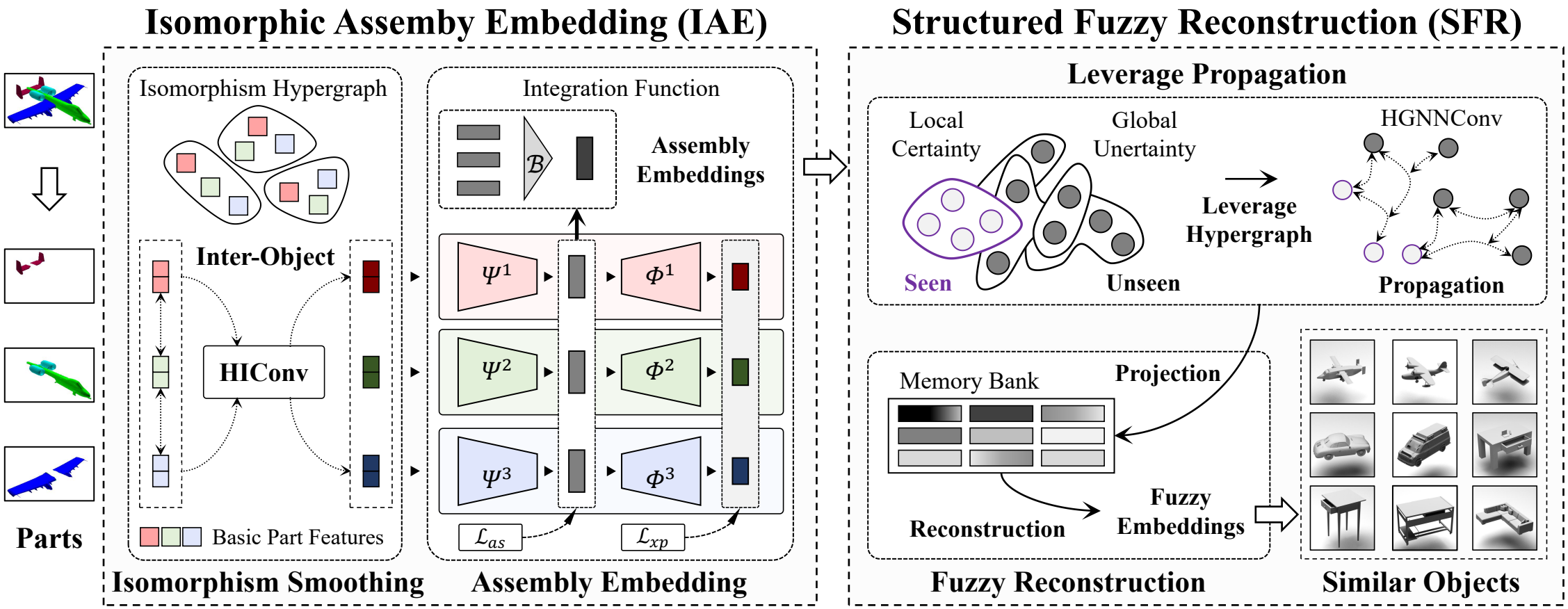
Assembly Fuzzy Representation on Hypergraph for Open-Set 3D Object Retrieval

