PolygonGNN: Representation Learning for Polygonal Geometries with Heterogeneous Visibility Graph

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2024

Background: polygonal representation

- Capturing and encoding the characteristics of **polygonal geometries**

- Polygon p: an ordered set of coordinates

- A representation learning model on multipolygon is desired


Building Pattern Classication

Challenges & Contributions

- Conserving inner-polygonal & inter-polygonal relationships

  - heterogeneous visibility graphs

- Quadratic complexity from pairwise relationships

  - heterogeneous spanning tree sampling

- Rotation and translation invariance

  - lossless rotation-translation-invariant geometric representation.

Overview of PolygonGNN Framework
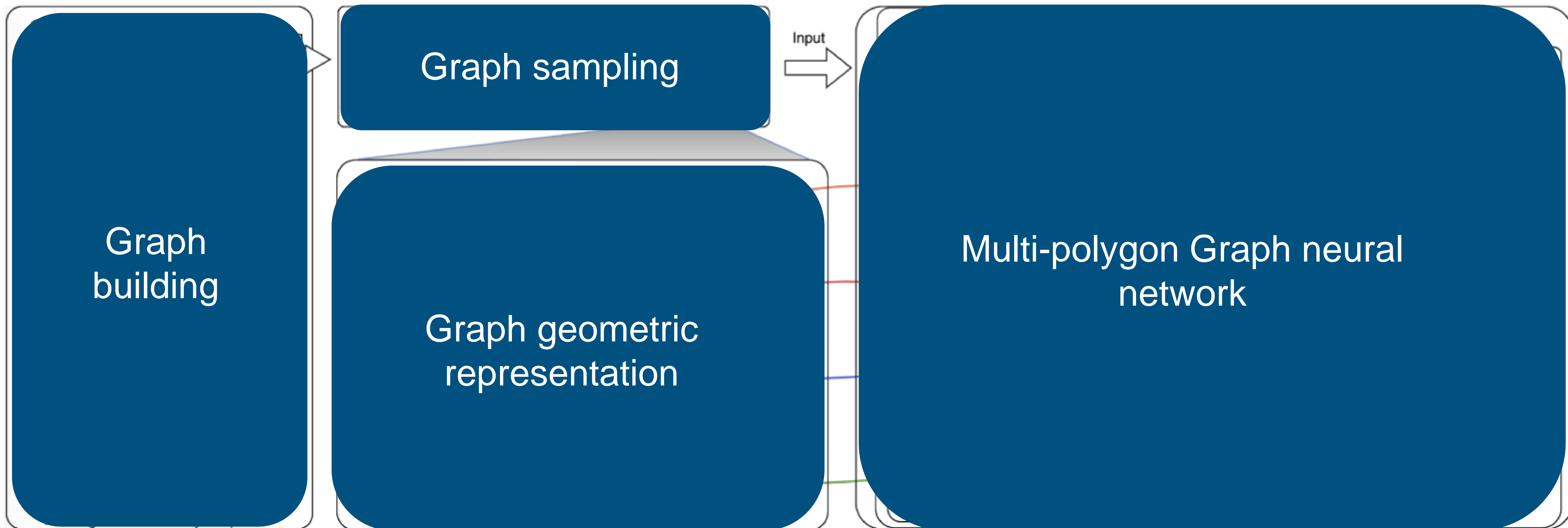
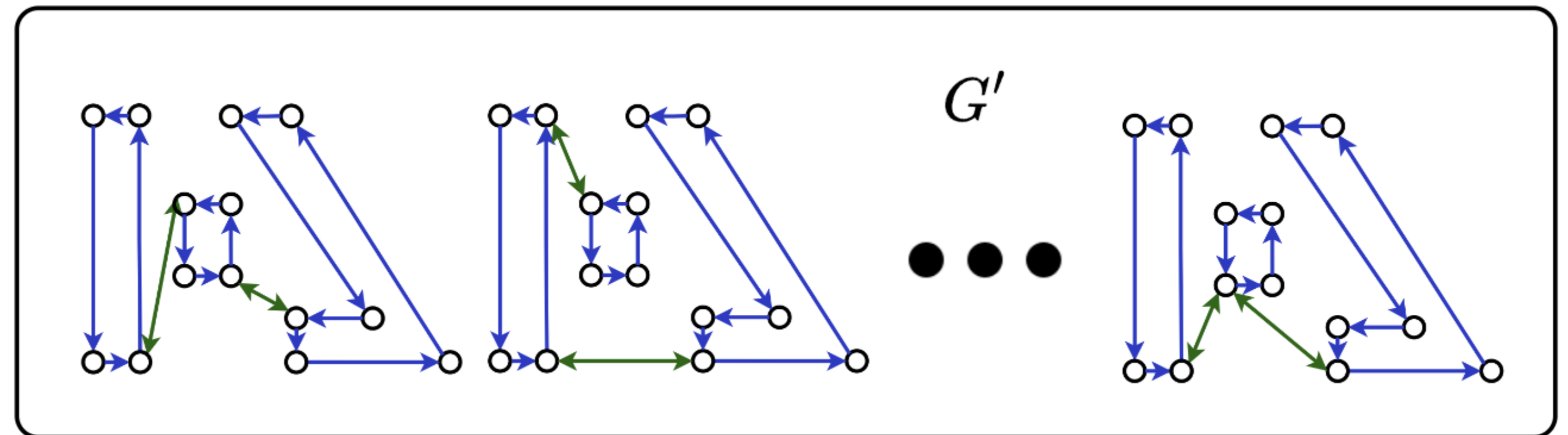# Heterogeneous Visibility Graphs
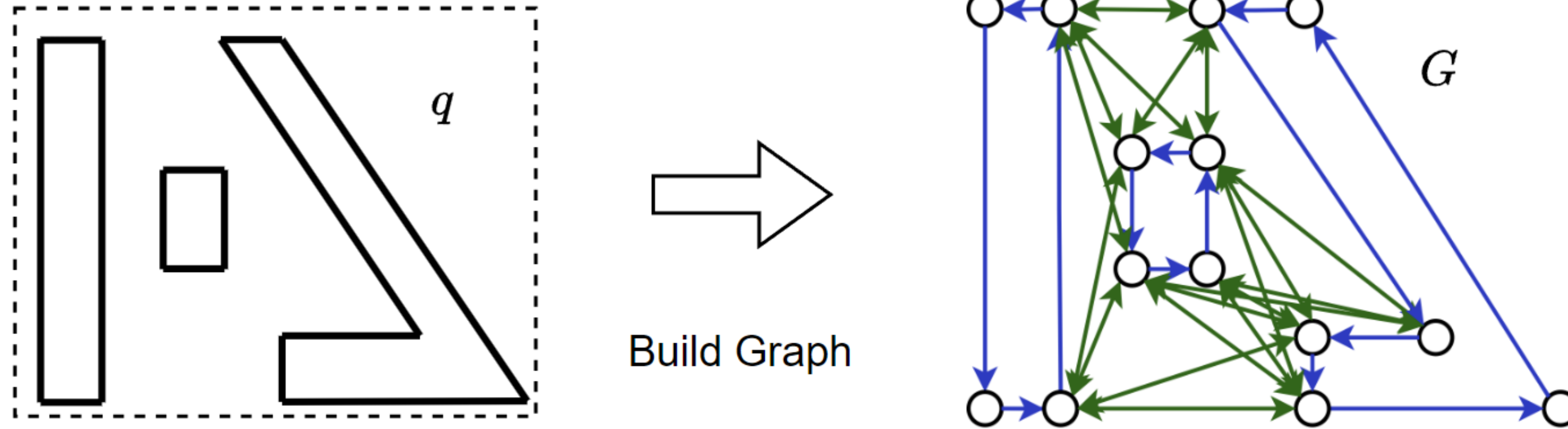
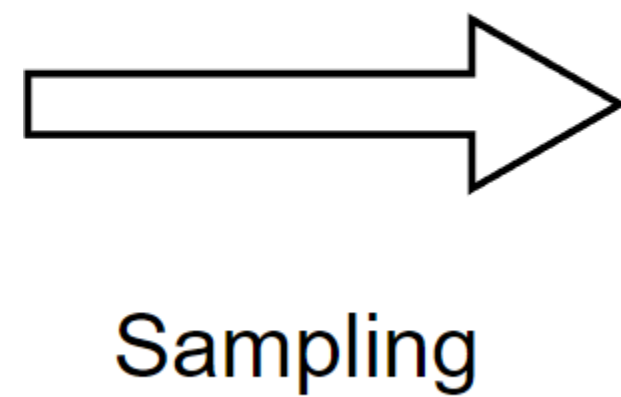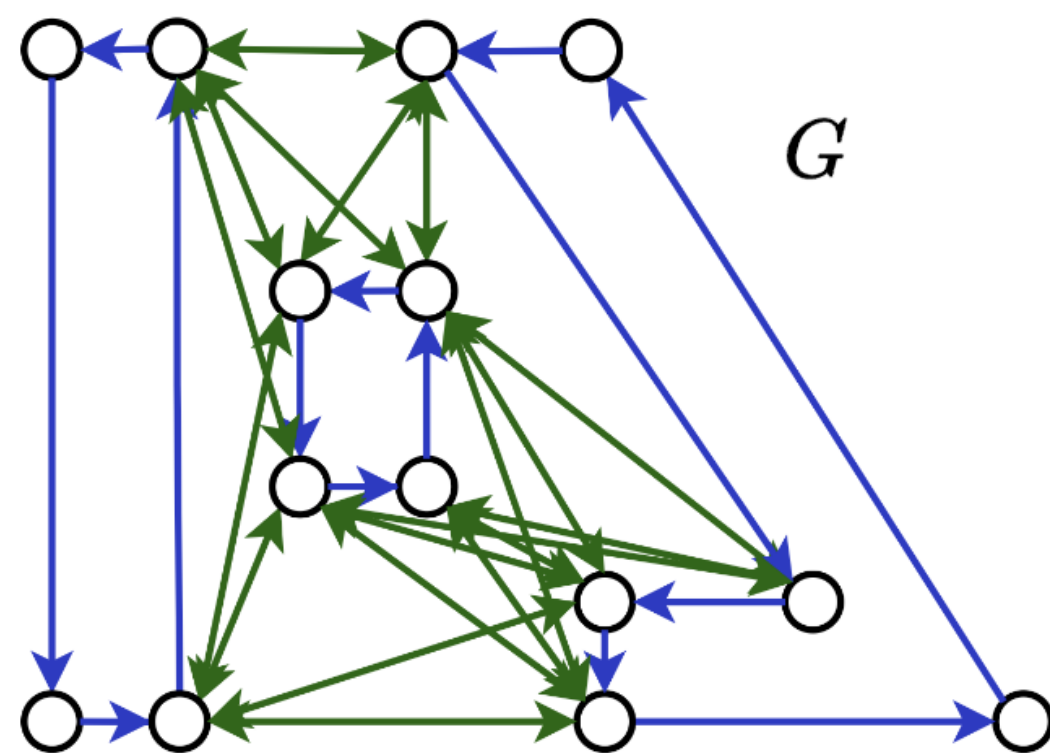
- Node V: polygon vertex

