Dynamics and Control 2

Introduction to Multi-agent Systems

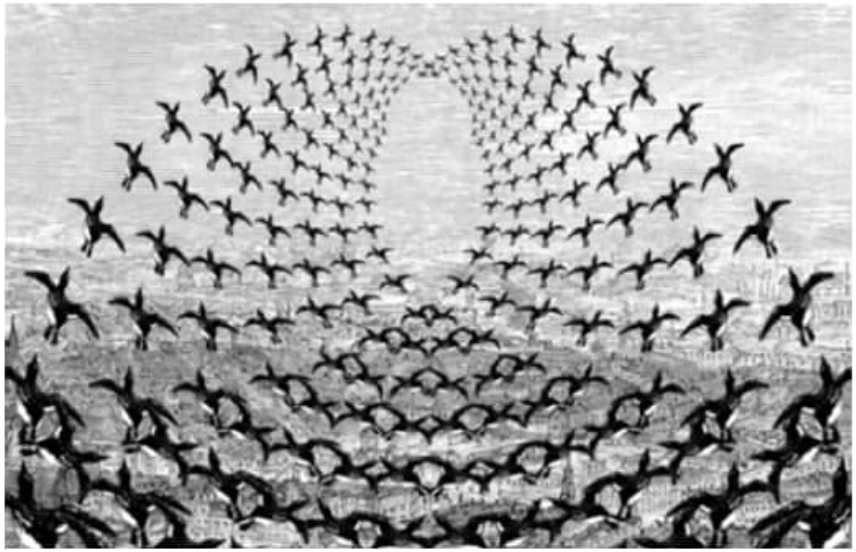
RRC Summer School 2021

June 30, 2021

Examples

Fish school

Birds flock



Locusts swarm

Fireflies synchronize

Algebraic Graph Theory

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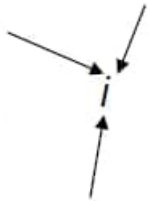
N nodes (agents) interconnected by communication links.
Each agent can only get information from its neighbors.

N_i In-neighbors of node i



Each agent has dynamics $\dot{x}_i = Ax_i + Bu_i$

Study the interaction of control and communication

Algebraic Graph Theory

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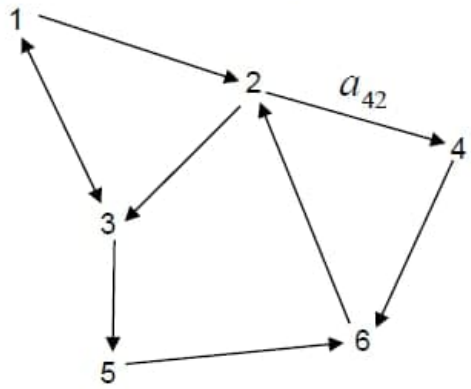
G= (V,E)

N nodes



Adjacency matrix

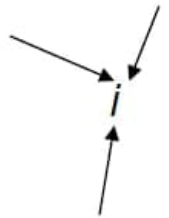
$$A = [a_{ij}]$$

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \end{bmatrix}$$

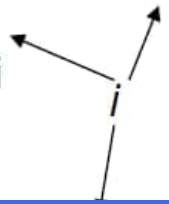
$$a_{ij} > 0 \; if \; (v_j, v_i) \in E$$

$$if \; j \in N_i$$

$d_i = \sum_{j=1}^{N} a_{ij}$ Row sum= in-degree N_i In-neighbors of node i



$d_i^o = \sum_{j=1}^{N} a_{ji}$ Col sum= out-degree N_o Out-neighbors of node i



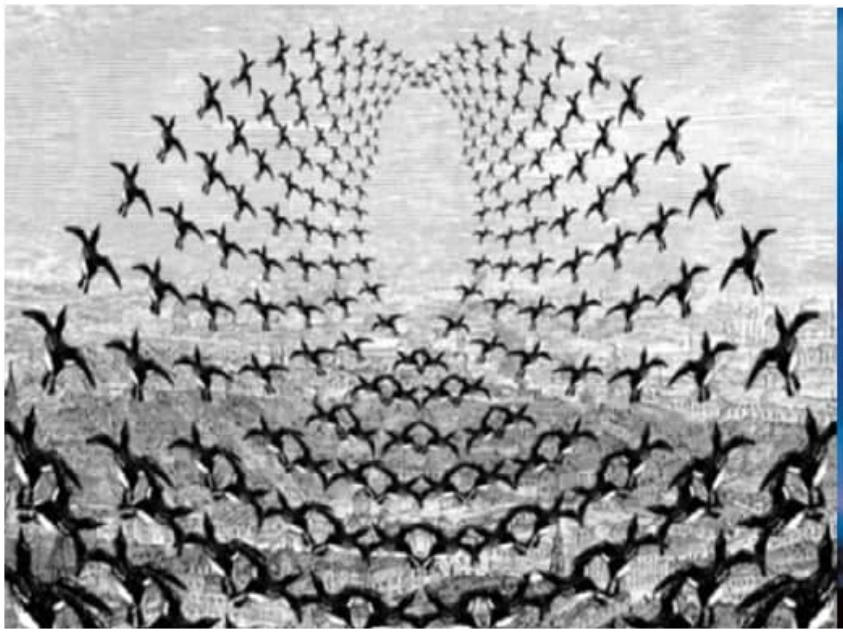
Reynold's Flocking

Reynolds' Rules:

Alignment : align headings $\dot{\theta}_i = \sum_{j \in N_i} a_{ij}(\theta_j - \theta_i)$

Cohesion : steer towards average position of neighbors- towards c.g.