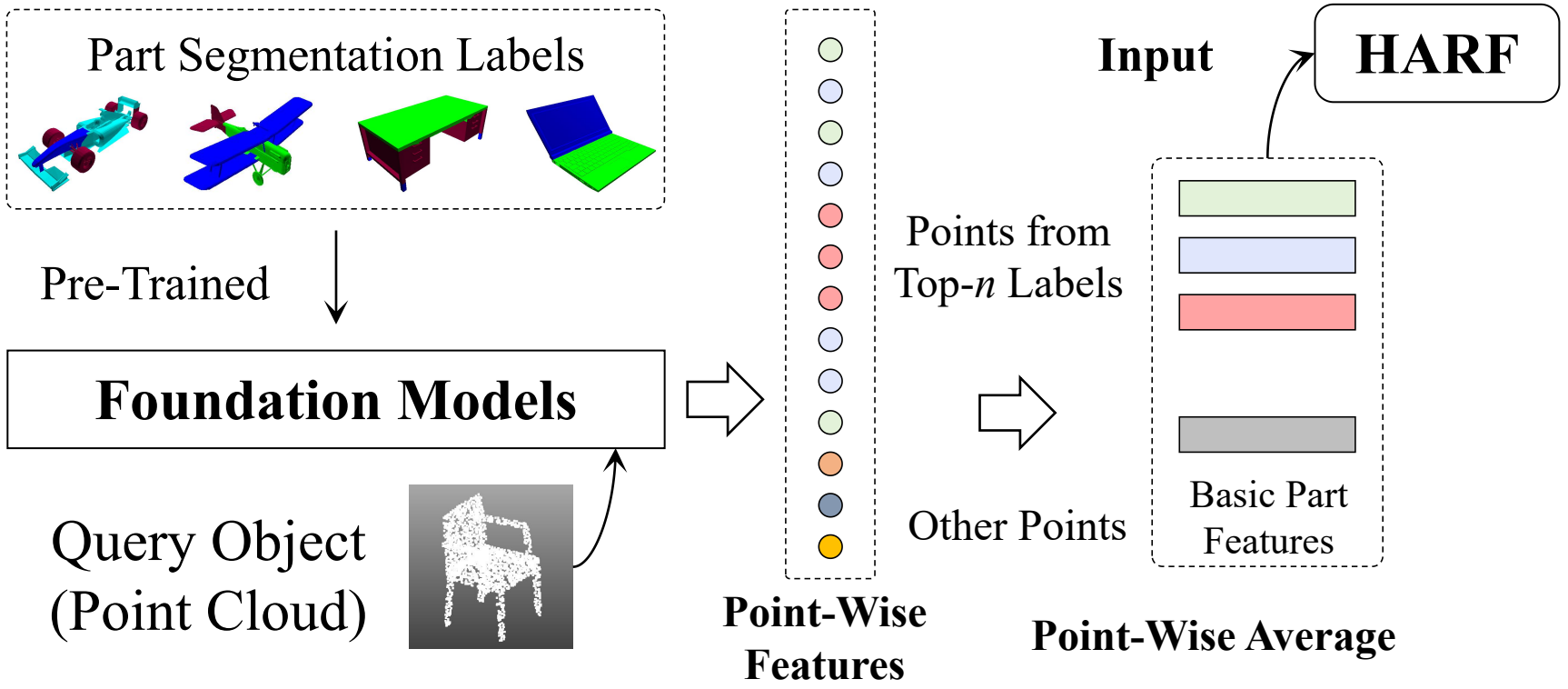
Motivation


Query Set
Parts
Intra-Object
Inter-Category
Target Set
Part Features
Seen
Unseen
Unseen Categories
Isomorphic
Assembled Embedding
Structured
Fuzzy Reconstruction
Unseen Categories

Framework


Isomorphic Assemby Embedding (IAE)
Structured Fuzzy Reconstruction (SFR)
Parts
Isomorphism Hypergraph
Integration Function
Assembly Embeddings
Inter-Object
HIConv
Basic Part Features
Isomorphism Smoothing
Assembly Embedding
Leverage Propagation
Local Certainty
Global Unertainty
HGNNConv
Leverage Hypergraph
Seen
Unseen
Propagation
Memory Bank
Projection
Reconstruction
Fuzzy Embeddings
Fuzzy Reconstruction
Similar Objects

Detailed Methods



Datasets

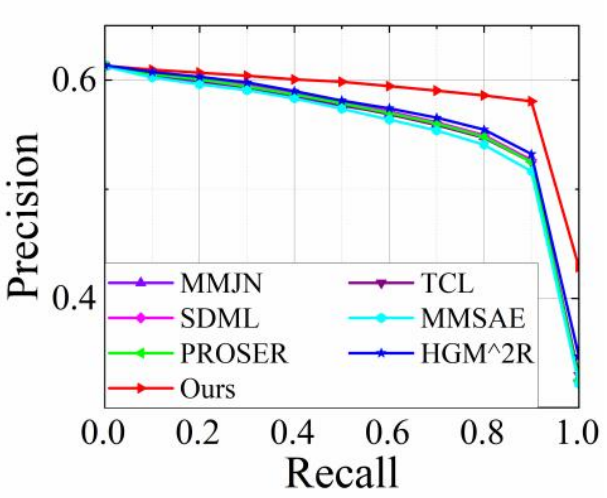
Dataset		OP-SHNP	OP-INTRA	OP-COSEG
Average Parts/Sample		3.2	3.1	2.3
Category	All	16	3	9
	Seen	6	1	3
	Unseen	10	2	6
Number	Train	5804	116	240
	Retrieval	6142	2318	802
	Query	945	302	85
	Target	5197	2016	717