- Node feature X: coordinates

- Edge E: polygon shape + visibility relationship

Heterogeneous Spanning Tree Sampling

- Edge E: polygon shape + visibility relationship

- Sampling visibility edge

Graph Geometric Representation
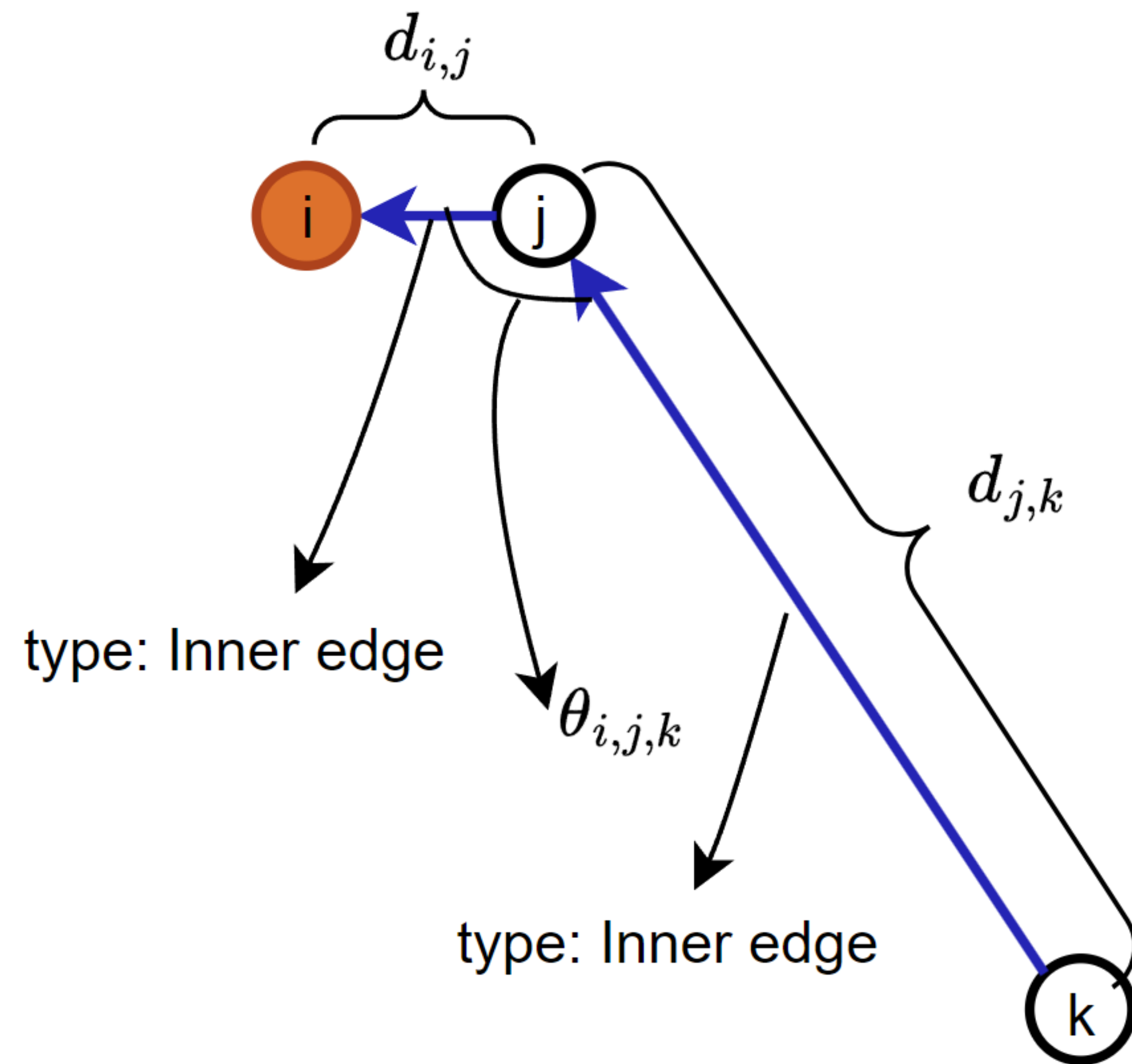
- Distance
- Distance
- Angle
- Edge Type
- Edge Type

