Consensus Based Distributed Multi-Agent Systems

Presented by : Chandima Fernando

Credits

- Ge, X., Yang, F. and Han, Q.L., 2017. Distributed networked control systems: A brief overview. *Information Sciences*, *380*, pp.117-131.
- Ren, W., Beard, R.W. and Atkins, E.M., 2007. Information consensus in multivehicle cooperative control. *IEEE Control Systems*, *27*(2), pp.71-82.

Motivation !

Overview

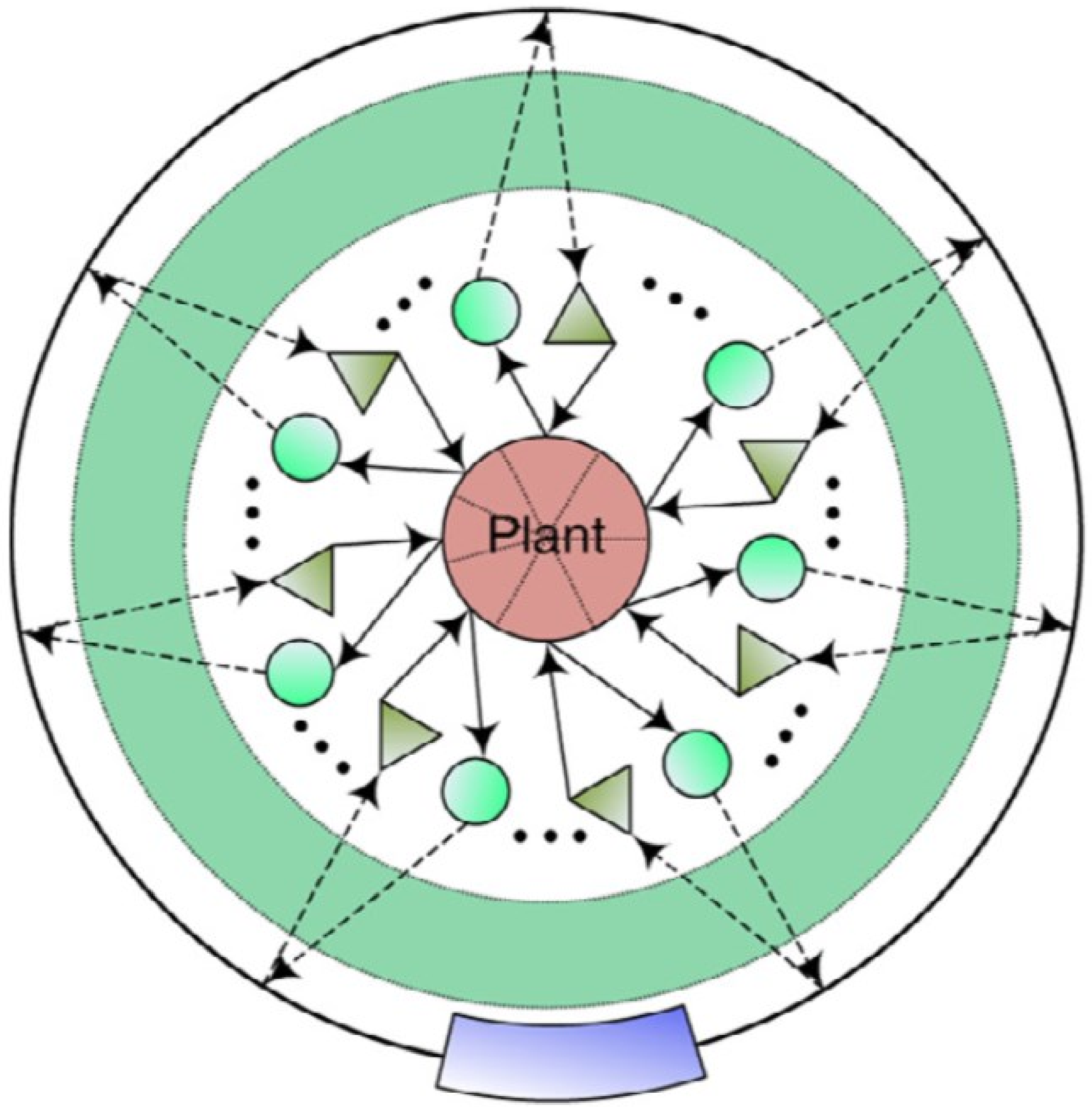
NEXT

- Types of Systems
    - Good and Bad
- Distributed Multi Agent Systems
    - Challenges in Distributed MAS
- Methodologies for DMASs
    - Graph Theory
    - State Based Agent Modeling
- Consensus Algorithms

