Summary of: Learning Decentralized Controllers for Robotic Swarms with Graph Neural Networks

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Outline

- Motivation
- Background
- Model
- Theoretical Results
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- Summary
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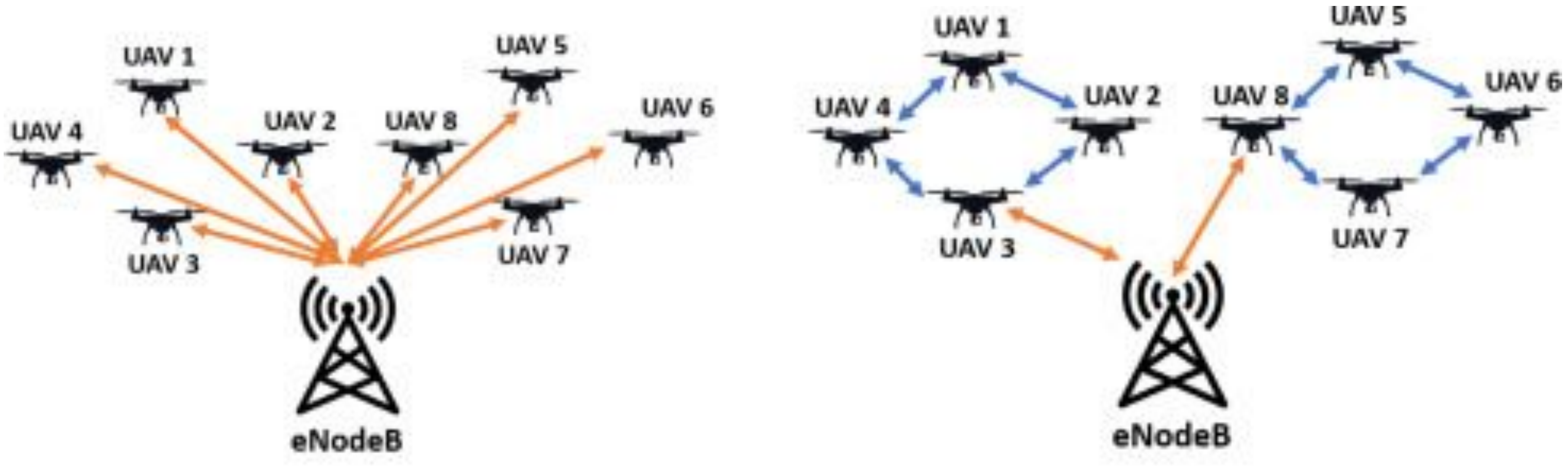
Motivation



(a) Centralized Model (b) Decentralized Model

Relevant Background Literature

Referenced Papers:

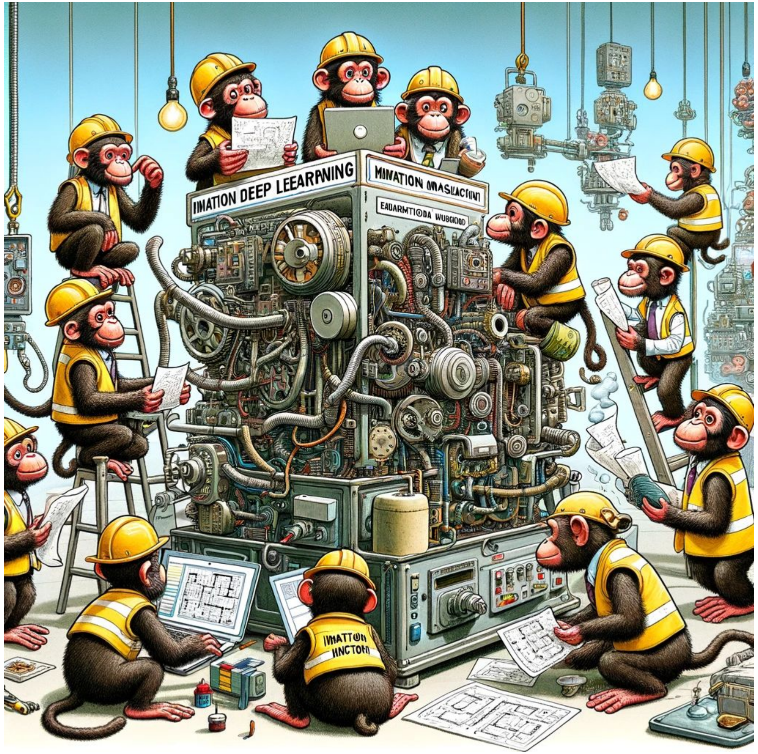
- Imitation Control - J. Paulos, S. W. Chen, D. Shishika, and K. Vijay. Decentralization of multiagent policies by learning what to communicate. In 2019 IEEE International Conference on Robotics and Automation (ICRA), Montreal, May 2019.
- Aggregation NN - F. Gama, A. G. Marques, G. Leus, and A. Ribeiro. Convolutional neural network architectures for signals supported on graphs. IEEE Trans. Signal Process., 67(4):1034–1049, Feb. 2019.
- Local Controller/Global Controller - H. G. Tanner, A. Jadbabaie, and G. J. Pappas. Stable flocking of mobile agents part ii: dynamic topology. In Decision and Control, 2003. Proceedings. 42nd IEEE Conference on, volume 2, pages 2016–2021. IEEE, 2003.

Main Contribution:

- Train Graph NN to do flocking

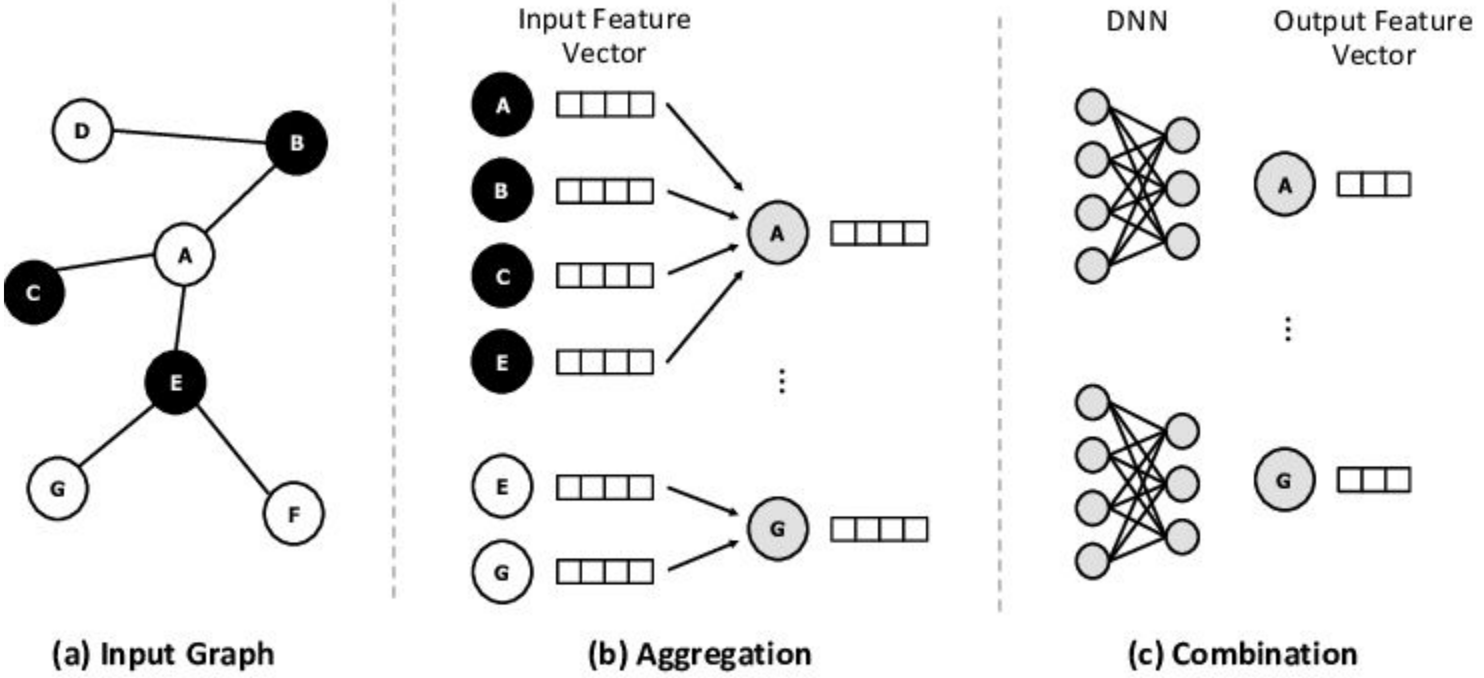
Imitation Control

Monkey See, Monkey Do



Presenter generated with Dalle3

Aggregation Graph Neural Networks



Global Controller

$$U(r_i, r_j) = \begin{cases} \frac{1}{\|r_{ij}\|^2} - \log(\|r_{ij}\|^2) & \text{if } \|r_{ij}\| > \rho \\ \frac{1}{\rho^2} - \log(\rho^2) & \text{otherwise} \end{cases}$$

$$\nabla_{r_i} U(r_i, r_j) = \begin{cases} -\frac{2r_{ij}}{\|r_{ij}\|^4} + \frac{2r_{ij}}{\|r_{ij}\|^2} & \text{if } \|r_{ij}\| > \rho \\ 0 & \text{otherwise} \end{cases}$$

$$u_i^* = -\sum_{j=1}^{N} (v_i - v_j) - \sum_{j=1}^{N} \nabla_{r_i} U(r_i, r_j).$$

Local Controller

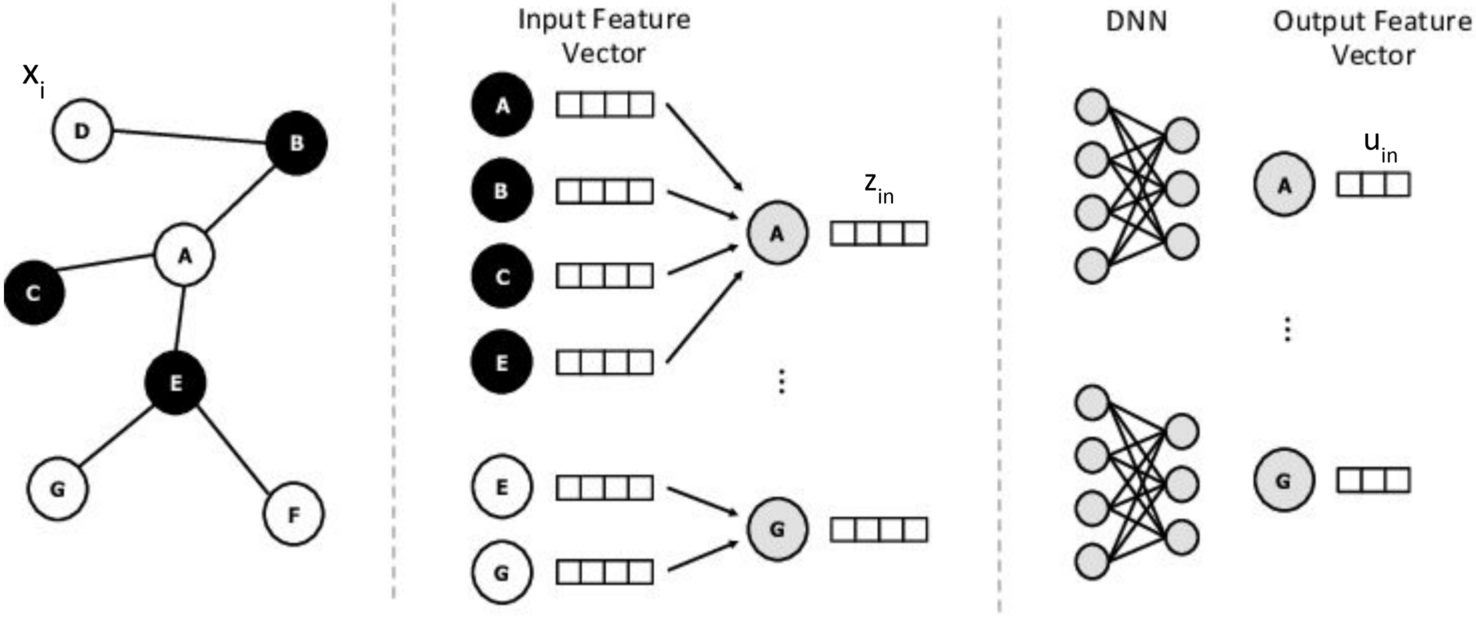
$$u_i^\dagger = -\sum_{j \in \mathcal{N}_i} (v_i - v_j) - \sum_{j \in \mathcal{N}_i} \nabla_{r_i} U(r_i, r_j).$$