Multipolygon-GNN

Overview of PolygonGNN Framework

(a) Transforming Multipolygon to Heterogeneous Visibility Graph

(b) Heterogeneous Spanning Tree Sampling

(c) Heterogeneous Geometric Representation

(d) Multipolygon Graph Neural Network

R_{inner} $\{d_{i,j}, d_{j,k}, \theta_{i,j,k}, \phi(e_{i,j}), \phi(e_{j,k})\}$

R_{cross}

$(h_i^{(l)}, h_j^{(l)}, h_k^{(l)}, g^{(l)})$
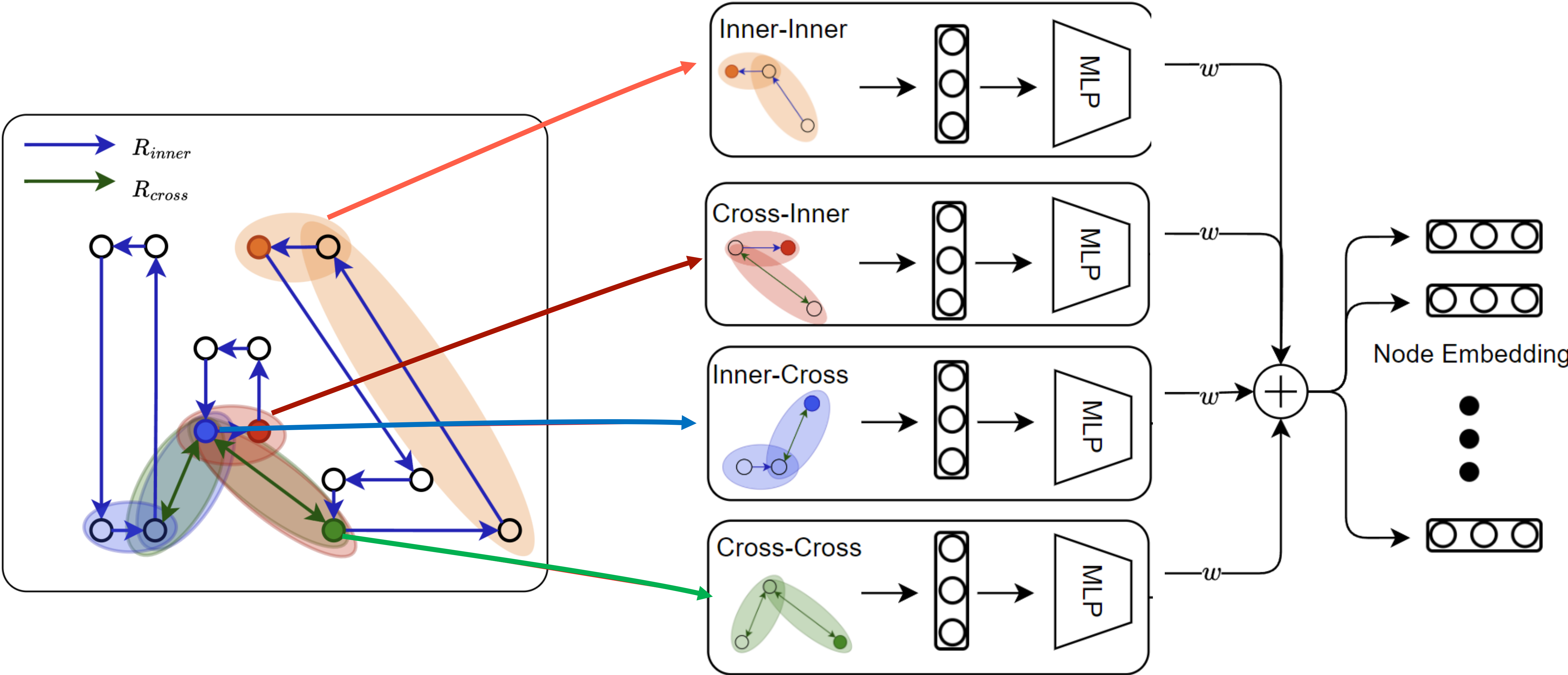
$g^{(l)} = \varphi^{(l)}(d_{i,j} \| d_{j,k} \| \theta_{i,j,k})$