Types of Systems

Centralized configuration

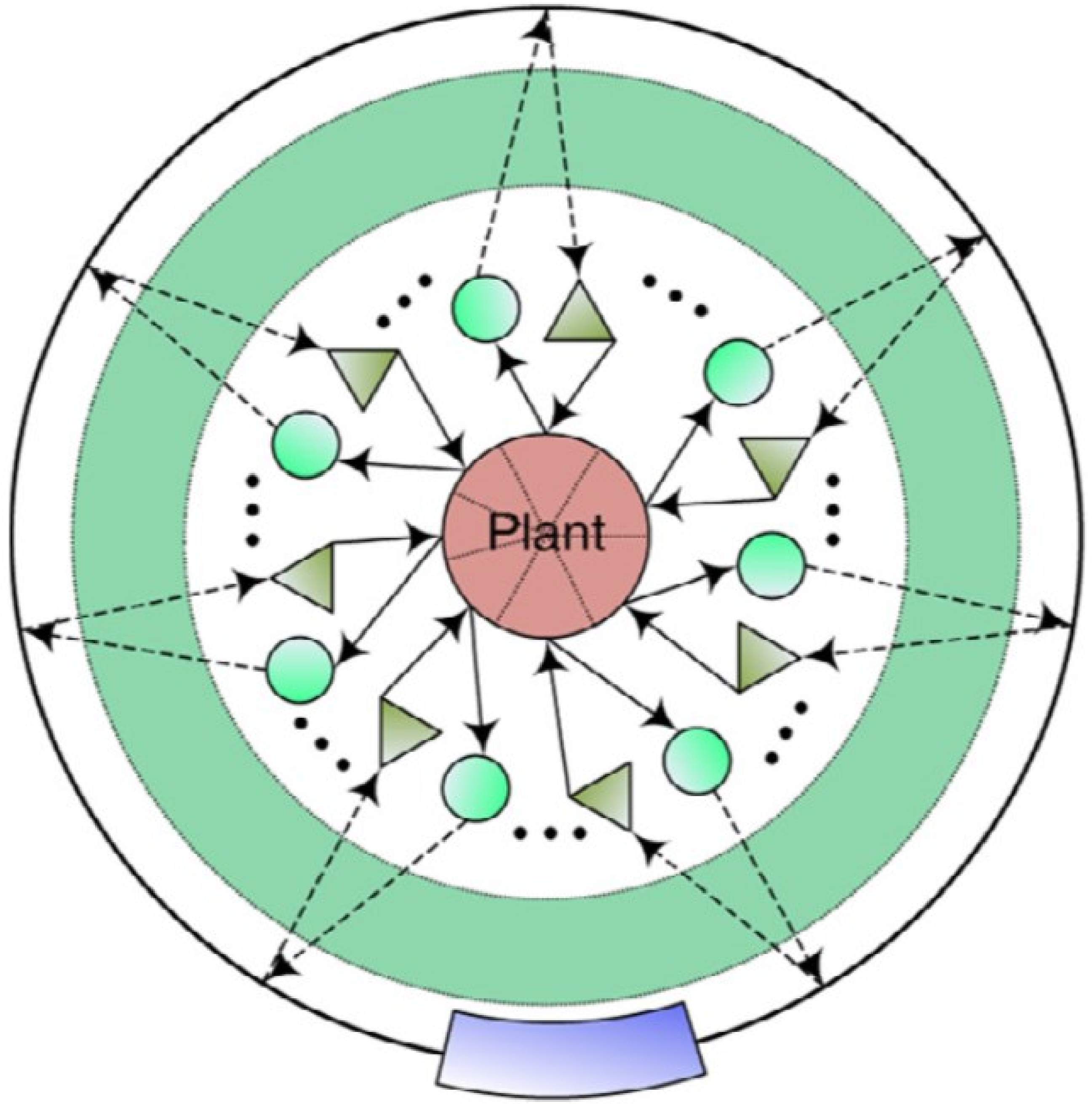
- All agents are required send the information back to a remote controller node and send the control back to each agent.



Types of Systems

Centralized configuration - Advantages

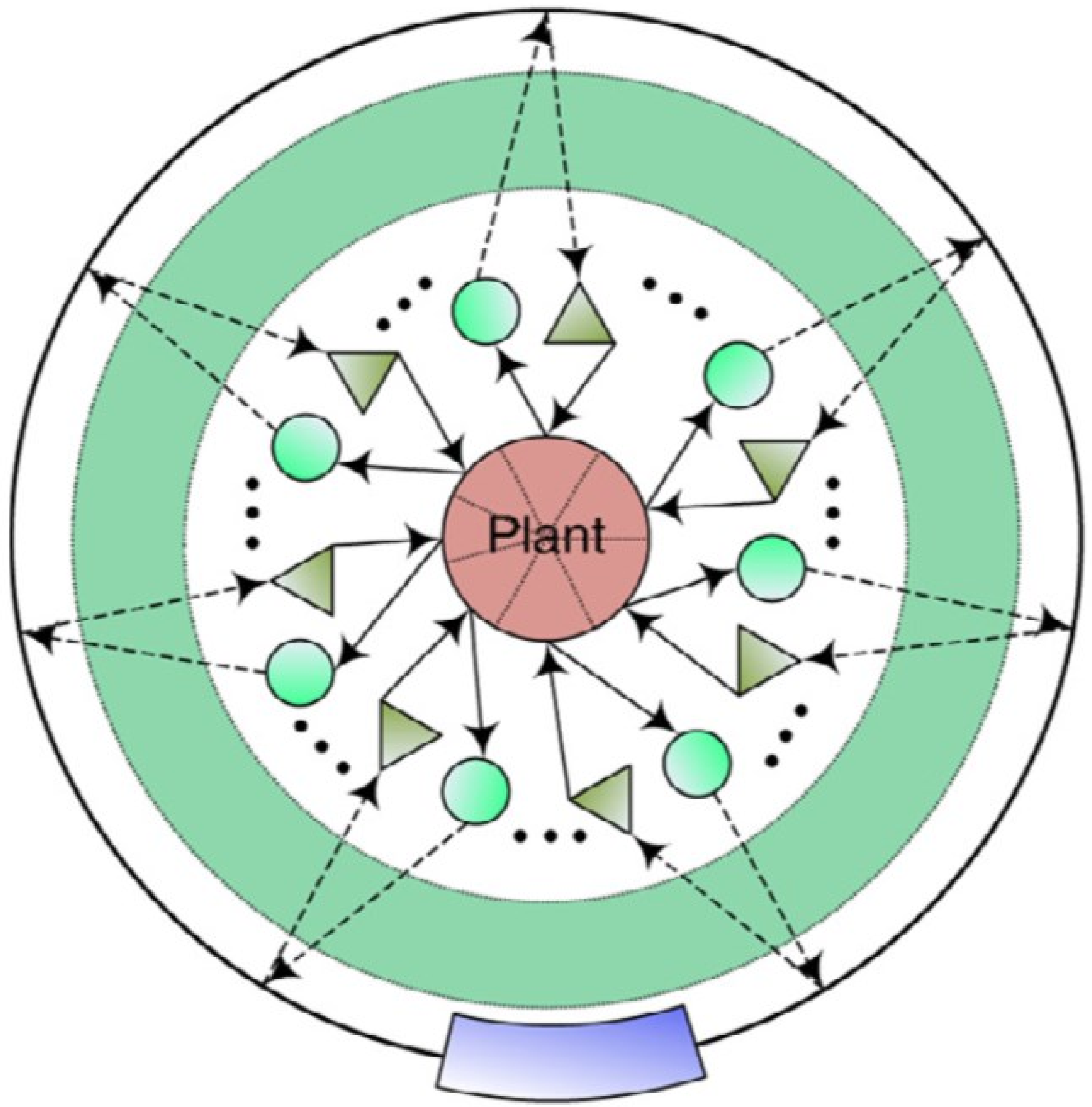
- Since all agent information is available at the controller side , control performance may be generally optimal.
- Analysis is relatively easy