Separation : steer to maintain separation from neighbors



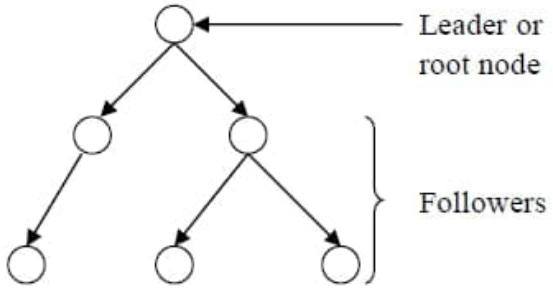
Graph Matrices

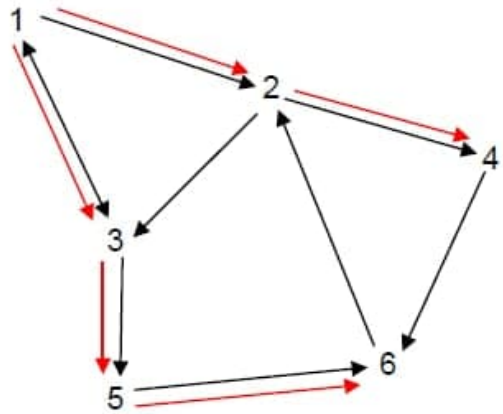
Strongly connected if for all nodes *i* and *j* there is a path from *i* to *j*.

Diameter= length of longest path between two nodes

Volume = sum of in-degrees $Vol = \sum_{i=1}^{N} d_i$

Tree- every node has in-degree=1





Spanning tree
Root node

Graph Matrices

$$a_{ij} = a_{ji}$$

$$A = [a_{ij}] = [a_{ji}] = A^T$$

$$L = D - A = D - A^T = L^T$$

Connected if for all nodes *i* and *j* there is a path from *i* to *j*.
If there is a path from *i* to *j*, there is a path from *j* to *i*

Graph Matrices

Any undirected graph has $L = L^T$

Hence, all its eigenvalues are real and can be ordered as

$$\lambda_1 \leq \lambda_2 \leq \cdots \leq \lambda_N$$

Examples 1

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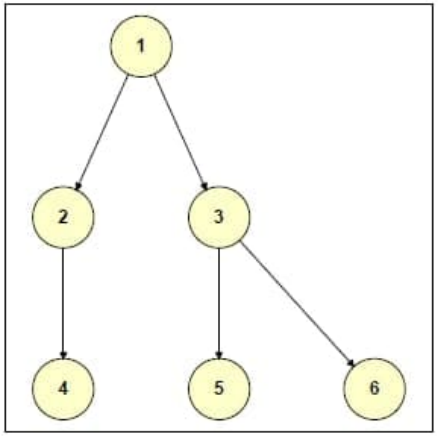
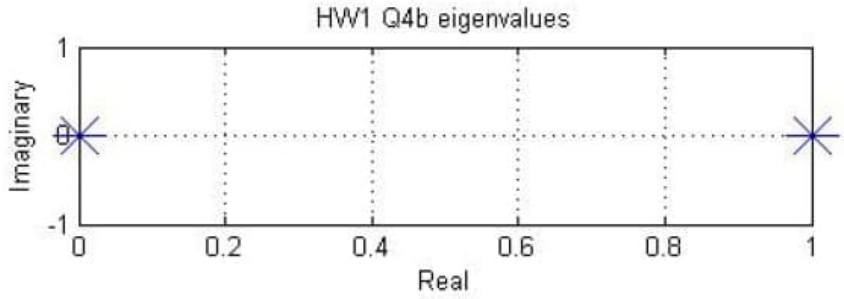
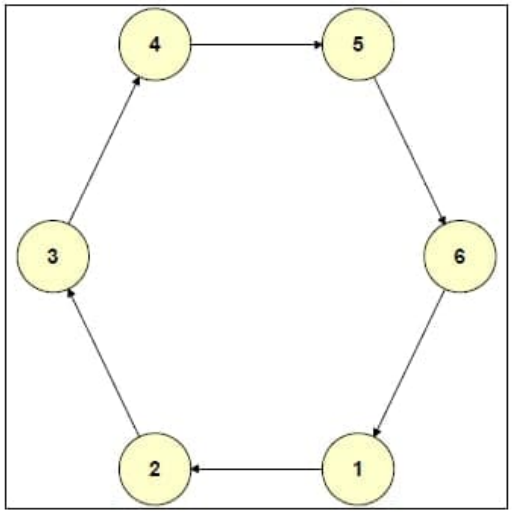
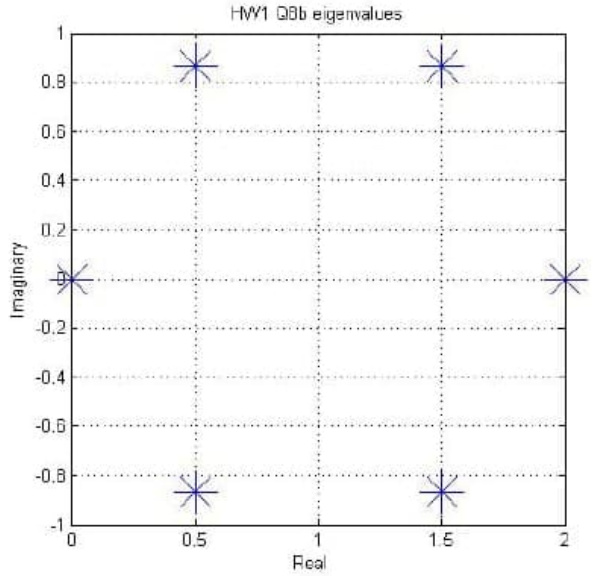
Directed Tree-
Chain of
command