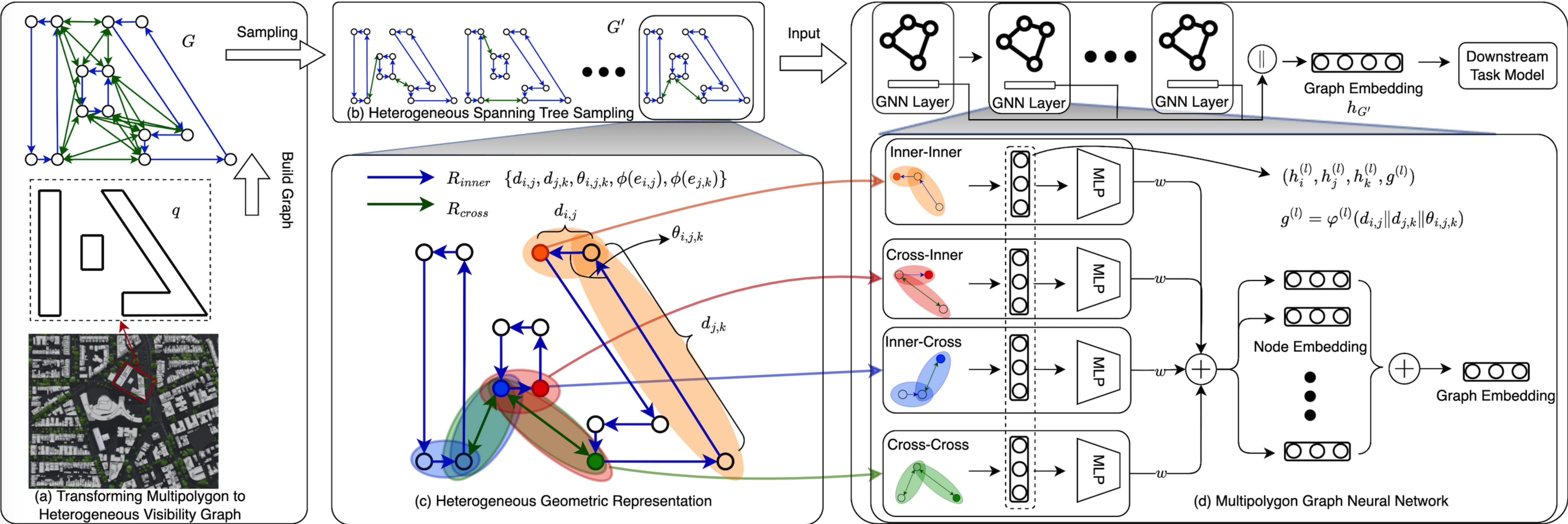
Datasets

Name	Number of samples	Number of classes	Polygon type	Task
MNIST-P-2	10,000	90	multipolygon	Digit classification
Building-2-R	3,469	10	multipolygon	Building shape classification
Building-2-C	5,000	10	multipolygon	Building shape classification
Building-S	5,000	10	Single polygon	Building shape classification
DBSR-cplx46K	46,567	2	multipolygon	Partially containing classification