Types of Systems

Centralized configuration - Disadvantages

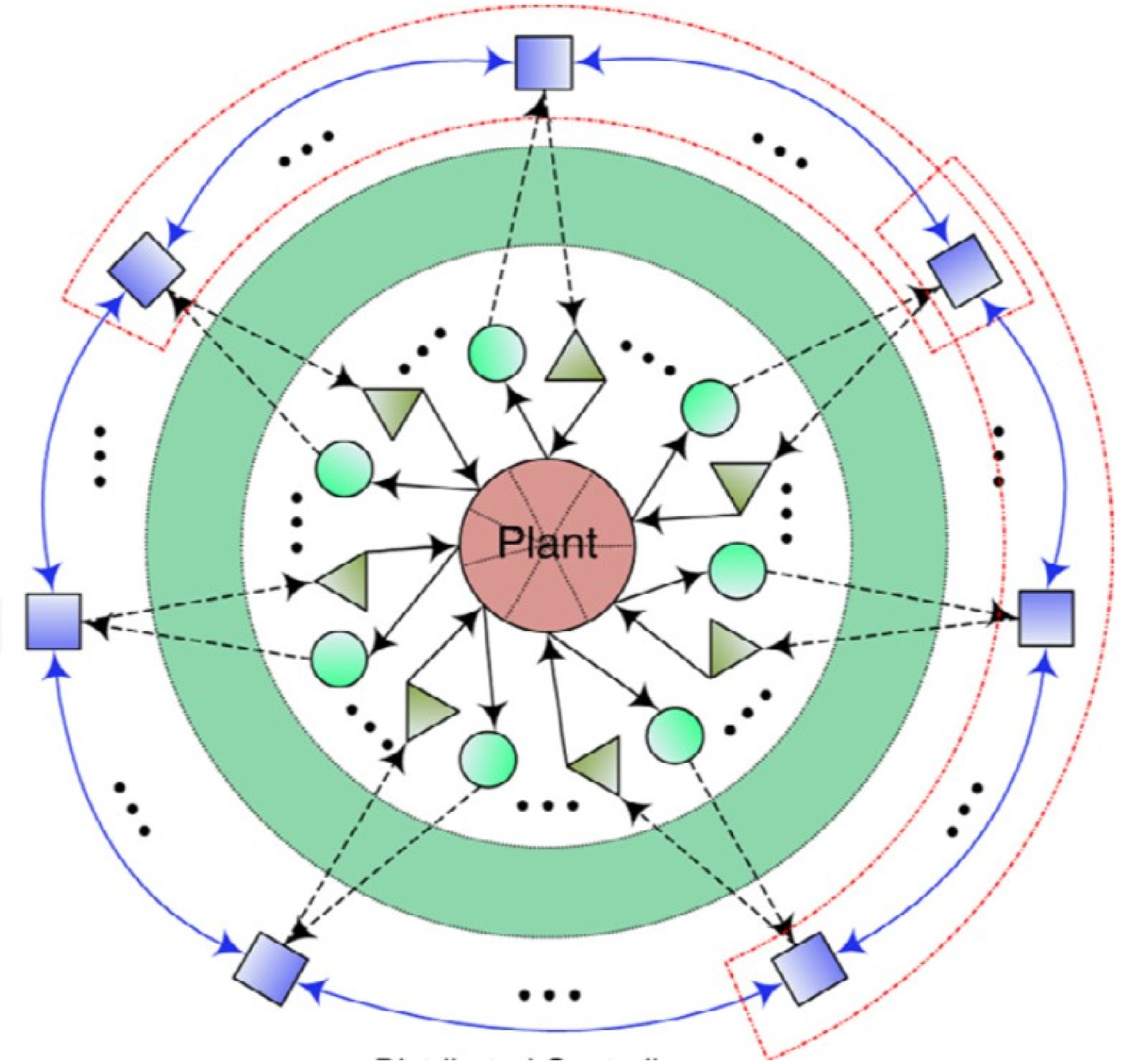
- Failure of the central processing unit -> failure of all agents
- High cost of collecting data from individual agent
- Increased computational burden



