InforMARL: Scalable Multi-Agent Reinforcement Learning through Intelligent Information Aggregation

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Background and Motivation

Background and Motivation

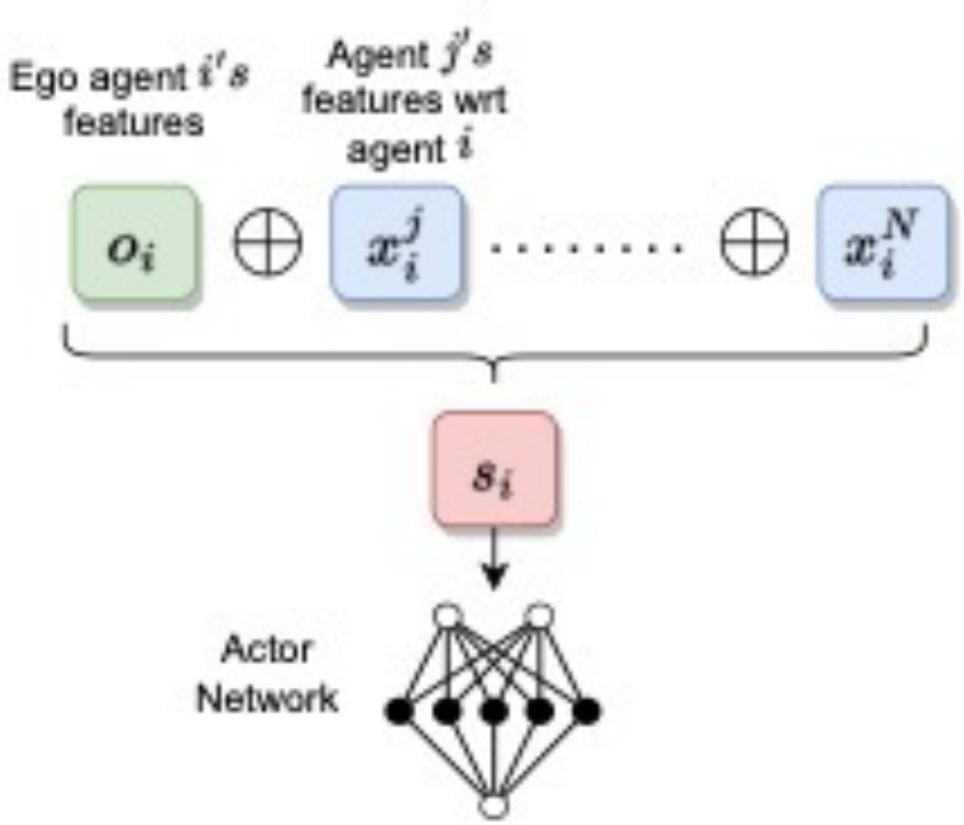
Key Features Expected from MARL Algorithms