Directed Ring-
Gossip network
OSCILLATIONS





Examples 2

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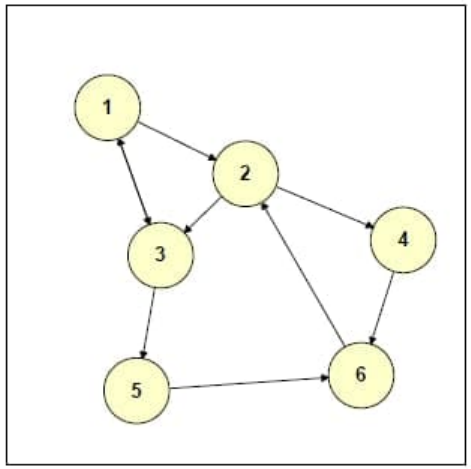
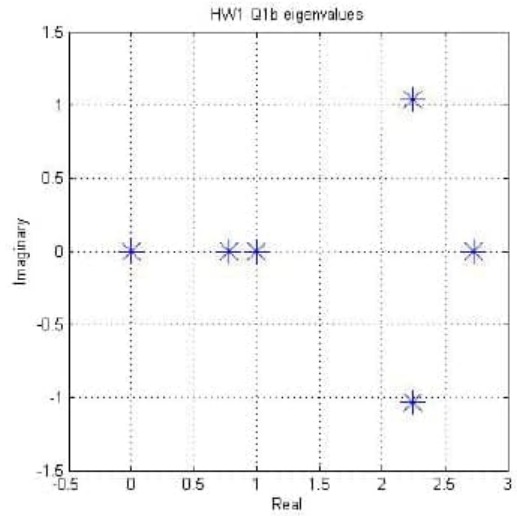
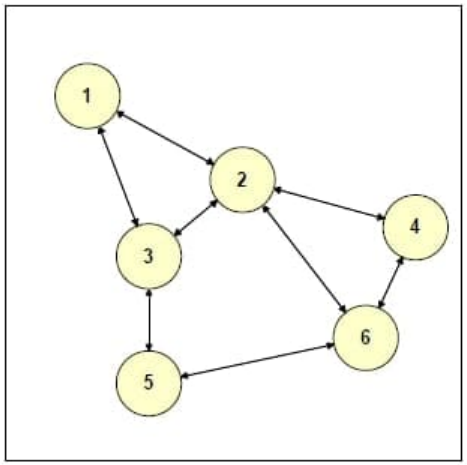
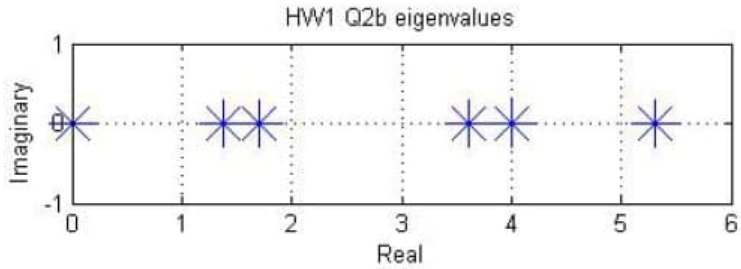
Directed graph-
Better conditioned





Undirected graph-
More ill-
conditioned





Simulation Engine - Microsoft AirSim

1. Open Source
2. Customizable Environments
3. APIs for learning
4. Easier to control

Applications

Links to the videos -

- Formation Flying in Microsoft AirSim using Connectivity graph [Neighbourhood]
- Quadrotor Formation Control with Collision Avoidance: Simulation in Unreal Engine 4 AirSim
- Vision-Based Distributed Formation Control of Unmanned Aerial Vehicles
- Vision based Collaborative Localization for Multiple UAVs
- Reinforcement Learning for Quadrotor Using AirSim

References

- Multi-agent Systems and Cooperative Control, by Dr. Frank Lewis
- Vision-Based distributed formation control of unmanned aerial vehicles, by Dr. Kevin Fathian

Thank you!