Back to the Future!

Summary

$$\sigma^{(\ell)}\left(H^{(\ell)} z_{in}^{(\ell-1)}\right)$$

y



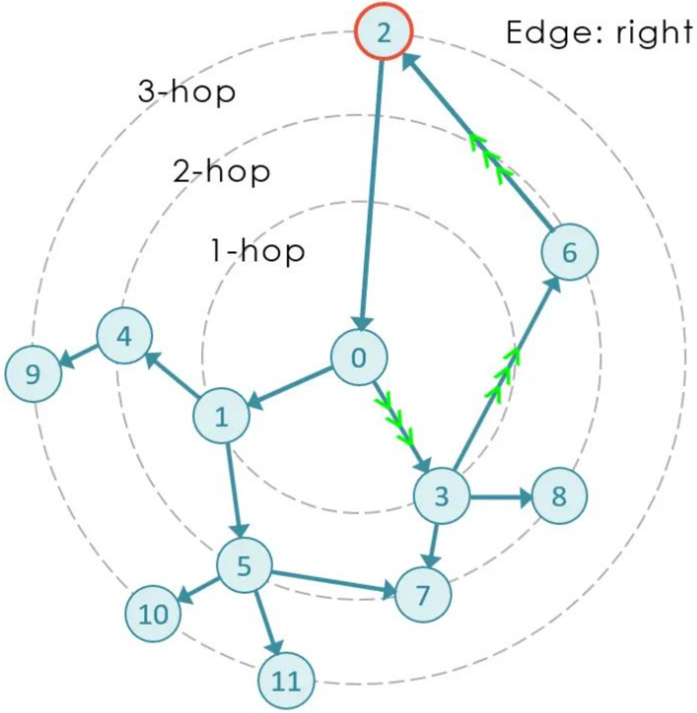
(a) Input Graph (b) Aggregation (c) Combination