Decentralized Execution

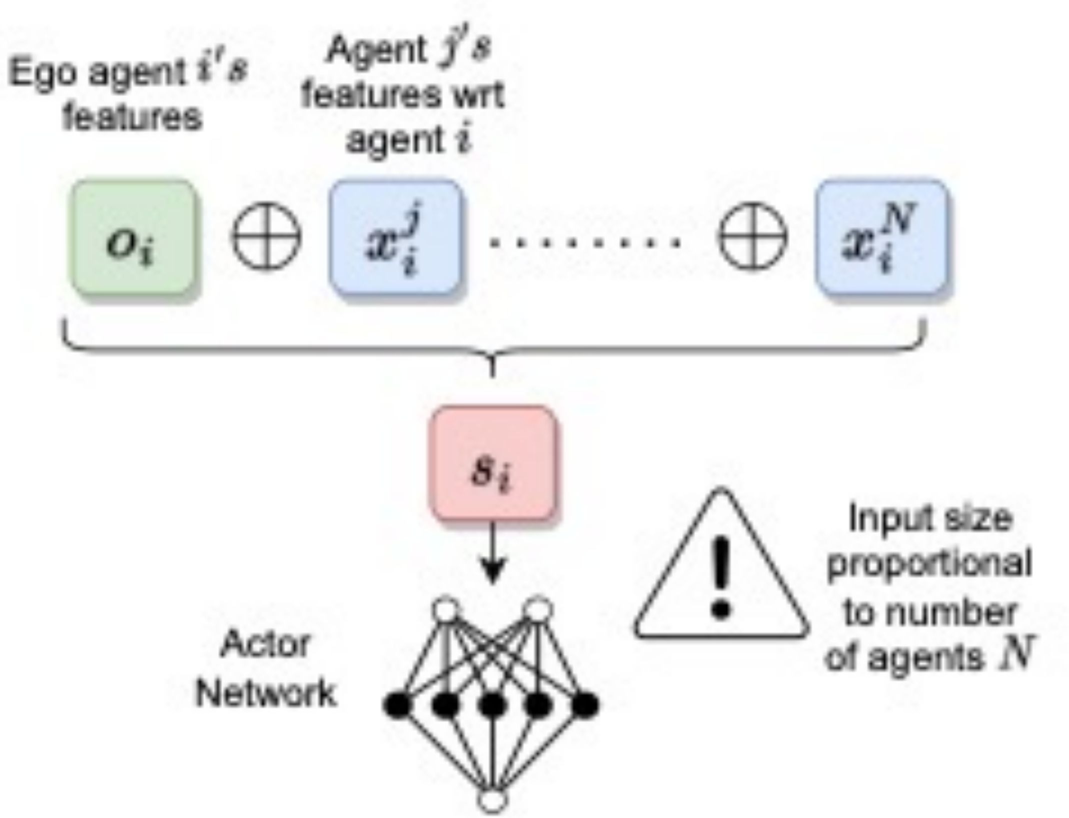
Scalability

Efficiency in training sample complexity

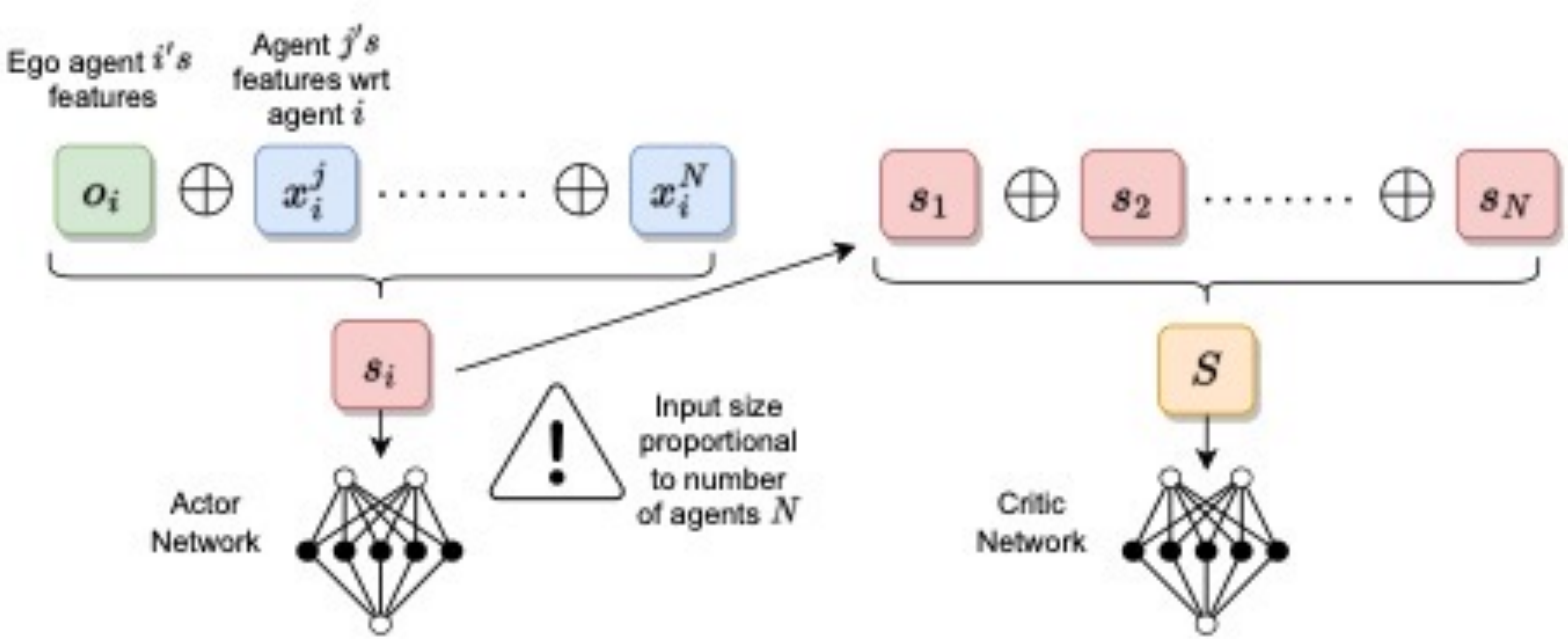
Motivation: Prior Approaches



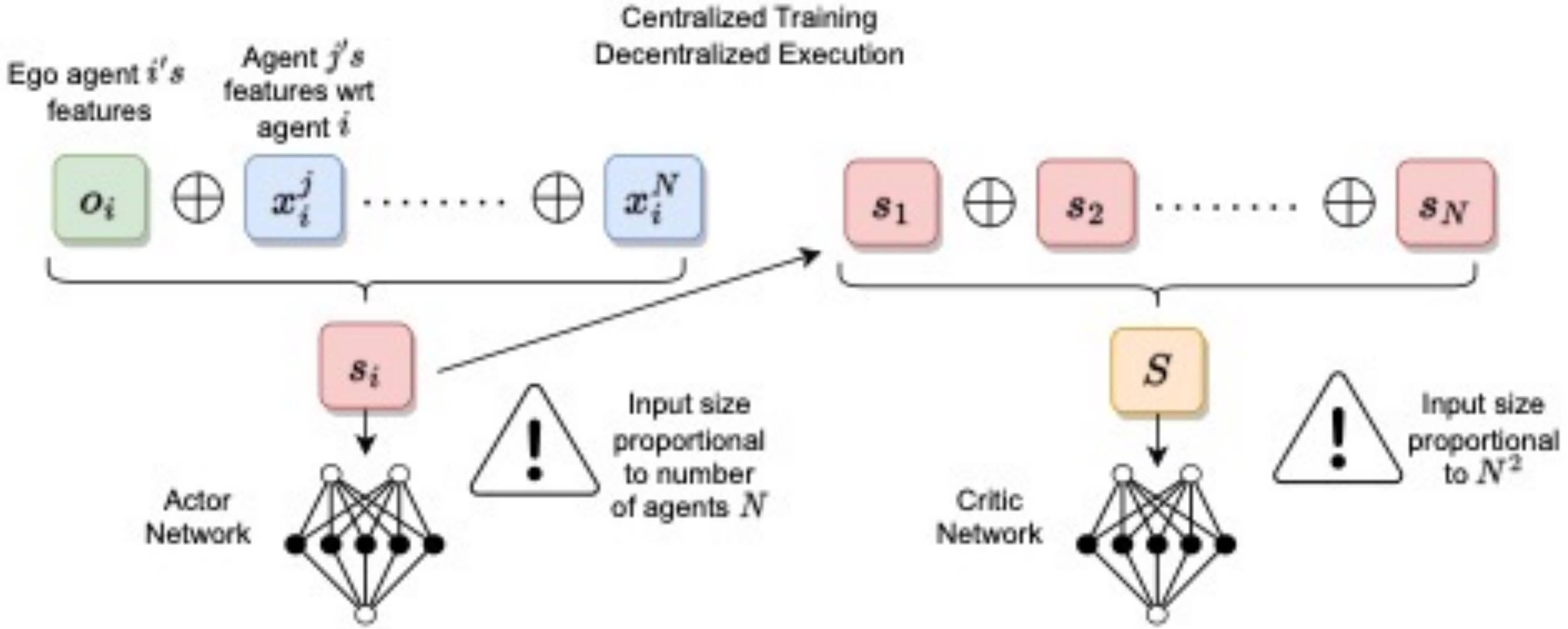
Motivation: Prior Approaches


Ego agent $i's$ features
Agent $j's$ features wrt agent i
o_i
$\oplus$
x_i^j
$\oplus$
x_i^N
s_i
Actor Network
Input size proportional to number of agents N

