Interacting With Multi-Robot Networks

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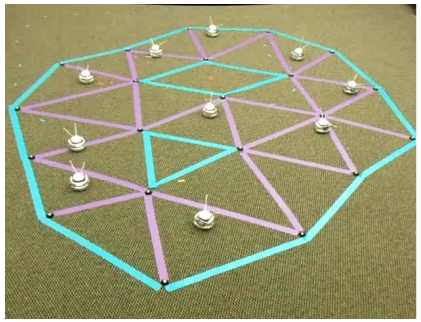
Outline:

1. Human-Swarm Interactions
2. From Lagrange to Euler
3. Conducting Robots



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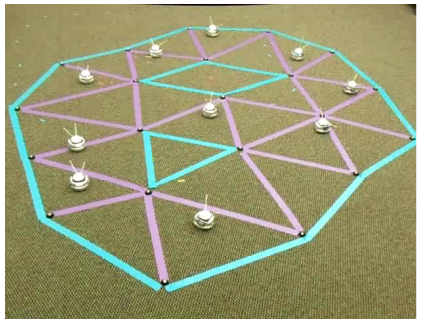
Outline:

Least-Squares



What Facebook Has Taught Me About Mark Spong

#3: The Crank

Mark W. Spong
September 12 near Allen, TX

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Like ·

#1: The Family Man

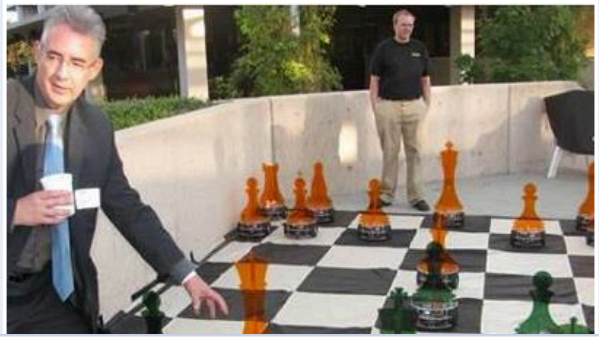
Mark W. Spong
September 22

At the Tech Titans Awards Gala in Dallas. I had the most beautiful date at the banquet. — with Lila Acosta Spong.

#4: The Scientist

Mark W. Spong
October 22

The UT Dallas robot chess team in action.



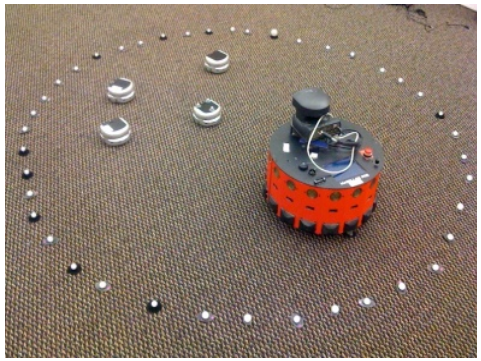
#2: The Wonk

Mark W. Spong
October 11 near Allen, TX

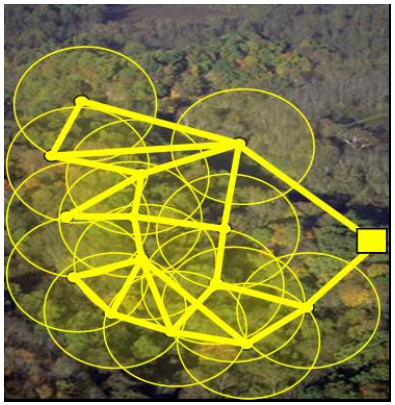
US constitution has a provision that the Vice President
assume the duties of the President in case the
ident is not capable of carrying out his/her duties.
ıld this provision be used to allow VP Biden to take on
emaining Presidential debates with Romney. Your
ions? LOL

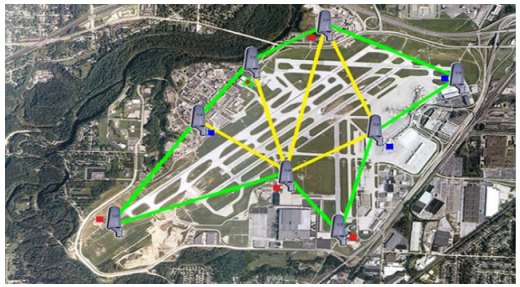
Human-Swarm Interactions?