Types of Systems

Distributed configuration

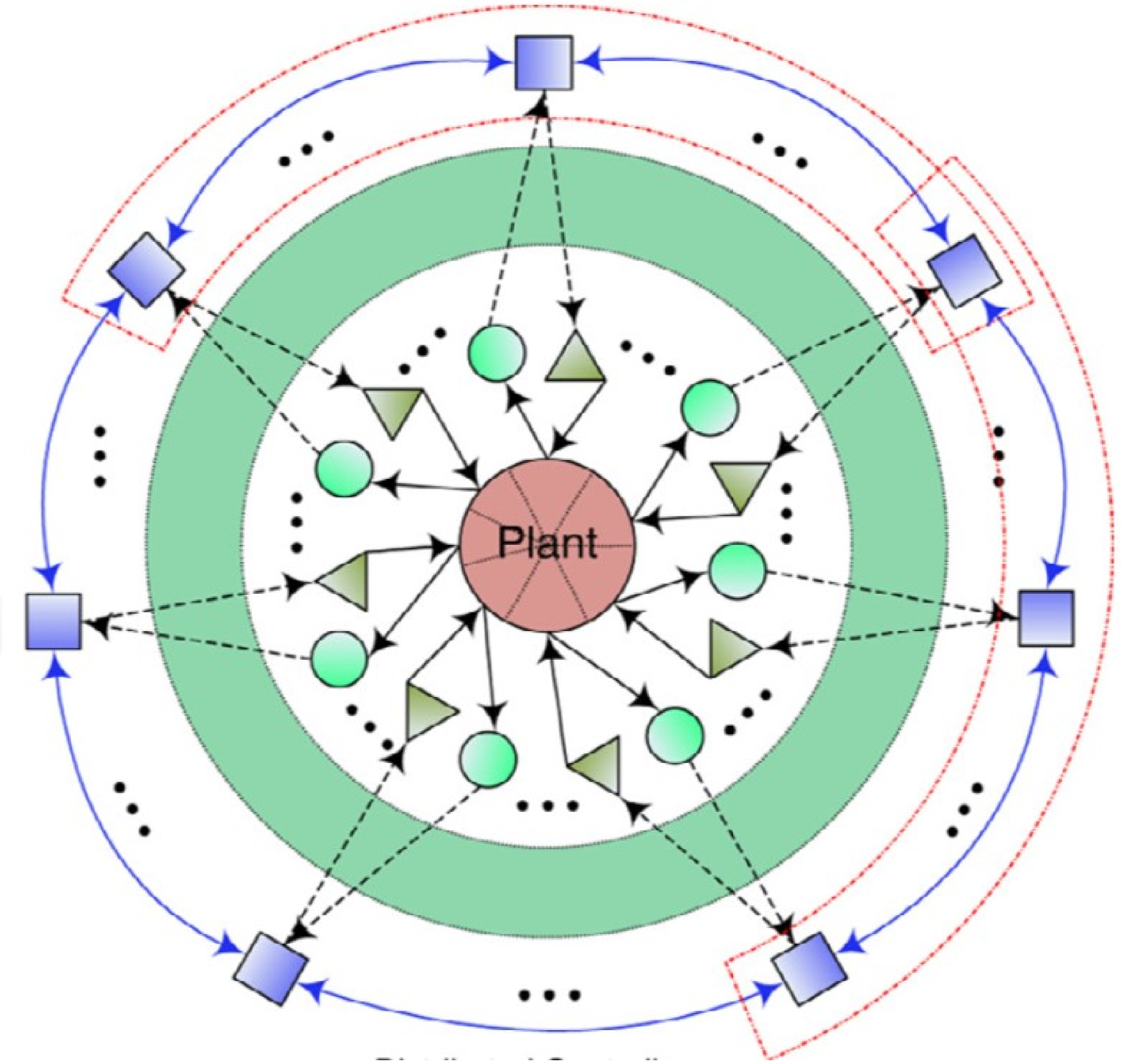
- Environment information through local communication.
- Each agent locally performs its local computation.
- Each agent acts individually.



Types of Systems

Distributed configuration

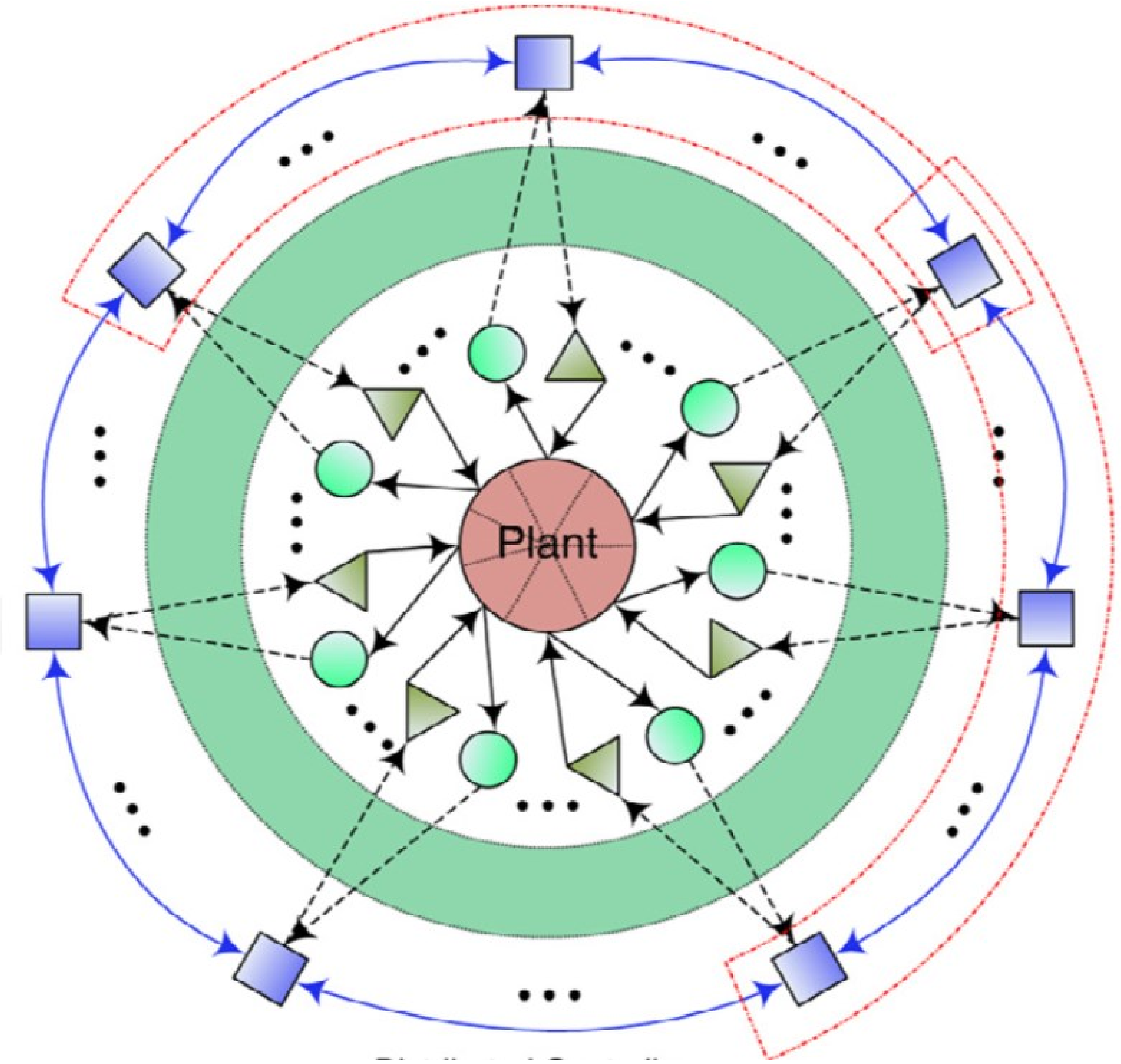
- Information of each agent is exchanged among other agents.
- Systems usually consists of a large number of simple interacting agents.