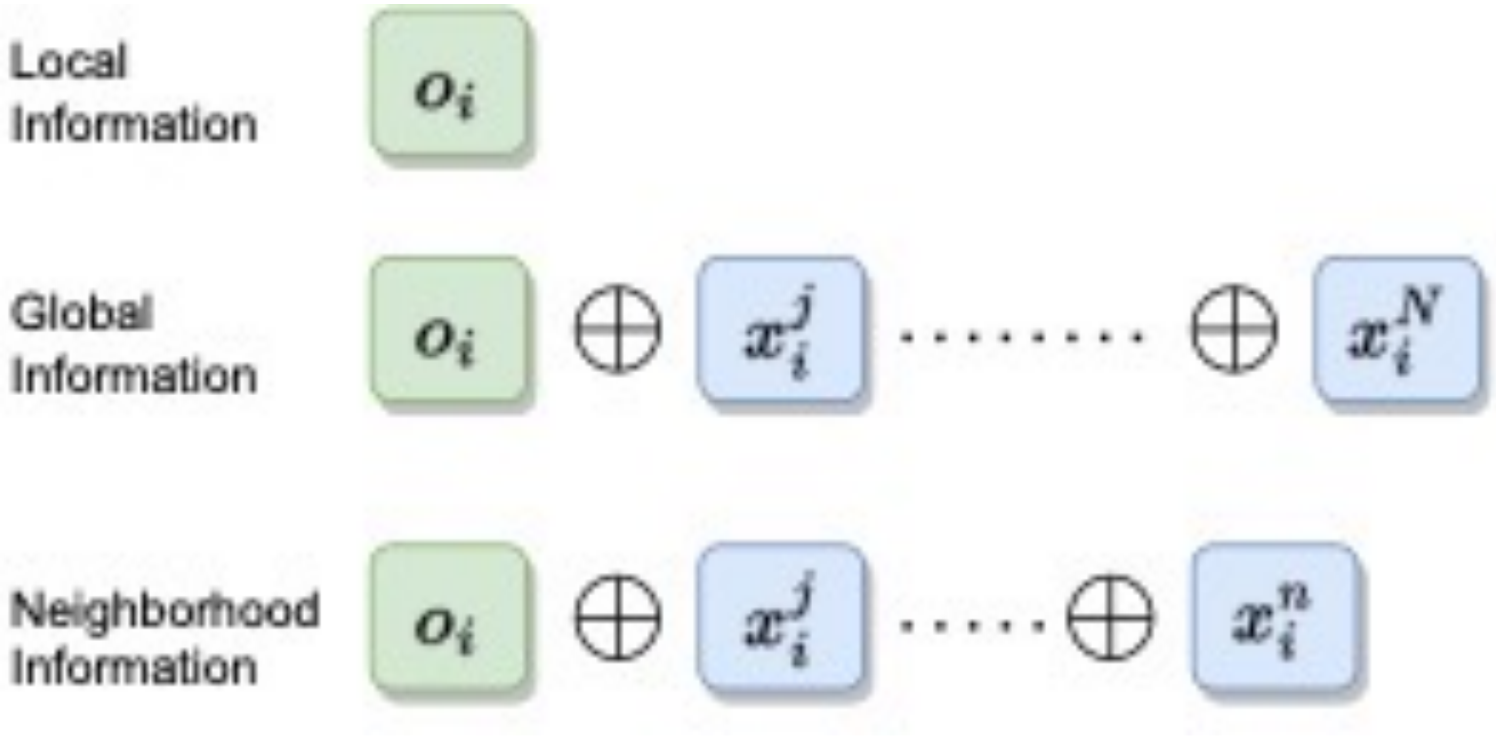
Motivation: Prior Approaches



Motivation: Prior Approaches

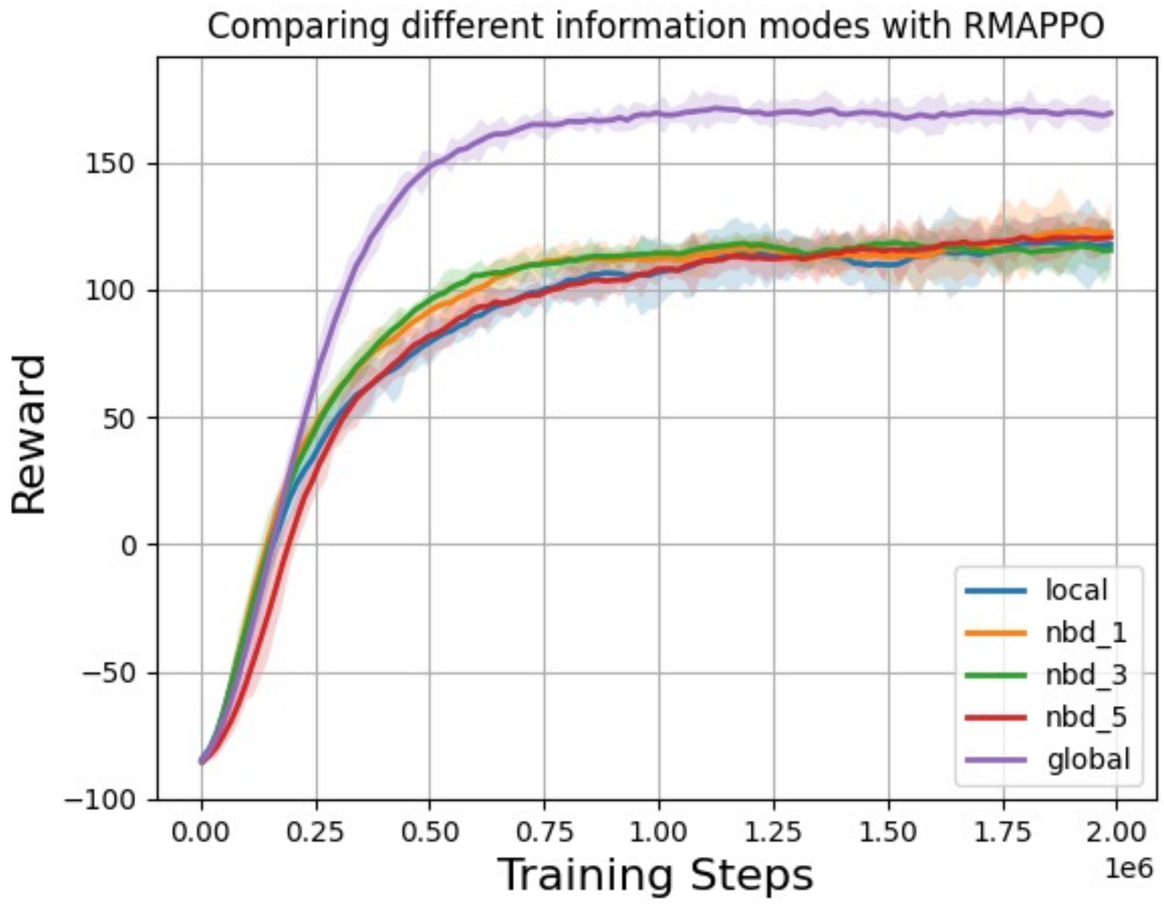


Motivating Experiment


Local Information
o_i
Global Information
$o_i \oplus x_i^j \cdots\cdots \oplus x_i^N$
Neighborhood Information
$o_i \oplus x_i^j \cdots \oplus x_i^n$