Metrics

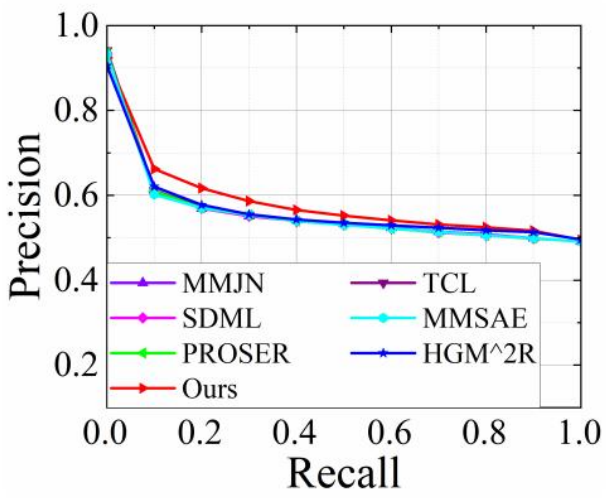
- **Average Precision (mAP)**
- **Normalized Discounted Cumulative Gain (NDCG)**
- **Average Normalized Modified Retrieval Rank (ANMRR)**
- **Precision-Recall Curve (PR-Curve)**

Rertrieval Performance

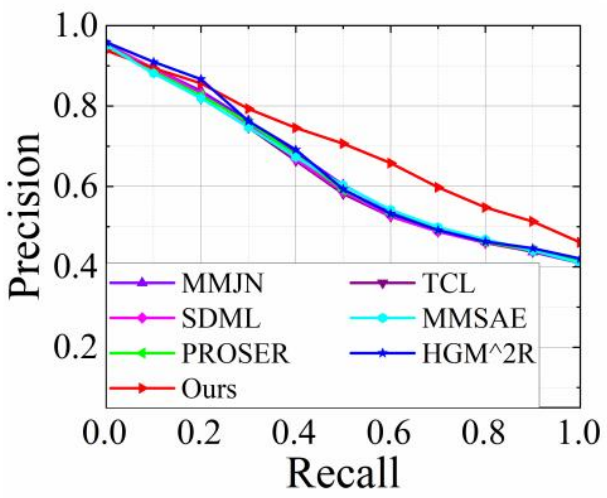
Method	OP-SHNP			OP-INTRA			OP-COSEG		
	mAP↑	NDCG↑	ANMRR↓	mAP↑	NDCG↑	ANMRR↓	mAP↑	NDCG↑	ANMRR↓
MMJN	0.5685	0.5856	0.2599	0.5465	0.5898	0.5053	0.6394	0.7623	0.4314
TCL	0.5683	0.5861	0.2608	0.5467	0.5970	0.5059	0.6285	0.7543	0.4401
SDML	0.5699	0.5870	0.2593	0.5456	0.5944	0.5064	0.6328	0.7638	0.4422
MMSAE	0.5637	0.5824	0.2659	0.5452	0.5919	0.5056	0.6350	0.7555	0.4334
PROSER	0.5687	0.5861	0.2607	0.5462	0.5943	0.5059	0.6343	0.7605	0.4348
HGM^{2}R	0.5736	0.5886	0.2549	0.5545	0.6019	0.4928	0.6452	0.7627	0.4355
Ours	**0.5947**	**0.5916**	**0.2239**	**0.5750**	**0.6382**	**0.4797**	**0.7015**	**0.7629**	**0.3604**



(a) PR Curve on OP-SHNP.



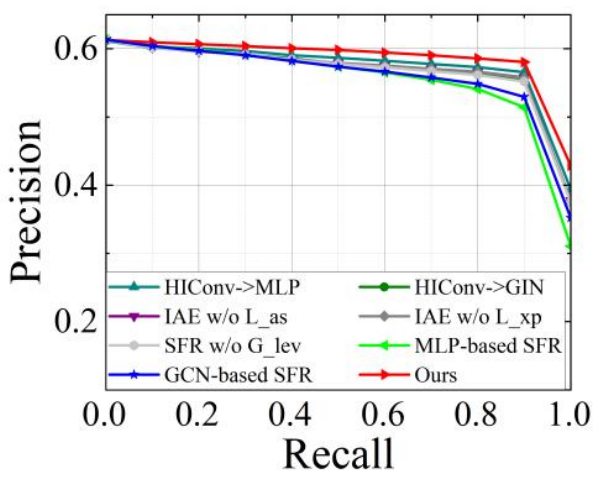
(b) PR Curve on OP-INTRA.