Types of Systems

Distributed configuration - Advantages

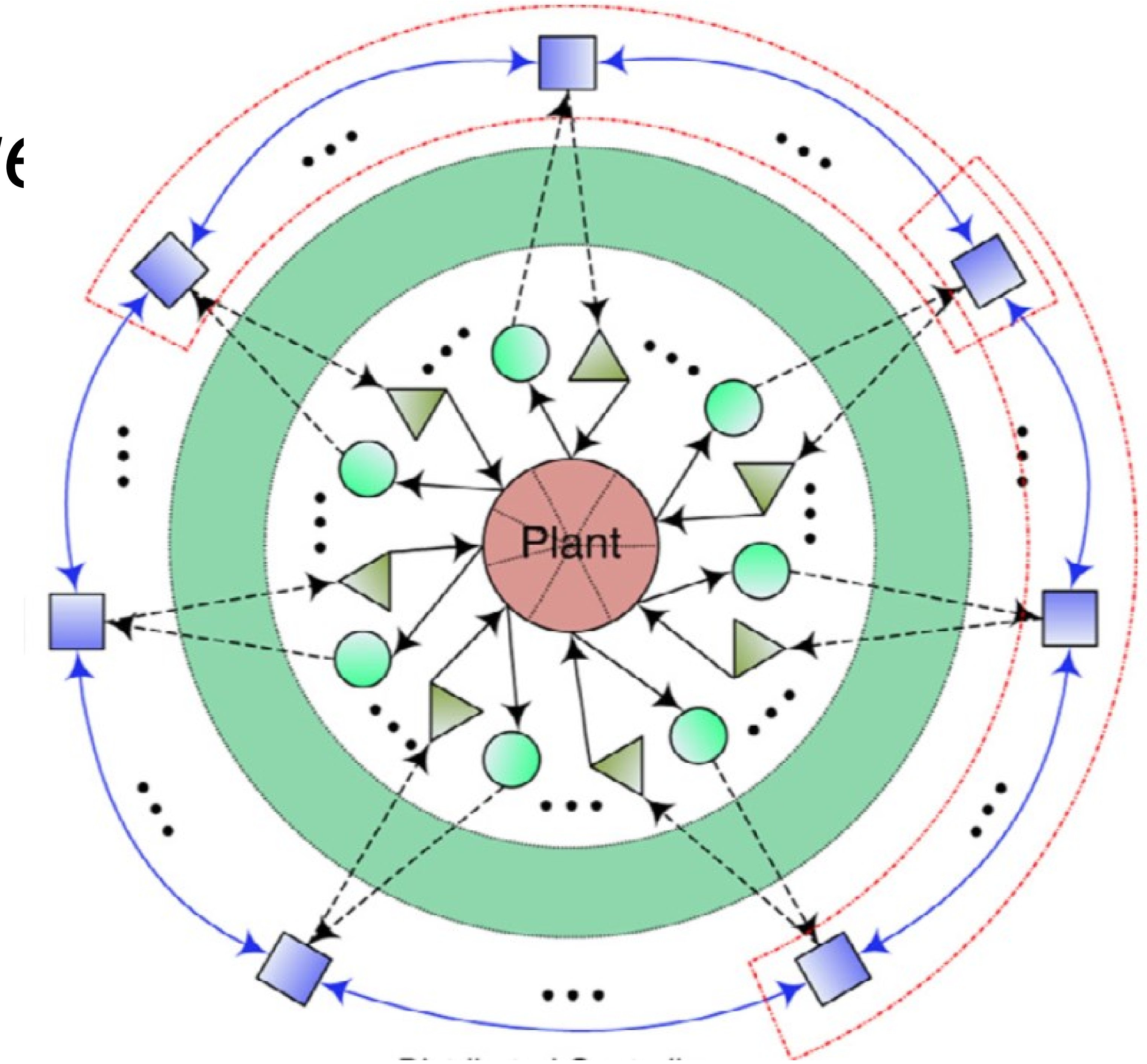
- Alleviates computation burden.
- Scalability.
- Robustness.



Types of Systems

Distributed configuration - Disadvantage

- Sub-optimal solutions
- Difficult to analyze stability properties



Overview

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  - State Based Agent Modeling
- Consensus Algorithms

Challenging issues in Distributed MAS

communication challenges

- *Network-induced delays*
  - Computational delays in agent components, such as sensors, controllers and actuators
  - Network access delays in network
  - Transmission delays in the communication network

  - May lead to deteriorated agent performance.