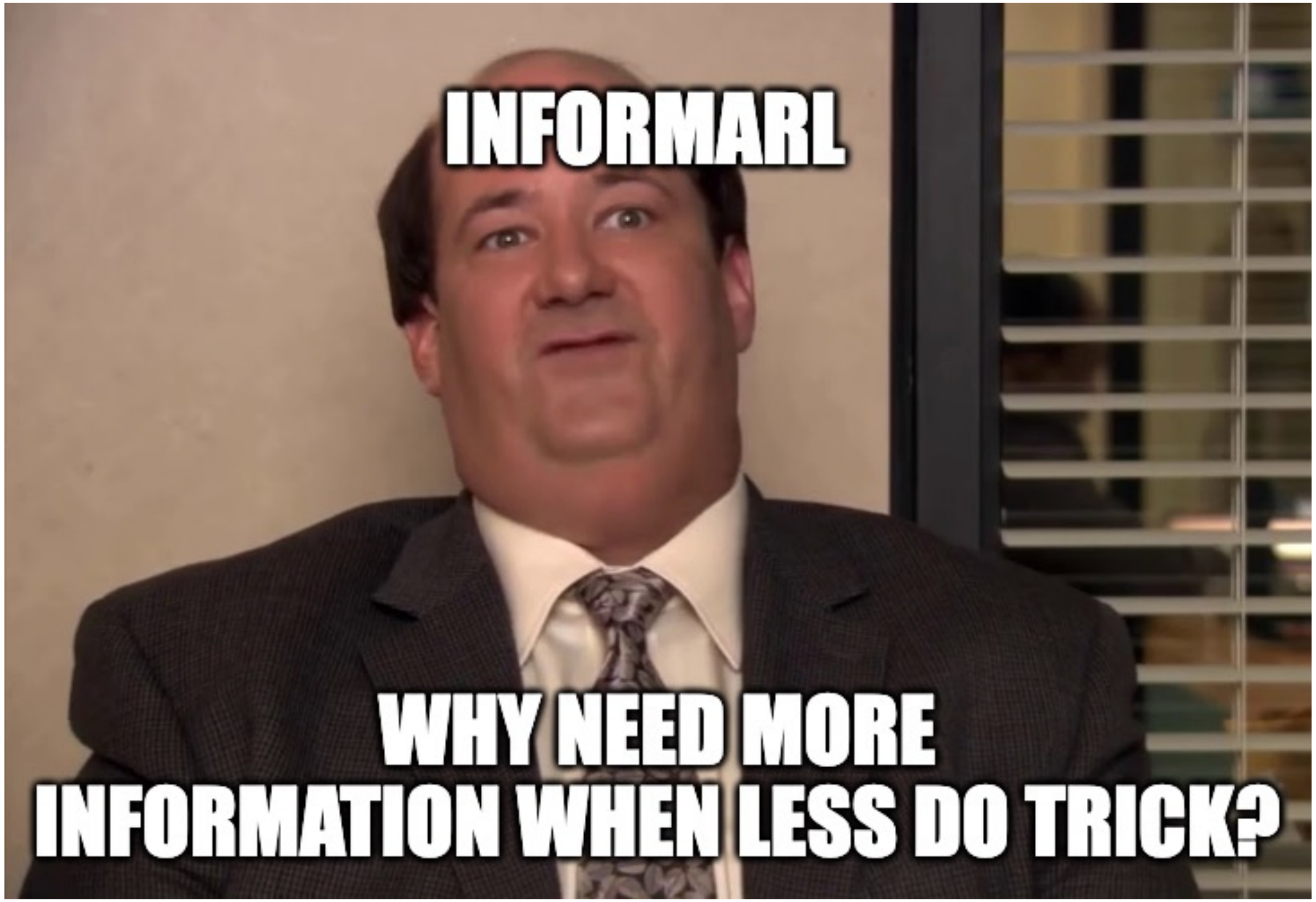
$< N$

Motivating Experiment

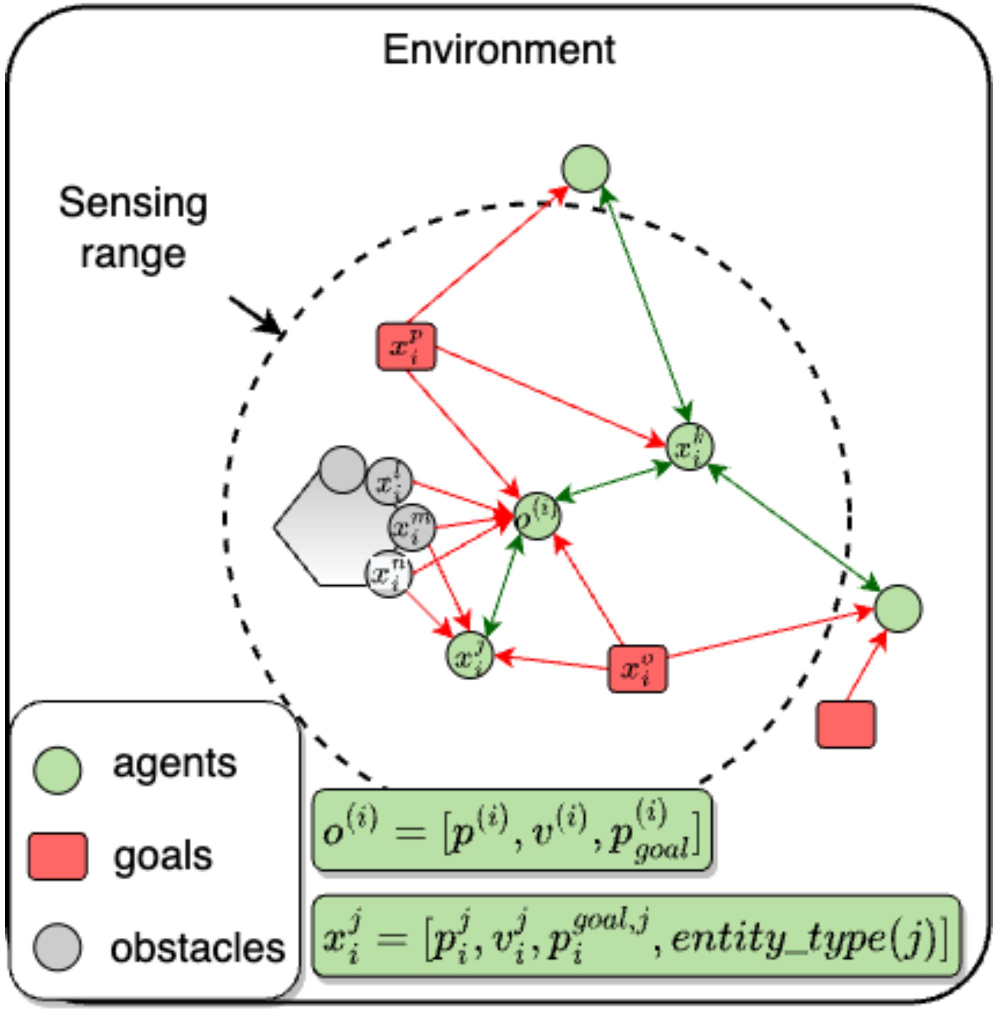


- In practice, we just have local information about the neighborhood
- And naïve concatenation of neighborhood information doesn’t work