Effectiveness

Dataset	Metric	ResNet1D	VeerCNN	NUFT-DDSL	NUFT-IFFT	PolygonGNN
MNIST-P-2	Acc	0.794 ±.012	0.667±.019	0.559±.014	0.357±.029	**0.897±.004**
	Prec	0.810±.018	0.709±.017	0.593±.013	0.391±.027	**0.901±.010**
	F1	0.794±.012	0.667±.018	0.561±.014	0.357±.028	**0.897±.007**
	AUC	0.995±.001	0.986±.008	0.964±.005	0.908±.010	**0.997±.000**
Building-2-C	Acc	0.146±.020	0.121±.005	0.088±.023	0.059±.031	**0.537±.025**
	Prec	0.175±.026	0.125±.007	0.108±.030	0.072±.034	**0.578±.026**
	F1	0.145±.021	0.111±.006	0.086±.024	0.060±.038	**0.537±.025**
	AUC	0.860±.055	0.836±.010	0.738±.051	0.703±.055	**0.985±.008**
Building-2-R	Acc	0.464±.014	0.372±.060	0.244±.028	0.244±.013	**0.663±.011**
	Prec	0.505±.014	0.375±.111	0.278±.029	0.287±.015	**0.696±.021**
	F1	0.451±.014	0.352±.079	0.223±.023	0.229±.025	**0.646±.015**
	AUC	0.855±.005	0.843±.025	0.736±.008	0.710±.009	0.964±.008
Building-S	Acc	0.749±.016	0.643±.059	0.847±.005	0.814±.002	**0.984±.007**
	Prec	0.773±.015	0.658±.073	0.861±.005	0.846±.001	**0.983±.007**
	F1	0.748±.018	0.644±.055	0.847±.006	0.817±.001	**0.984±.007**
	AUC	0.954±.005	0.934±.021	0.986±.001	0.984±.000	**0.999±.000**
DBSR-cplx46K	Acc	0.955±.012	0.986±.001	0.990±.001	0.990±.001	**0.992±.001**
	Prec	0.956±.010	0.986±.001	0.990±.001	0.987±.001	**0.992±.001**
	F1	0.955±.012	0.986±.001	0.990±.001	0.990±.001	**0.992±.001**
	AUC	0.995±.001	0.997±.000	0.997±.000	0.997±.000	**0.998±.000**

- PolygonGNN shows the highest score among all baselines across all datasets

Ablation Study

- Multipolygon-GNN

- Sampling strategy

Dataset	Metric	HAN	HGT	PolygonGNN w/o S	PolygonGNN
MNIST-P-2	Acc	0.865±.013	0.872±.016	0.880±.009	**0.897±.004**
	Prec	0.871±.012	0.877±.010	0.885±.012	**0.901±.010**
	F1	0.865±.012	0.872±.012	0.879±.010	**0.897±.007**
	AUC	0.996±.001	0.996±.001	0.996±.001	**0.997±.000**
Building-2-C	Acc	0.318±.027	0.347±.023	0.536±.013	**0.537±.025**
	Prec	0.331±.045	0.367±.041	0.568±.014	**0.578±.026**
	F1	0.310±.033	0.339±.029	0.530±.013	**0.537±.025**
	AUC	0.932±.014	0.944±.015	0.984±.003	**0.985±.008**
Building-2-R	Acc	0.599±.079	0.637±.071	0.659±.020	**0.663±.011**
	Prec	0.623±.083	0.651±.077	0.679±.020	**0.696±.021**
	F1	0.585±.080	0.625±.076	0.642±.019	**0.646±.015**
	AUC	0.917±.039	0.946±.026	**0.969±.010**	0.964±.008
Building-S	Acc	0.898±.007	0.950±.004	0.984±.009	**0.984±.007**
	Prec	0.901±.006	0.951±.004	0.984±.009	**0.983±.007**
	F1	0.898±.006	0.950±.004	0.984±.009	**0.984±.007**
	AUC	0.992±.000	0.998±.000	**0.999±.000**	0.999±.000
DBSR-cplx46K	Acc	0.983±.001	0.990±.002	0.990±.001	**0.992±.001**
	Prec	0.983±.001	0.990±.002	0.990±.001	**0.992±.001**
	F1	0.983±.001	0.990±.001	0.990±.001	**0.992±.001**
	AUC	0.997±.000	0.997±.000	**0.998±.000**	**0.998±.000**