Challenging issues in Distributed MAS

communication challenges

- *Data packet dropouts*
  - Random and deterministic
- *Data packet disorder*
  - Packets arriving at different temporal orders

Challenging issues in Distributed MAS

communication challenges

- *Quantization error*
  - When agents decode the transmitted analog signals
- *Time-varying network topology*
  - Agent mobility, agent failure and agent adding

Challenging issues in Distributed MAS

computation challenges

- Modeling of communication networks
- Increase of number of agents
- Increase of numbers of agents components (sensors, controllers and actuators)
- Complexity of control algorithms

Challenging issues in Distributed MAS

control challenges

- Resources are limited and often shared between multiple agents
- Agents resources are limited
- Real-time distributed scheduling algorithms are needed

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Methodologies for Distributed MAS

State Based Agent Modeling

- Dynamics of an agent can be modeled using physics

$x_1 = x(t)$ be the position.

$x_2 = \dot{x}(t)$ be the velocity.

$x_3 = \ddot{x}(t)$ be the acceleration of an agent at time t.

Methodologies for Distributed MAS

State Based Agent Modeling

- Assume we can control the acceleration directly with a force u,

$$x_1 = x(t)\ ;\ x_2 = \dot{x}(t)\ ;\ x_3 = \ddot{x}(t) = u$$

- After substitution,

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = u$$

Methodologies for Distributed MAS

State Based Agent Modeling

Represent the same

$$\dot{x}_1 = x_2 \,;\; \dot{x}_2 = u$$

With matrix notation :

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{matrix} x_1 \\ x_2 \end{matrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$

$$\dot{x} = Ax + Bu$$

Methodologies for Distributed MAS

Notions of graph theory

Let the multi-agent communication system be represented by a N node graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, with a set of nodes representing each agent $\mathcal{V} = \{v_1, v_2, .., v_N\}$. An edge of $\mathcal{G}$ represents communication between the agents and is denoted by $\varepsilon_{ij} = (v_i, v_j)$. The set of edges $\mathcal{E} \subseteq \mathcal{V} \times \mathcal{V}$ can be

Methodologies for Distributed MAS

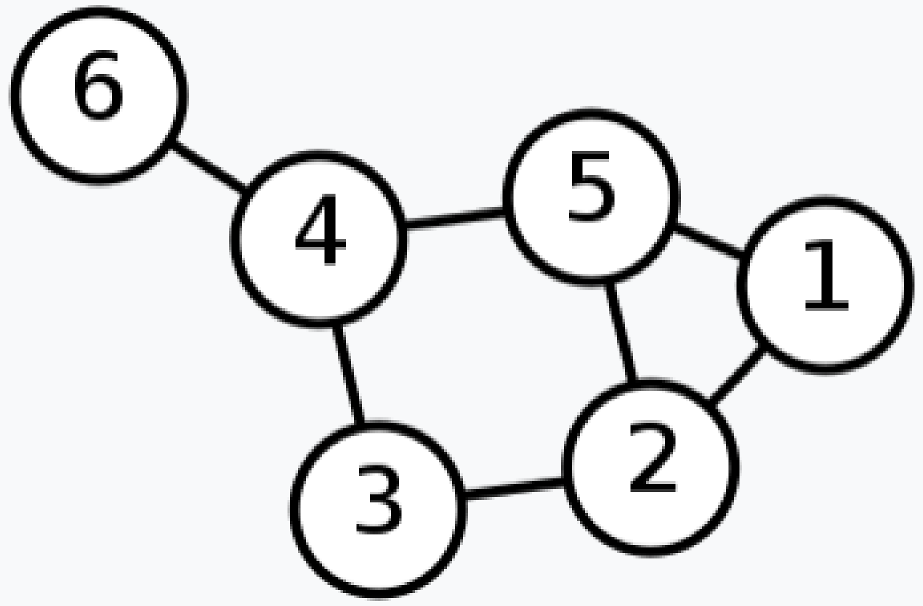
Notions of graph theory

$\mathcal{A} = [a_{ij}]$ of the graph $\mathcal{G}$ is defined as

$$a_{ij} = \begin{cases} 1, & \varepsilon_{ij} \in \mathcal{E} \\ 0, & \text{otherwise.} \end{cases}$$

Methodologies for Distributed MAS

Notions of graph theory

Labeled graph	Degree matrix	Adjacency matrix
	$\begin{pmatrix} 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$

Methodologies for Distributed MAS

Notions of graph theory

Degree matrix	Adjacency matrix		Laplacian matrix
$\begin{pmatrix} 2&0&0&0&0&0\\ 0&3&0&0&0&0\\ 0&0&2&0&0&0\\ 0&0&0&3&0&0\\ 0&0&0&0&3&0\\ 0&0&0&0&0&1 \end{pmatrix}$ −	$\begin{pmatrix} 0&1&0&0&1&0\\ 1&0&1&0&1&0\\ 0&1&0&1&0&0\\ 0&0&1&0&1&1\\ 1&1&0&1&0&0\\ 0&0&0&1&0&0 \end{pmatrix}$	=	$\begin{pmatrix} 2&-1&0&0&-1&0\\ -1&3&-1&0&-1&0\\ 0&-1&2&-1&0&0\\ 0&0&-1&3&-1&-1\\ -1&-1&0&-1&3&0\\ 0&0&0&-1&0&1 \end{pmatrix}$

Consensus Algorithms

- Consensus means agreement
  - These algorithms allow agents to agree on a shared state.
- This shared state can be
  - Position
  - Velocity
  - Information on a global map
  - A sensor value