Motivating Experiment



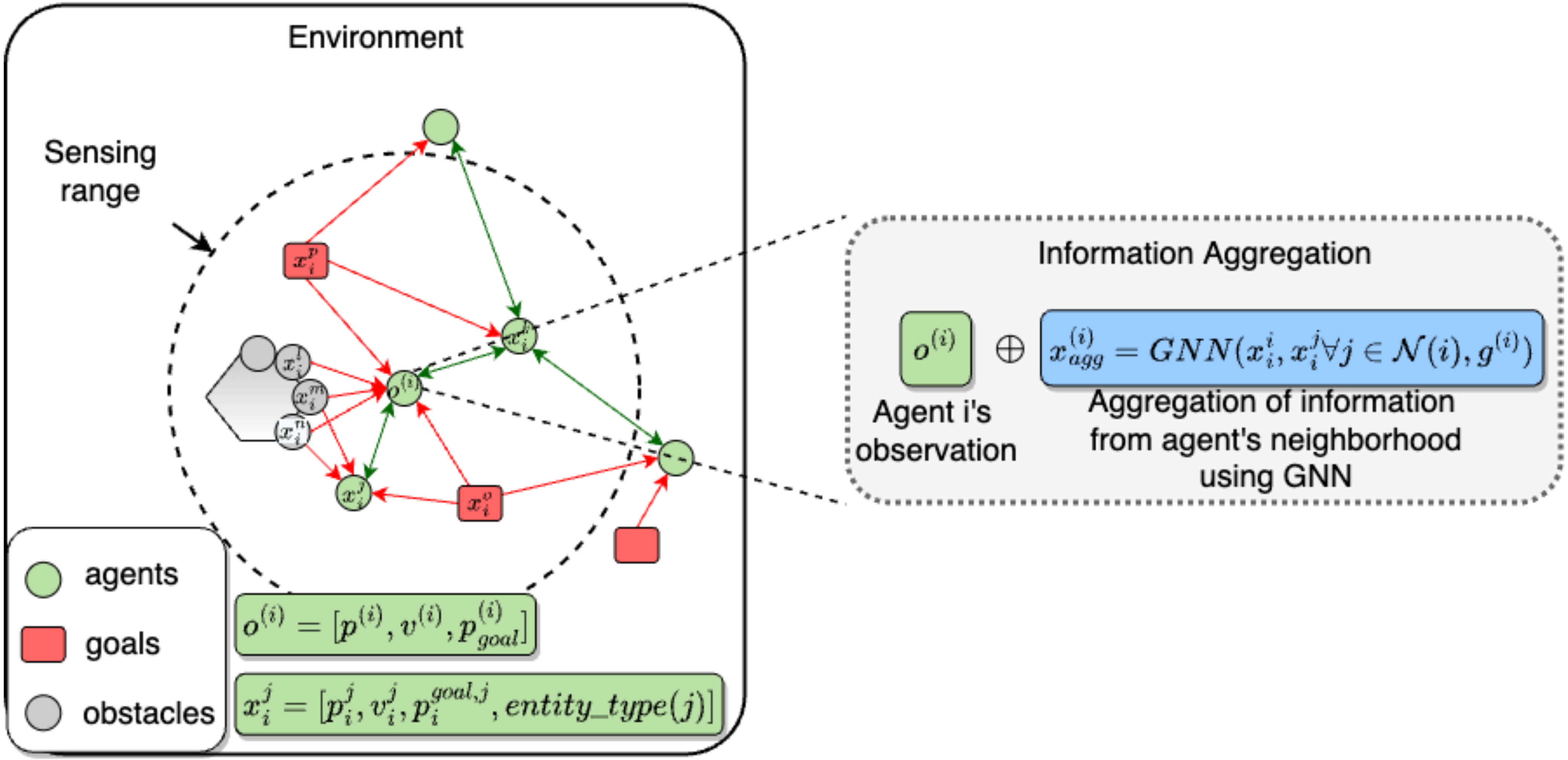
Method



$$o^{(i)} = [p^{(i)}, v^{(i)}, p^{(i)}_{goal}]$$

$$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$$

Method



$$o^{(i)} = [p^{(i)}, v^{(i)}, p^{(i)}_{goal}]$$

$$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$$

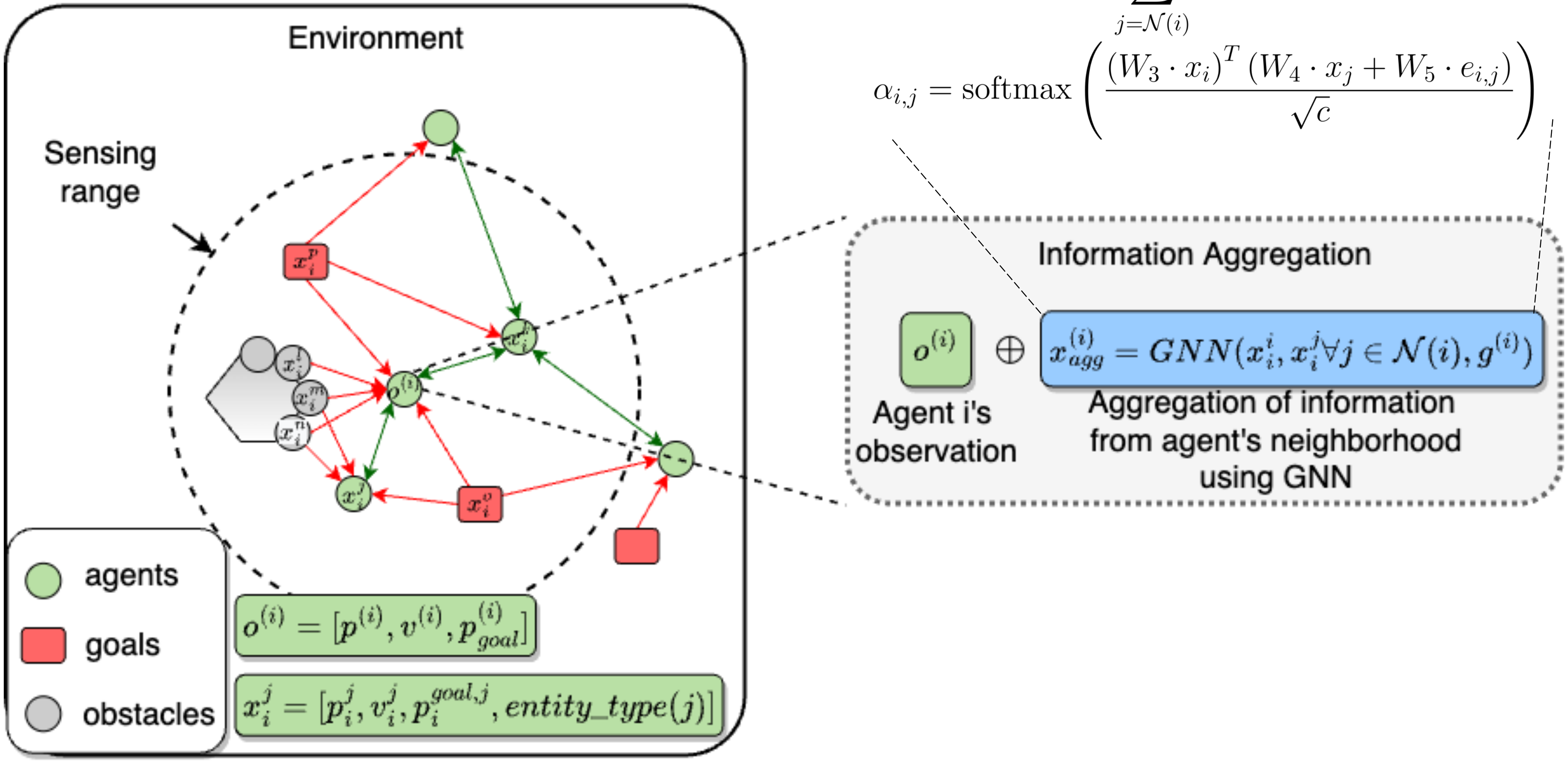
$$x_{agg}^{(i)} = GNN(x_i^i, x_i^j \forall j \in \mathcal{N}(i), g^{(i)})$$

Aggregation of information from agent's neighborhood using GNN

Method

$$x_i^{'} = W_1 \cdot x_i + \sum_{j=\mathcal{N}(i)} \alpha_{i,j} W_2 \cdot x_j$$

$$\alpha_{i,j} = \text{softmax}\left(\frac{(W_3 \cdot x_i)^T (W_4 \cdot x_j + W_5 \cdot e_{i,j})}{\sqrt{c}}\right)$$