Application Domains

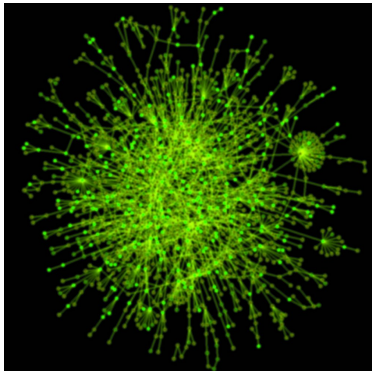


Multi-agent robotics

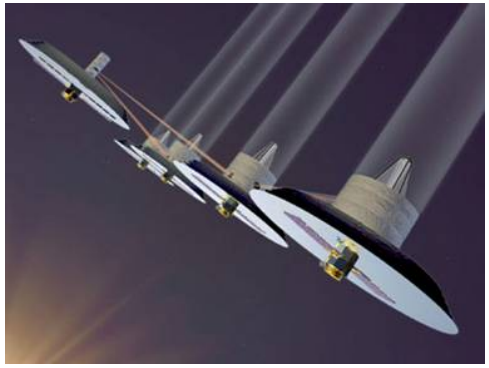




Sensor and communications networks



Biological networks

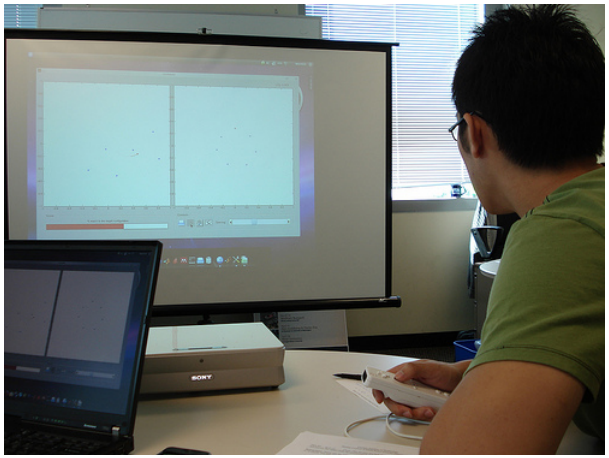


Coordinated control

Leader-Based Interactions

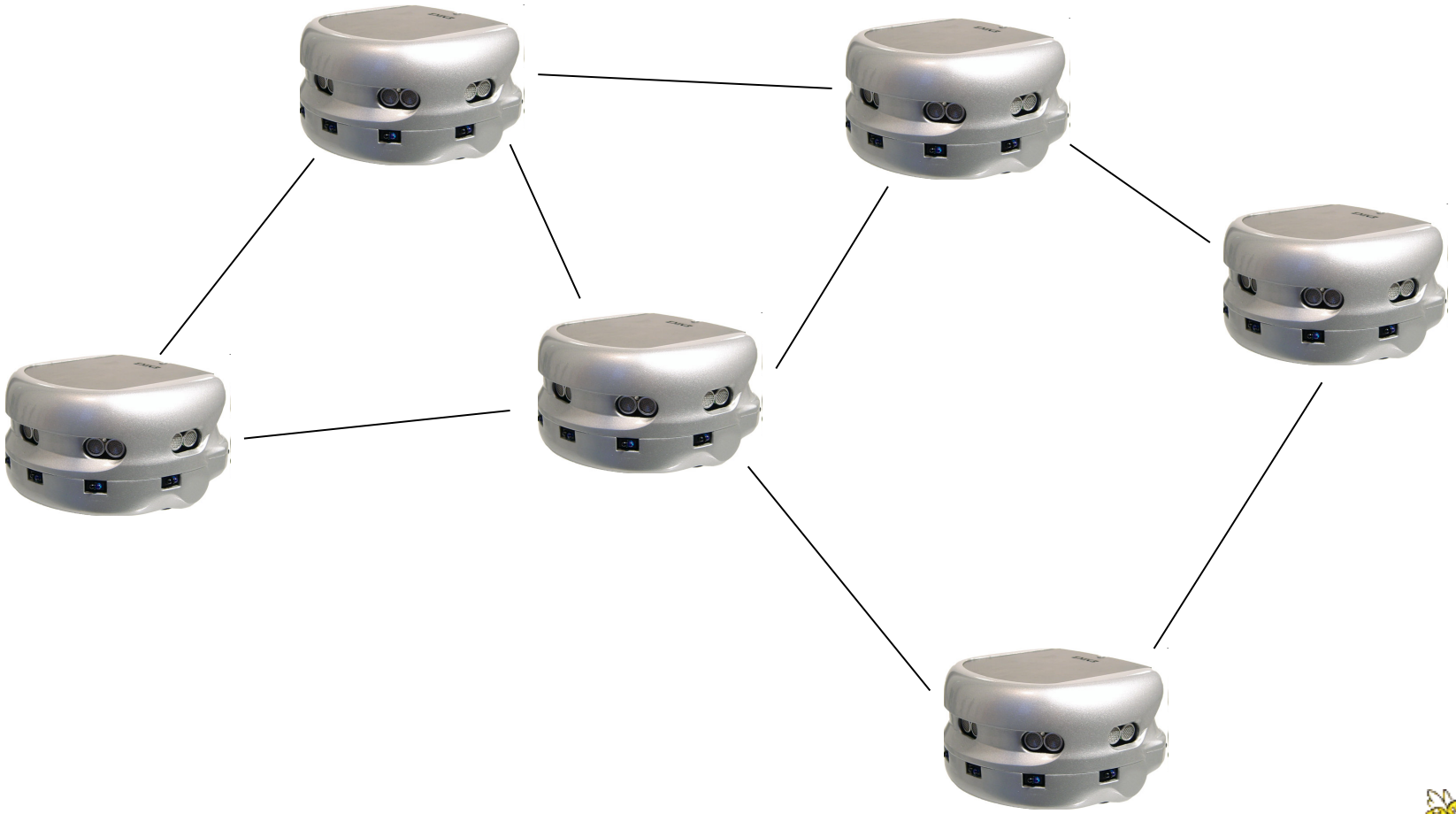
Interaction Models?

- It is not clear how people should interact with networks of robots
- Overall, we are pretty bad* at this…



  - Leader-Follower Models (virtual and actual)
  - Boundary Control
  - Behavioral Interactions
  - **Fluid-Based Interactions**