Consensus Algorithms

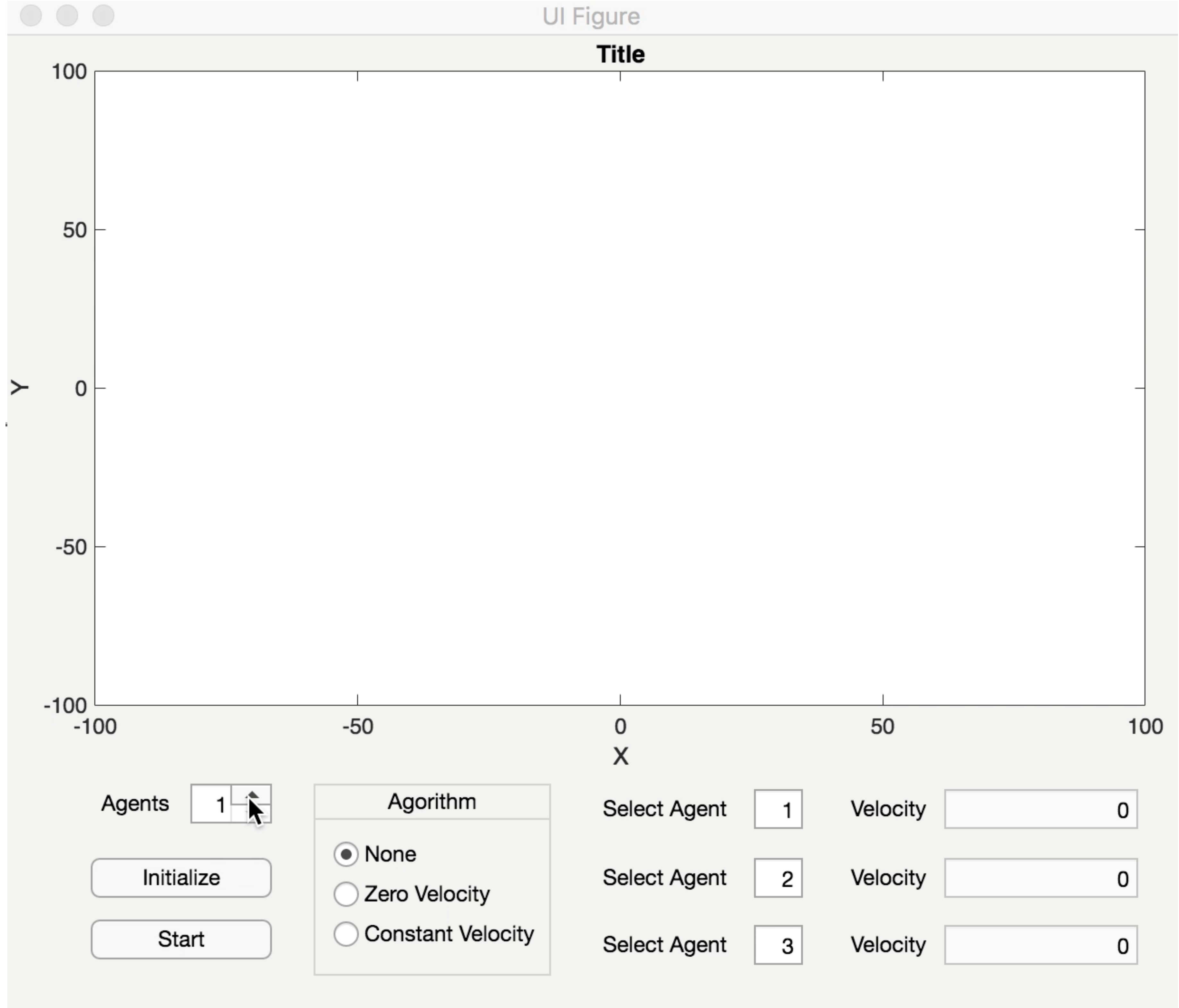
- Basic algorithm looks like this :

$$u_i(t) = \sum_{j=1}^{n} a_{ij}\left[r_j(t) - r_i(t)\right]$$

Consensus Algorithms

Position Consensus

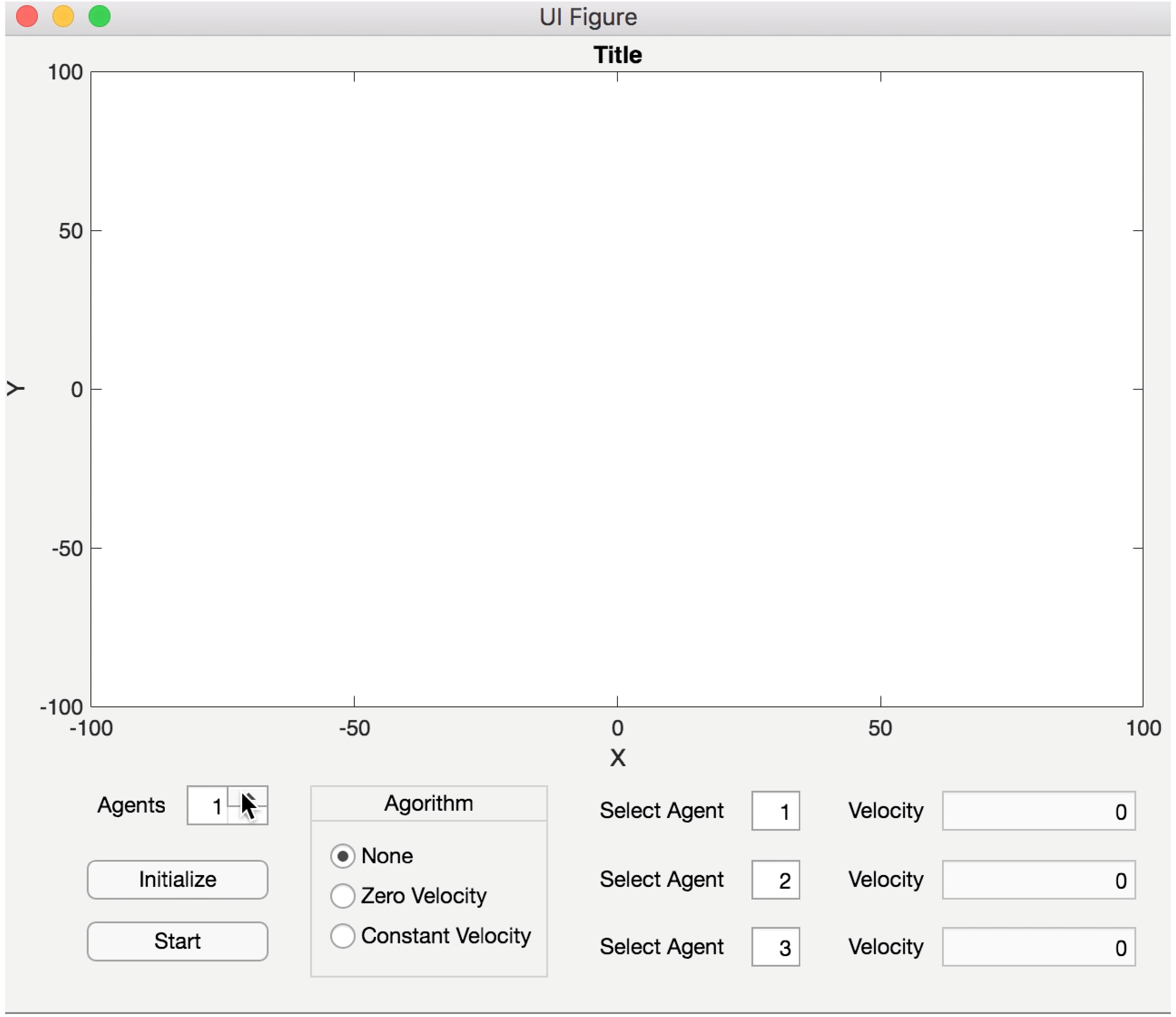
$$u_i = -\sum_{j=1}^{n} a_{ij}(r_i - r_j) - \alpha v_i,$$