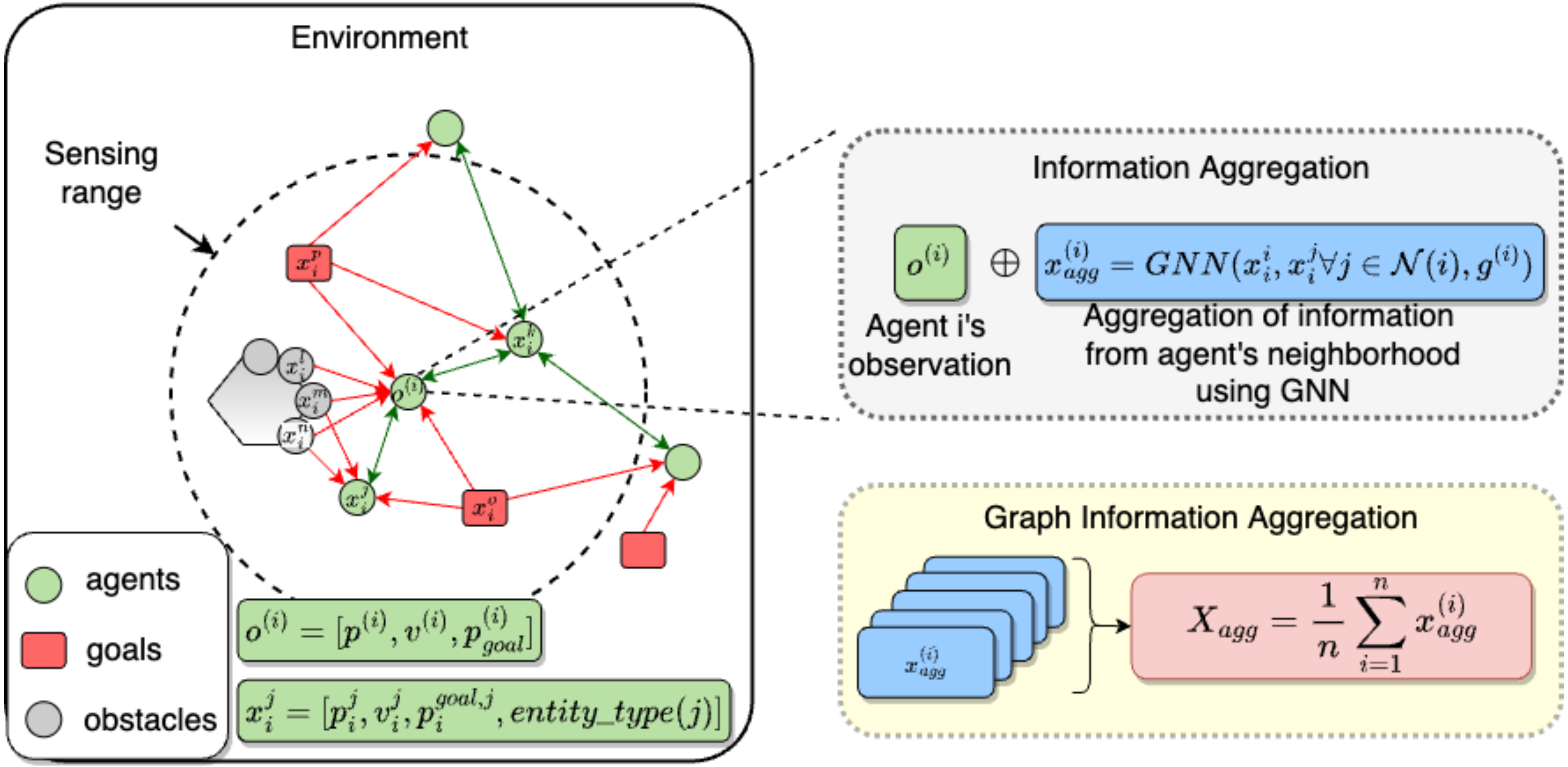


$o^{(i)} = [p^{(i)}, v^{(i)}, p^{(i)}_{goal}]$

$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$

$x^{(i)}_{agg} = GNN(x^i_i, x^j_i \forall j \in \mathcal{N}(i), g^{(i)})$

Method



$$o^{(i)} = [p^{(i)}, v^{(i)}, p_{goal}^{(i)}]$$

$$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$$

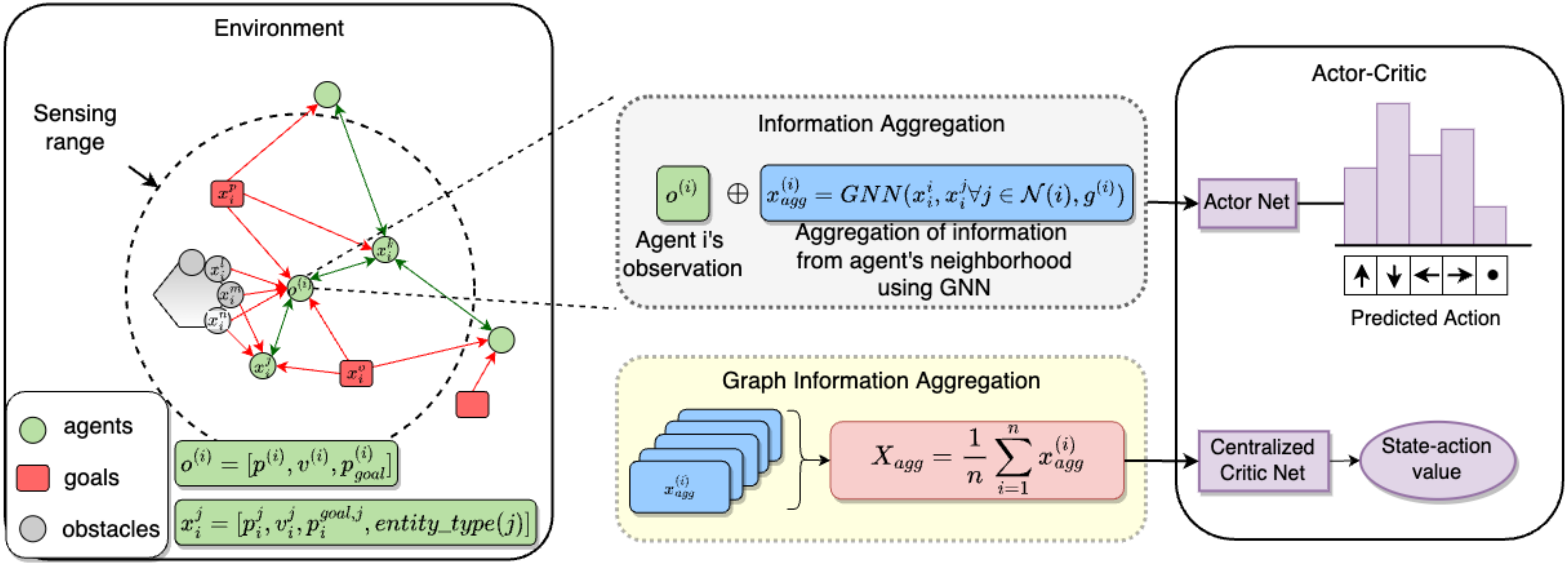
$$o^{(i)} \oplus x_{agg}^{(i)} = GNN(x_i^i, x_i^j \forall j \in \mathcal{N}(i), g^{(i)})$$

Agent i's observation

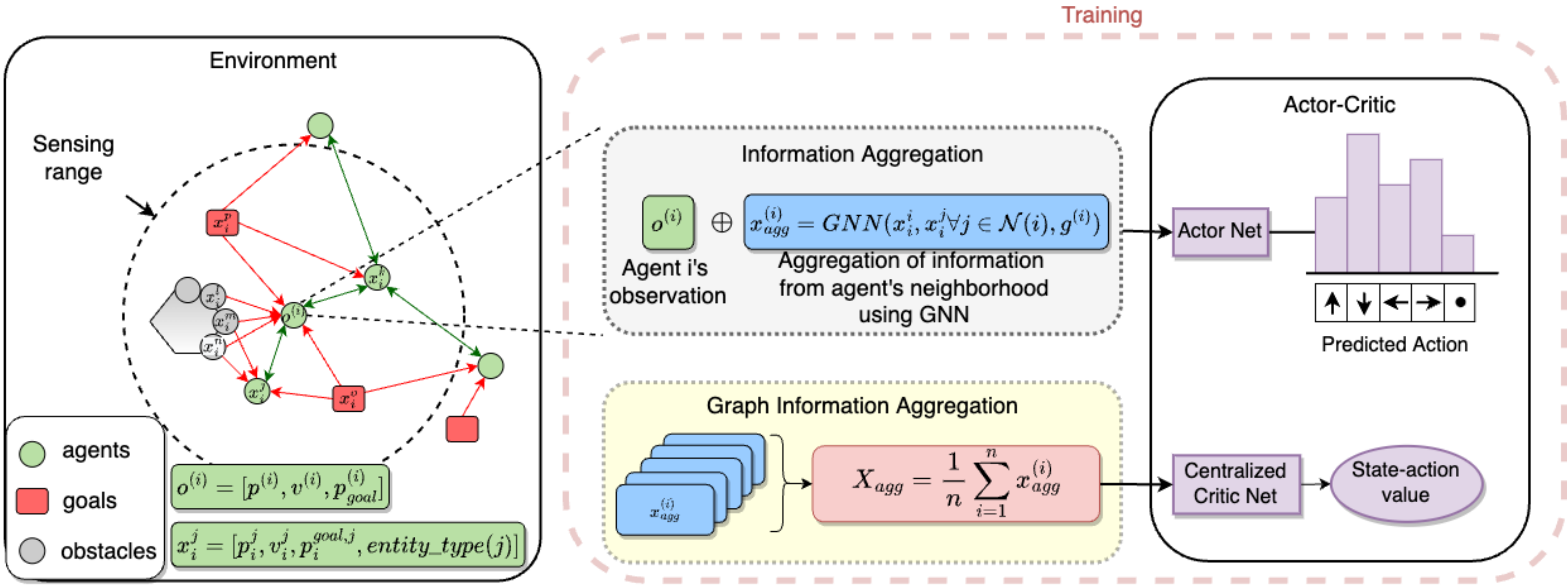
Aggregation of information from agent's neighborhood using GNN

$$X_{agg} = \frac{1}{n} \sum_{i=1}^{n} x_{agg}^{(i)}$$

Method


Environment
Sensing range
x_i^p
x_i^k
x_i^l
x_i^m
x_i^n
$o^{(i)}$
x_i^j
x_i^v
agents
goals
obstacles
$o^{(i)} = [p^{(i)}, v^{(i)}, p^{(i)}_{goal}]$
$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$
Information Aggregation
$o^{(i)}$
$\oplus$
$x^{(i)}_{agg} = GNN(x_i^i, x_i^j \forall j \in \mathcal{N}(i), g^{(i)})$
Agent i's observation
Aggregation of information from agent's neighborhood using GNN
Graph Information Aggregation
$x^{(i)}_{agg}$
$X_{agg} = \frac{1}{n} \sum_{i=1}^{n} x^{(i)}_{agg}$
Actor-Critic
Actor Net
↑ ↓ ← → •
Predicted Action
Centralized Critic Net
State-action value