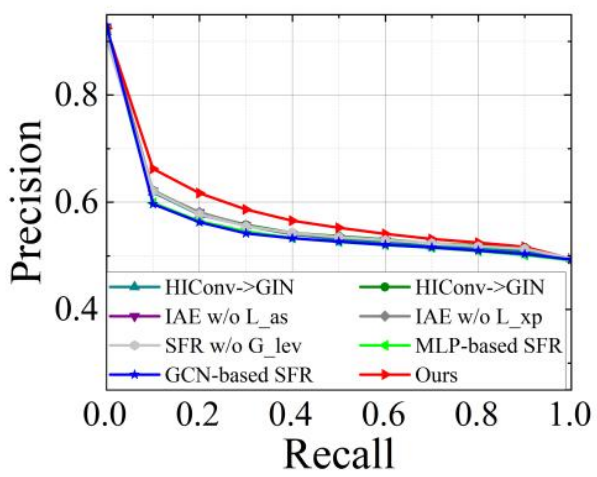
(c) PR Curve on OP-COSEG.

Ablation Studies

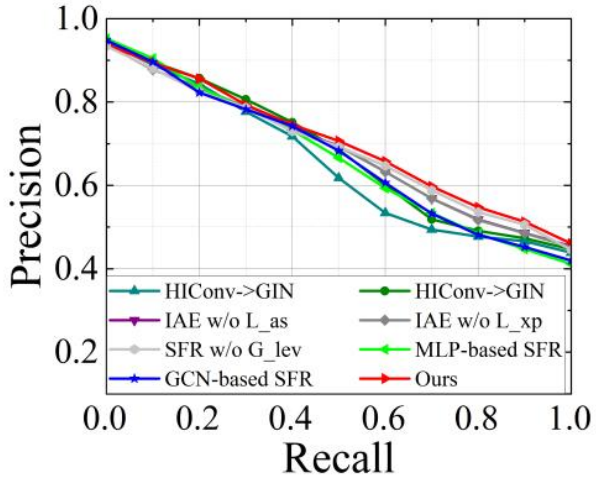
Ablation	OP-SHNP			OP-INTRA			OP-COSEG		
	mAP↑	NDCG↑	ANMRR↓	mAP↑	NDCG↑	ANMRR↓	mAP↑	NDCG↑	ANMRR↓
HIConv→GIN	0.5761	0.5826	0.2465	0.5567	0.6050	0.4947	0.6782	0.7625	0.4001
HIConv→MLP	0.5837	0.5854	0.2357	0.5523	0.6035	0.4948	0.6505	0.7664	0.4334
IAE w/o $\mathcal{L}_{as}$	0.5767	0.5838	0.2464	0.5560	0.6077	0.4946	0.6829	0.7542	0.3823
IAE w/o $\mathcal{L}_{xp}$	0.5767	0.5840	0.2464	0.5561	0.6078	0.4944	0.6828	0.7542	0.3824
SFR w/o $\mathcal{G}_{lev}$	0.5755	0.5825	0.2474	0.5545	0.6019	0.4928	0.6887	0.7540	0.3768
MLP-based SFR	0.5636	0.5851	0.2665	0.5429	0.5814	0.4997	0.6662	0.7610	0.4062
GCN-based SFR	0.5679	0.5845	0.2603	0.5430	0.5854	0.4982	0.6674	0.7618	0.4072
IAE+SFR	**0.5947**	**0.5916**	**0.2239**	**0.5750**	**0.6382**	**0.4797**	**0.7015**	**0.7629**	**0.3604**



(a) PR Curve on OP-SHNP.



(b) PR Curve on OP-INTRA.



(c) PR Curve on OP-COSEG.

Conclusion

- In this paper, we introduce the Hypergraph-Based Assembly Fuzzy Representation (HARF) framework, which navigates the intricacies of open-set 3D object retrieval through a bottom-up lens of *Part Assembly*. Specifically, we propose the Hypergraph Isomorphism Convolusion (HIConv) and adopt the Isomorphic Assembly Embedding (IAE) module for assembly isomorphism and unification, generating the integration embeddings with geometric-semantic consistency. Besides, we employ the Structure Fuzzy Reconstruction (SFR) approach to exploit high-order correlations among objects and fuzzify representations for open-set category generalization. This module constructs a leveraged hypergraph based on local-certainty and global-uncertainty correlations to mitigate distribution skew. We construct three open-set retrieval datasets for 3D objects with part-level annotations, *i,e.*, OP-SHNP, OP-INTRA, and OP-COSEG. Extensive experiments and ablation studies on these three benchmarks show our method outperforms current state-of-the-art methods. However, due to data limitations, this paper does not currently consider the assembly fuzzy representation for varying numbers of parts, which will be a focus of our future research. We believe this paper provides a novel perspective for open-set retrieval by exploring from local to global levels.