Multi-Agent Interactions

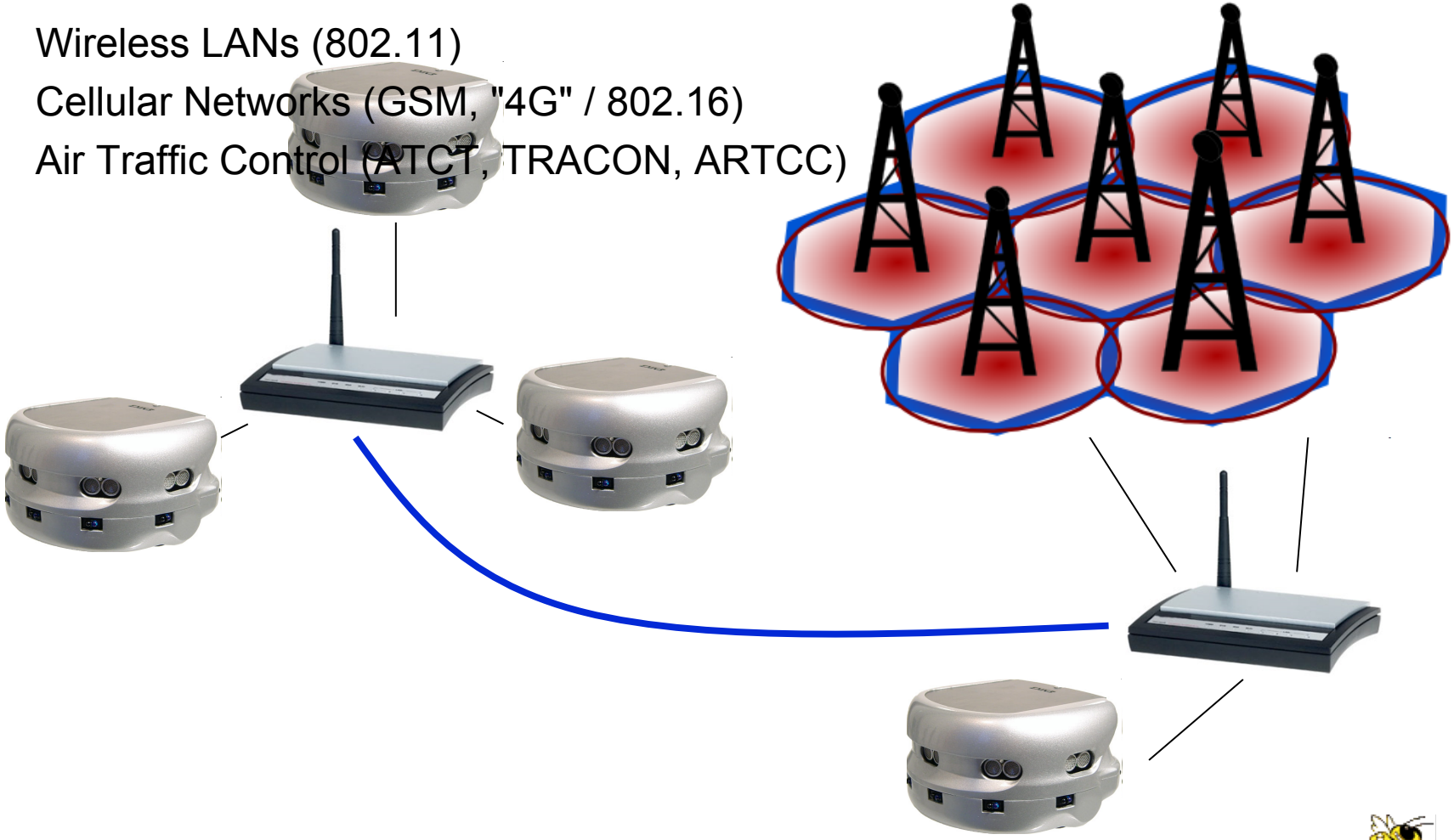