Method


Training
Environment
Sensing range
x_i^p
x_i^k
x_i^l
x_i^m
x_i^n
$o^{(i)}$
x_i^j
x_i^o
agents
goals
obstacles
$o^{(i)} = [p^{(i)}, v^{(i)}, p_{goal}^{(i)}]$
$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$
Information Aggregation
$o^{(i)}$
$\oplus$
$x_{agg}^{(i)} = GNN(x_i^i, x_i^j \forall j \in \mathcal{N}(i), g^{(i)})$
Agent i's observation
Aggregation of information from agent's neighborhood using GNN
Graph Information Aggregation
$x_{agg}^{(i)}$
$X_{agg} = \frac{1}{n} \sum_{i=1}^{n} x_{agg}^{(i)}$
Actor-Critic
Actor Net
↑ ↓ ← → •
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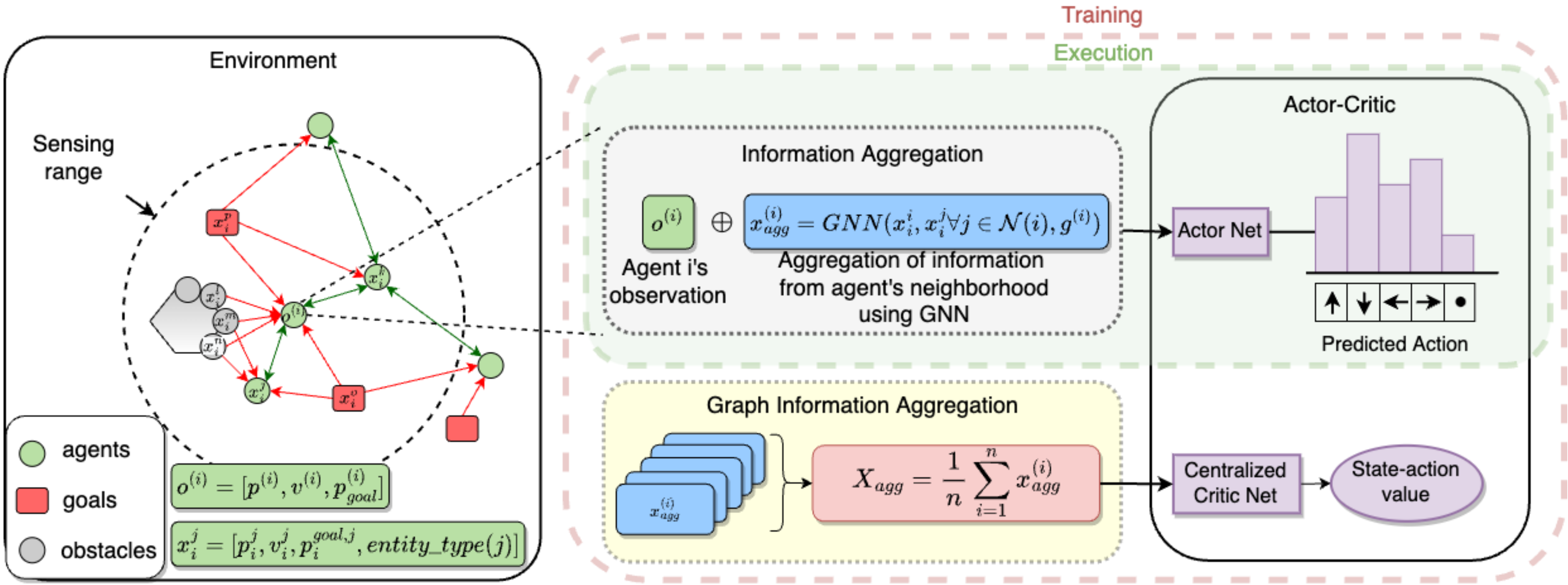
Method



Training

Execution

Environment

Sensing range

agents

goals

obstacles

$o^{(i)} = [p^{(i)}, v^{(i)}, p^{(i)}_{goal}]$

$x_i^j = [p_i^j, v_i^j, p_i^{goal,j}, entity\_type(j)]$

Information Aggregation

$o^{(i)}$ $\oplus$ $x^{(i)}_{agg} = GNN(x_i^i, x_i^j \forall j \in \mathcal{N}(i), g^{(i)})$