S_n

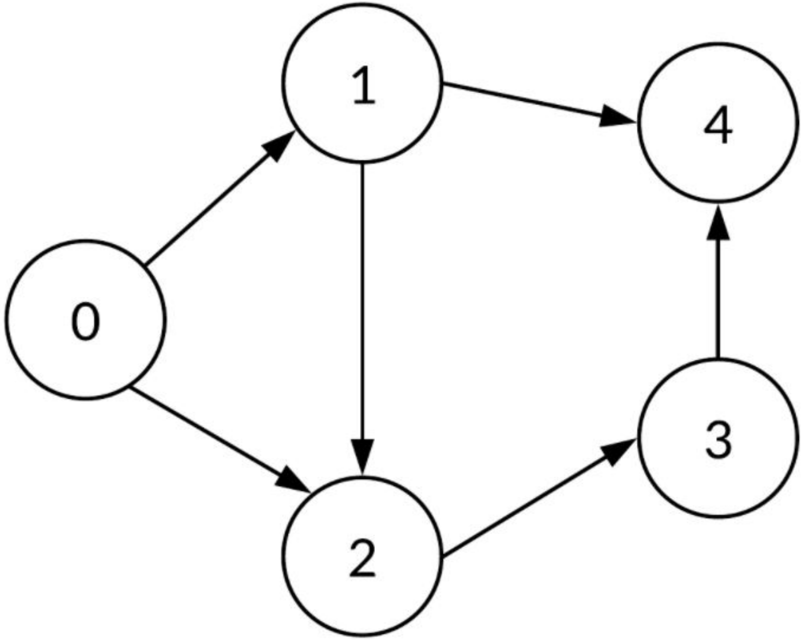
k-hops

$$\mathcal{N}_{in}^{k} = \{j' \in \mathcal{N}_{j(n-1)}^{k-1} \,|\, j' \in \mathcal{N}_{in}\}$$

$$\mathcal{H}_{in} = \bigcup_{k=0}^{K-1} \{x_{j(n-k)} \,:\, j \in \mathcal{N}_{in}^{k}\}$$



Graph Shift Operator



~~Adjacency Matrix~~ Graph Shift Operator [S_n]

	0	1	2	3	4
0	0	1	1	0	0
1	0	0	1	0	1
2	0	0	0	1	0
3	0	0	0	0	1
4	0	0	0	0	0

Feature Matrix

$$y_{kn} = S_n y_{(k-1)(n-1)},$$

$$[y_{0n}]_i = [x_n]_i = x_{in}^T$$

$$z_{in} = \left[[y_{0n}]_i\,; [y_{1n}]_i\,; \ldots ; \left[y_{(K-1)n}\right]_i\right]$$

Feature Vector

$$[x_n]_i = \left[\sum_{j \in \mathcal{N}_i} (v_{i,n} - v_{j,n}), \sum_{j \in \mathcal{N}_i} \frac{r_{ij,n}}{\|r_{ij,n}\|^4}, \sum_{j \in \mathcal{N}_i} \frac{r_{ij,n}}{\|r_{ij,n}\|^2} \right]$$

Final Control / Loss Function

$$z_{in}^{(\ell)} = \sigma^{(\ell)}\left(H^{(\ell)} z_{in}^{(\ell-1)}\right)$$

$$H^* = \operatorname*{argmin}_H \sum_{(x_n, \pi^*(x_n)) \in \mathcal{T}} \mathcal{L}(u_n, u_n^*)$$

DAgger (Dataset Aggregation)

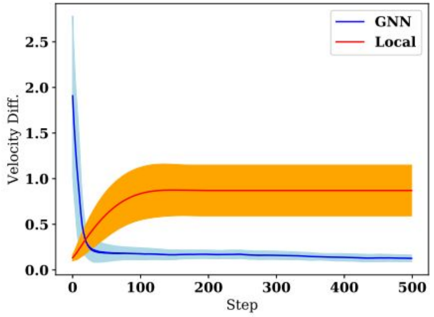
For each iteration:

- Generate a trajectory where, for each timestep, the expert policy is selected with probability β and the learner's policy is selected with probability 1 - β.
- Train using the generated trajectory.
- Decay β by a factor of γ until it reaches β_{min}.

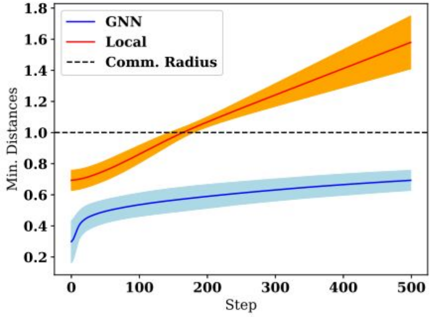
Theoretical Results

- Leans on the previous theoretical results demonstrating global controller convergence.
- Doesn’t show much theory as to why training works.