Consensus Algorithms

Velocity Consensus

$$u_i = -\sum_{j=1}^{n} a_{ij}[(r_i - r_j) + \alpha(v_i - v_j)],$$

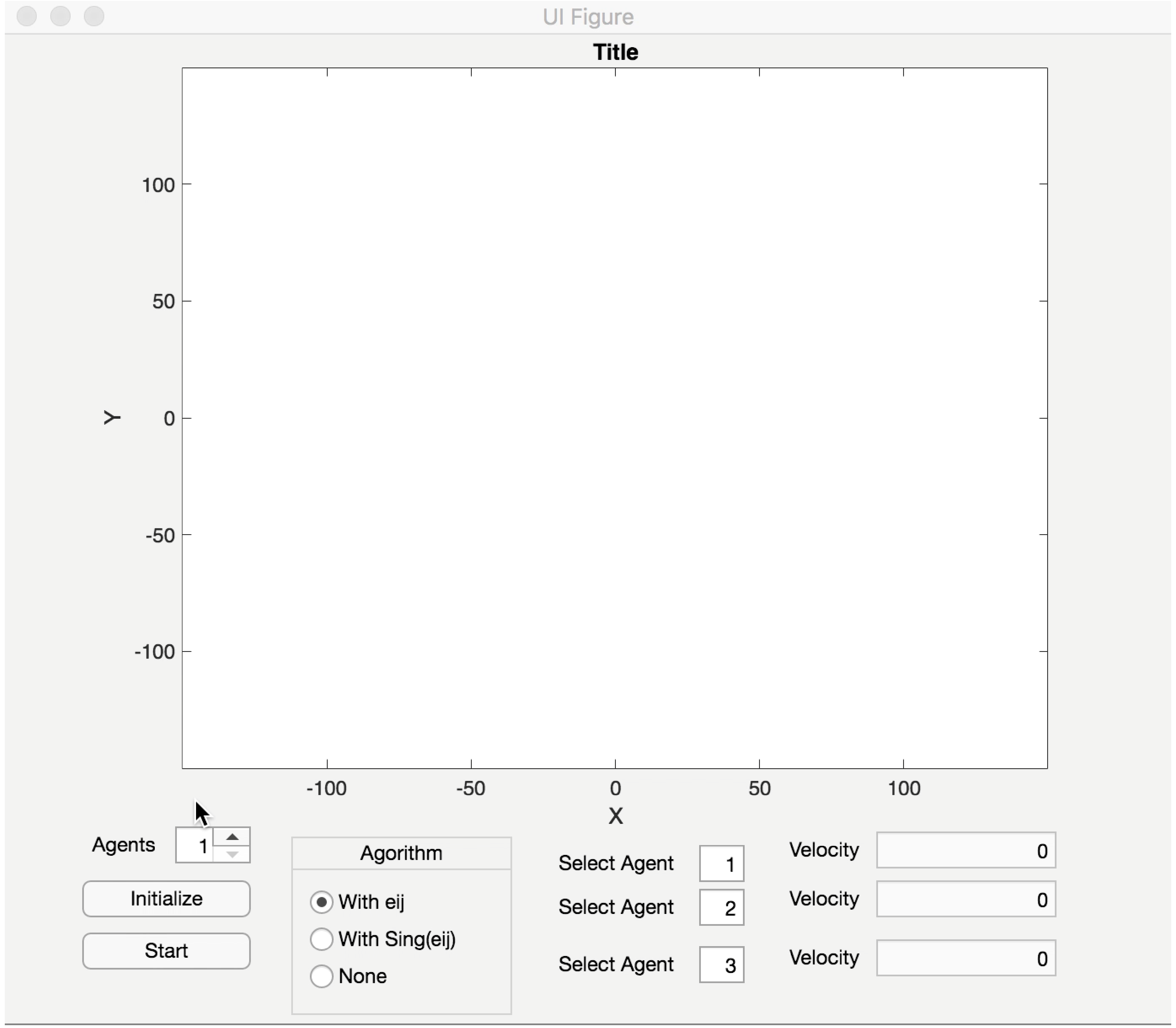


Consensus Algorithms

Formation Making

$$u_i = \sum_{j \in \mathcal{N}_i} e_{k_{ij}} (p_j - p_i)$$

$$e_{k_{ij}} = \|p_i - p_j\|^2 - (d_{ij}^*)^2$$



Consensus Algorithms

Formation Making

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Thanks