Agent i's observation

Aggregation of information from agent's neighborhood using GNN

Graph Information Aggregation

$x^{(i)}_{agg}$

$X_{agg} = \frac{1}{n}\sum_{i=1}^{n} x^{(i)}_{agg}$

Actor-Critic

Actor Net

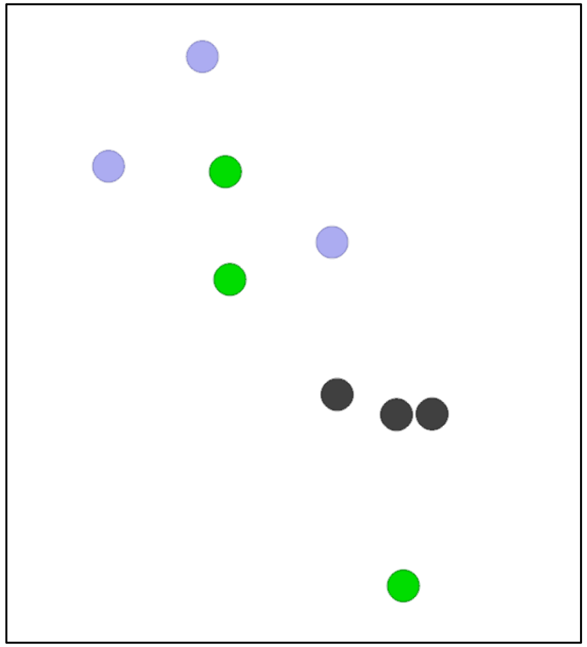
↑ ↓ ← → •

Predicted Action

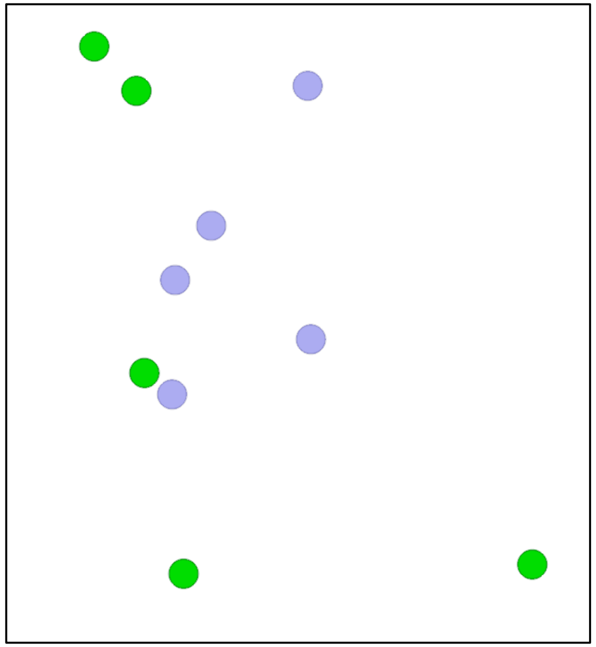
Centralized Critic Net

State-action value

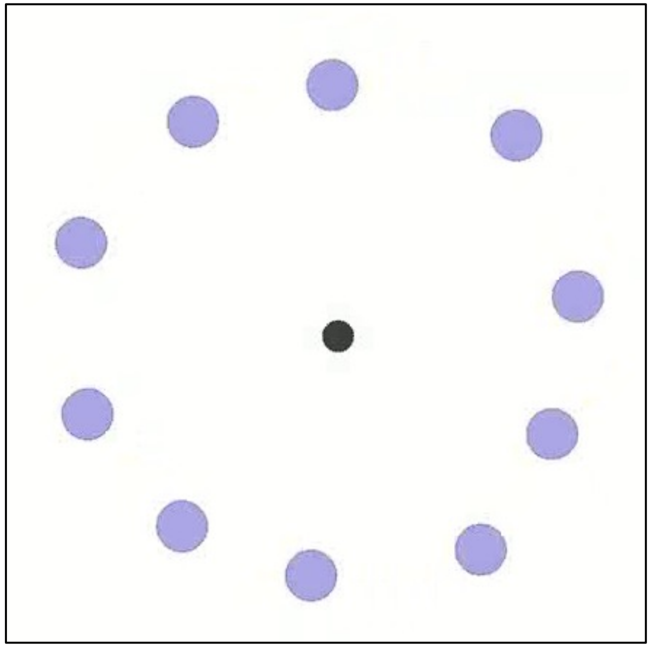
Experiments: Environments



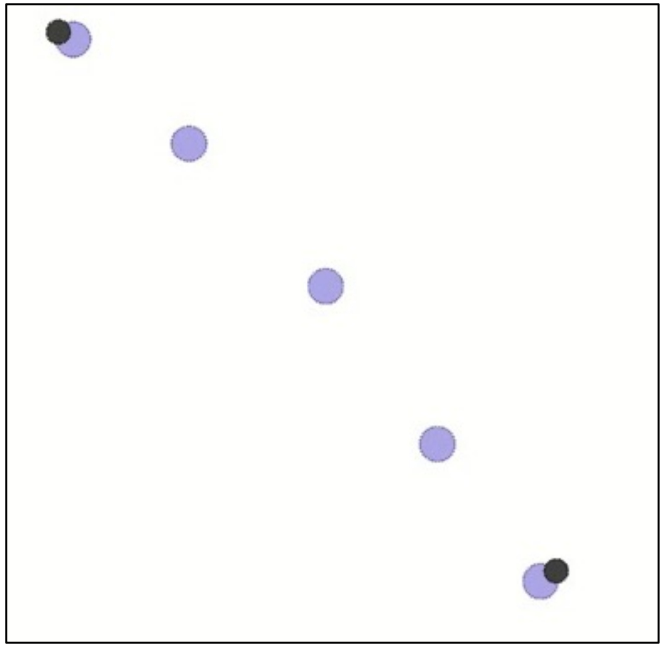
Target



Coverage

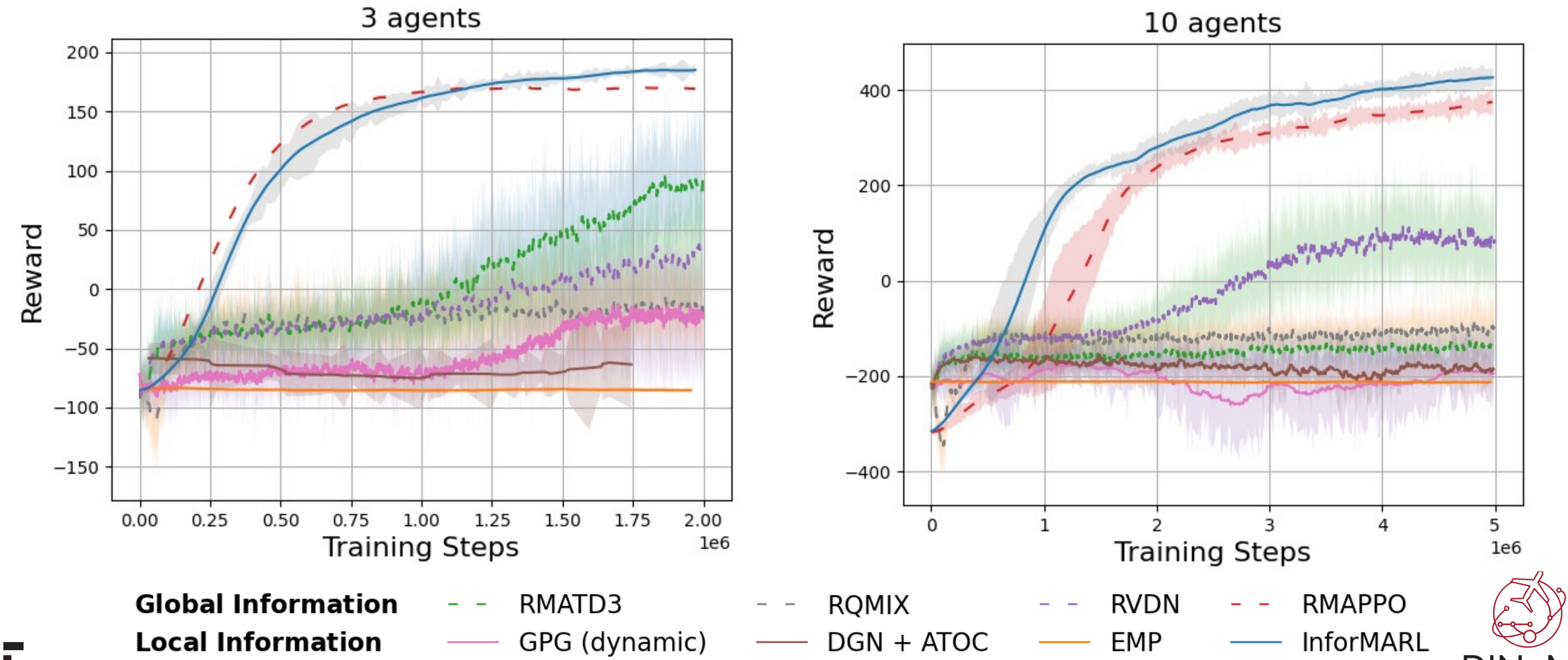


Formation



Line Formation

Experiments: Sample complexity



DINaMo

Experiments: Scalability

↑ - higher better
↓ - lower better

Testing	Training	n=3	n=7	n=10
m=3	Reward/agent ↑	63.21	63.25	62.87
	Avg. completion time ↓	0.39	0.40	0.40
	Avg. #collisions/agent ↓	0.40	0.46	0.49
	Completion rate ↑	100%	100%	99%
m=7	Reward/agent ↑	61.16	62.23	61.32
	Avg. completion time ↓	0.38	0.40	0.40
	Avg. #collisions/agent ↓	0.74	0.66	0.70
	Completion rate ↑	100%	100%	100%
m=10	Reward/agent ↑	58.59	58.23	58.67
	Avg. completion time ↓	0.38	0.40	0.39
	Avg. #collisions/agent ↓	0.95	0.88	0.87
	Completion rate ↑	100%	99%	100%
m=15	Reward/agent ↑	53.19	53.46	54.21
	Avg. completion time ↓	0.39	0.40	0.40
	Avg. #collisions/agent ↓	1.28	1.21	1.20
	Completion rate ↑	100%	99%	99%

DINaMo

Experiments: Other environments

Task environment	m	Metric	RMAPPO (global info)	InforMARL (local info)
Coverage	m=3	Avg. completion time ↓	0.34	0.36
		Completion rate ↑	100%	100%
	m=7	Avg. completion time ↓	0.42	0.43
		Completion rate ↑	100%	99%
Formation	m=3	Avg. completion time ↓	0.31	0.30
		Completion rate ↑	100%	100%
	m=7	Avg. completion time ↓	0.47	0.43
		Completion rate ↑	100%	100%
Line	m=3	Avg. completion time ↓	0.24	0.21
		Completion rate ↑	100%	100%
	m=7	Avg. completion time ↓	0.38	0.36
		Completion rate ↑	100%	100%

↑ - higher better
↓ - lower better

Conclusions

- InforMARL uses a graph neural network (GNN)-based architecture for **scalable** multi-agent RL in a **decentralized** fashion.
- InforMARL is **transferable** to scenarios with a different number of entities in the environment than what it was trained on.
- InforMARL has **better sample complexity** than most other standard MARL algorithms with global observations