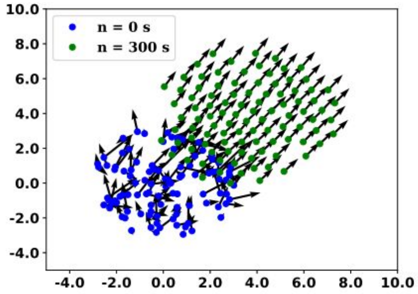
Simulation Results



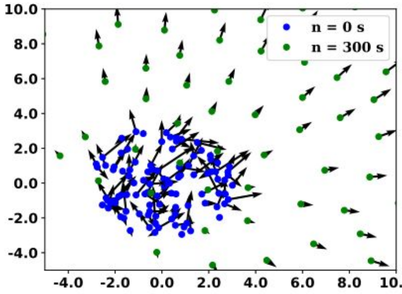
(a) Average difference in velocities



(b) Average minimum distance to a neighbor

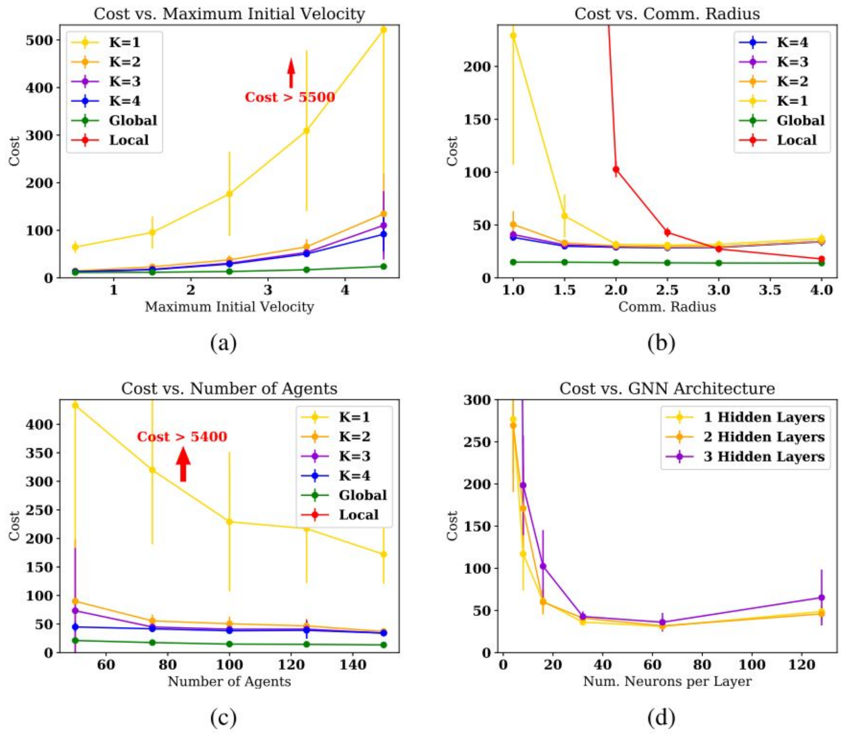


(c) Flock positions using the GNN



(d) Flock positions using the local controller

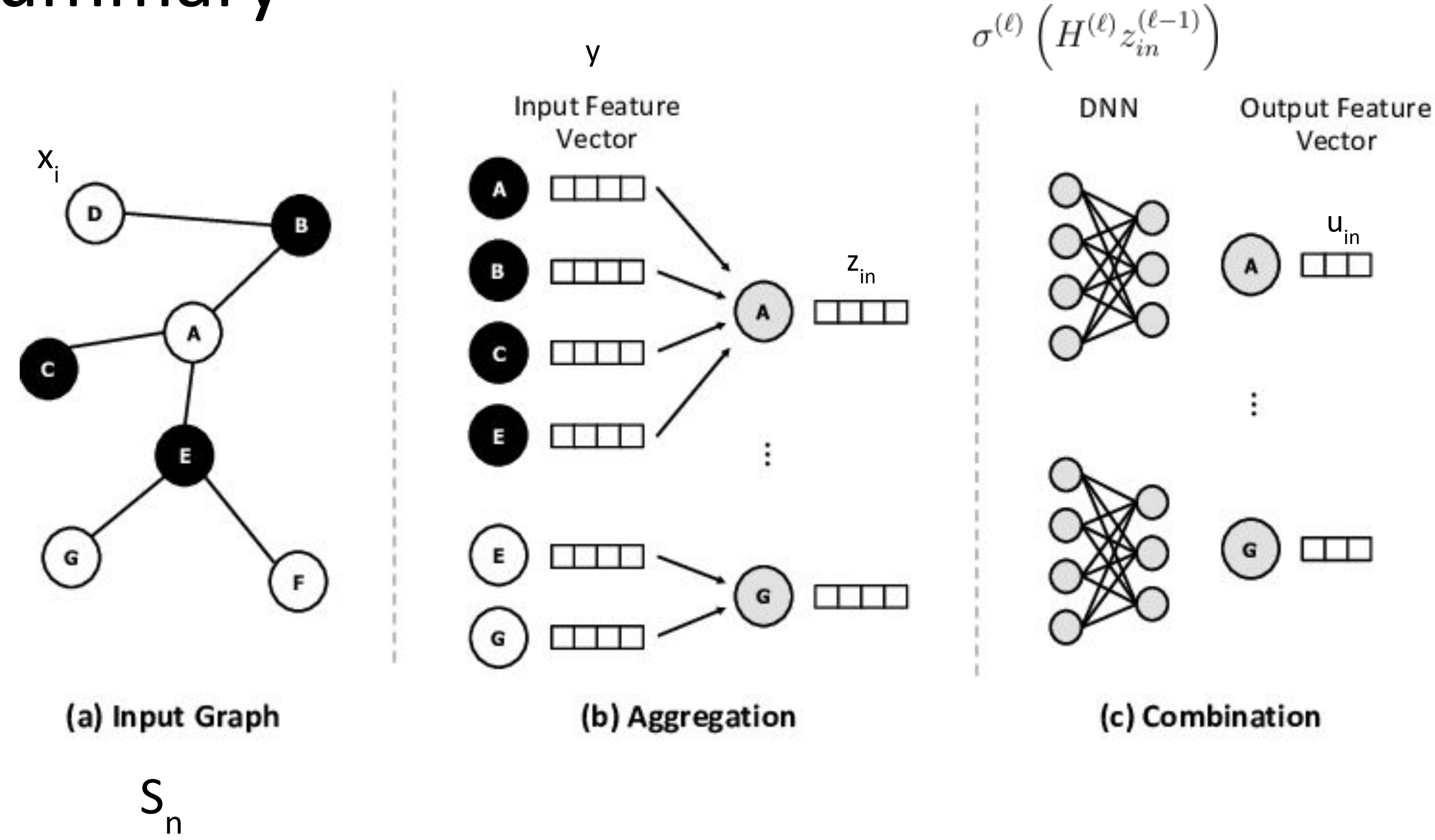
Simulation Results (Continued)



My Results/Their Results Again

Their code can be found at:
https://github.com/katetolstaya/multiagent_gnn_policies/tree/master

Summary



$\sigma^{(\ell)}\left(H^{(\ell)} z_{in}^{(\ell-1)}\right)$
y
Input Feature Vector
DNN
Output Feature Vector
x_i
D
B
A
C
E
G
F
z_{in}
u_{in}
(a) Input Graph
(b) Aggregation
(c) Combination
S_n

Future Work

- Hardware verification
- Many other imitation learning tasks
- Different Graph NN Architectures