Embedding Visualization
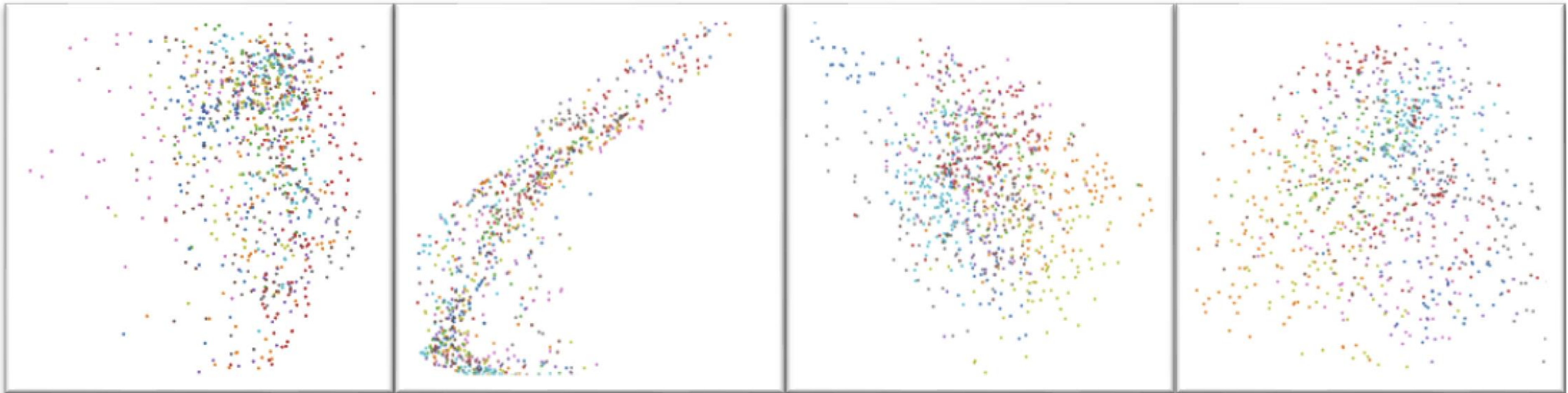
ResNet1D   VeerCNN   NUFT-DDSL   NUFT-IFFT
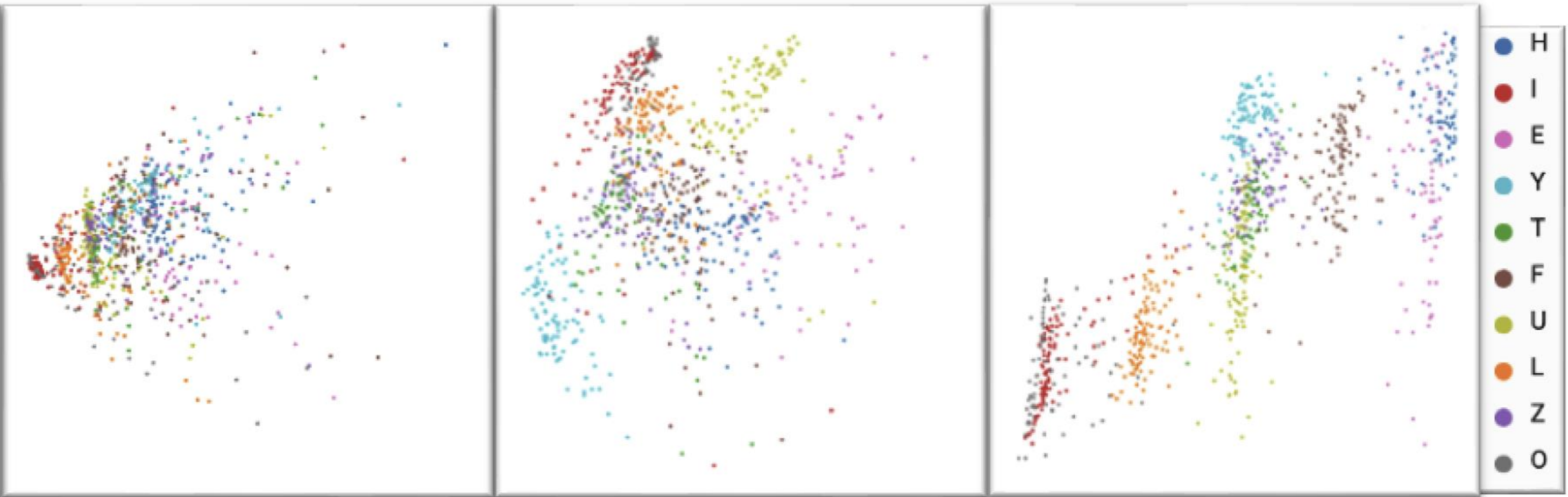
HAN   HGT   PolygonGNN