…With Infrastructure

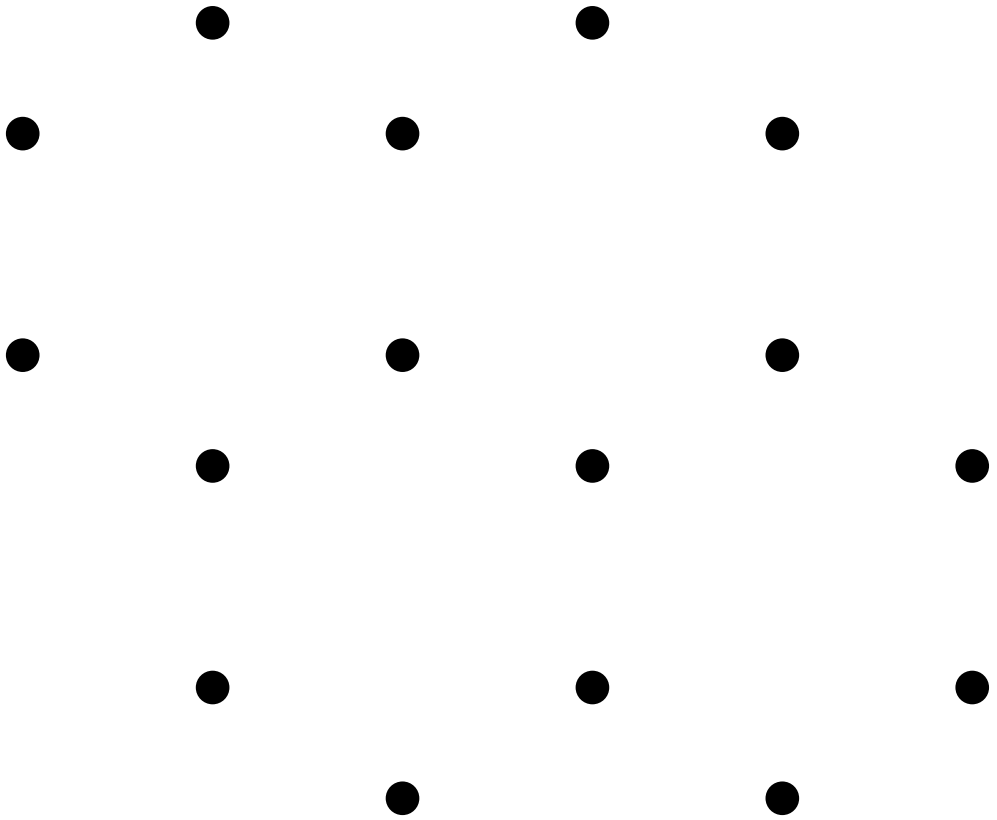
Wireless LANs (802.11)