Visualization of Prediction Cases

29, 29, 69, 29,
29, 29, 24, 24

58, 59, 58, 38,
55, 57, 53, 53

38, 30, 39, 38,
39, 38, 36, 34

35, 55, 75, 75,
55, 56, 36, 36

68, 68, 65, 68,
66, 66, 60, 60

81, 81, 81, 81,
91, 51, 11, 11

94, 47, 47, 27,
47, 47, 97, 45

95, 98, 95, 83,
75, 75, 35, 25
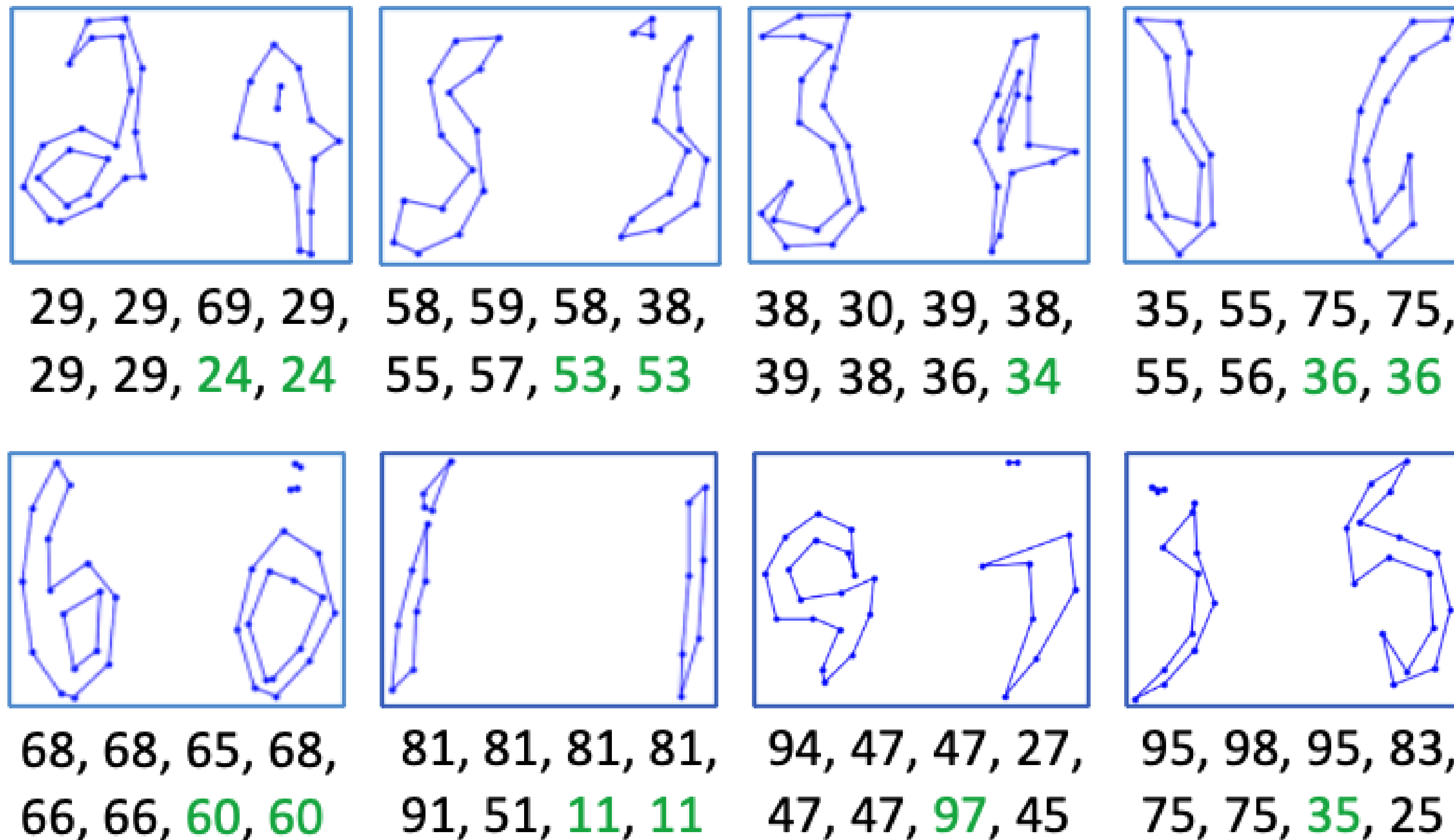
Green are correct predictions

- Predictions made by ResNet1D, VeerCNN, NUFT-DDSL, NUFT-IFFT, HAN, HGT, PolygonGNN w/o S, and PolygonGNN

- PolygonGNN adeptly handles minor imperfections

Summary

- Heterogeneous visibility graphs conserving inner-polygonal & inter-polygonal relationships

- Heterogeneous spanning tree sampling to solve quadratic complexity from pairwise relationships

- Lossless rotation-translation-invariant geometric representation

- PolygonGNN advances the representation learning for polygonal geometries, with a particular focus on multipolygons

paper

code