Cellular Networks (GSM, "4G" / 802.16)

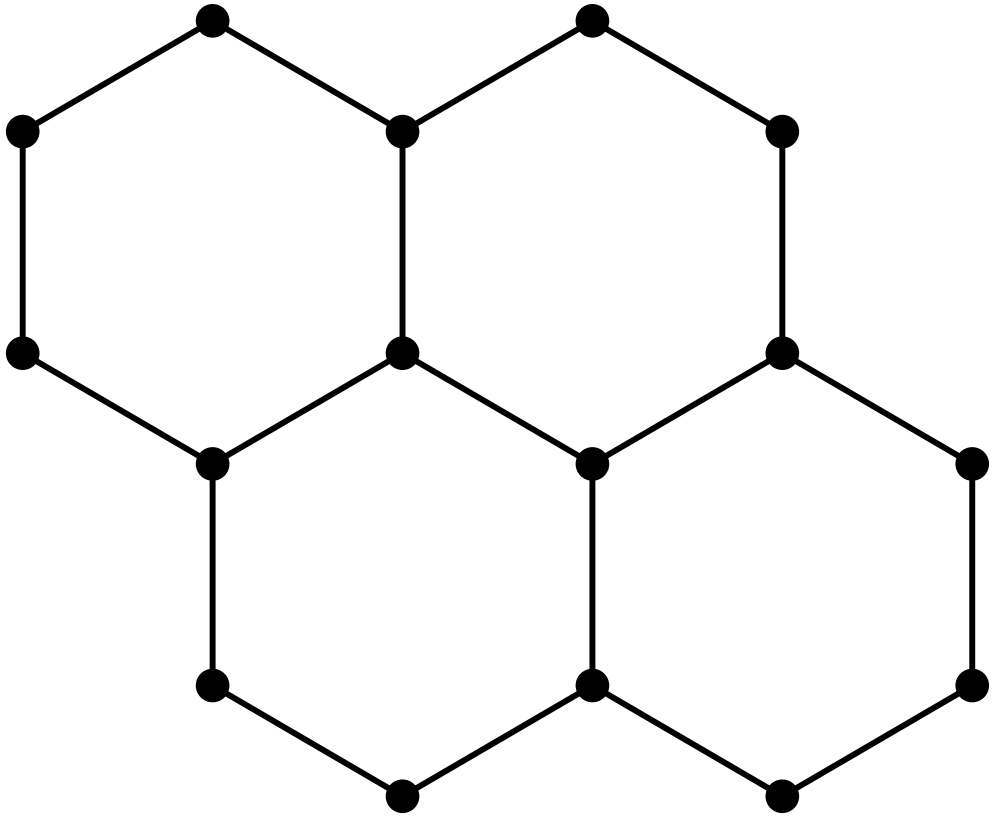
Air Traffic Control (ATCT, TRACON, ARTCC)



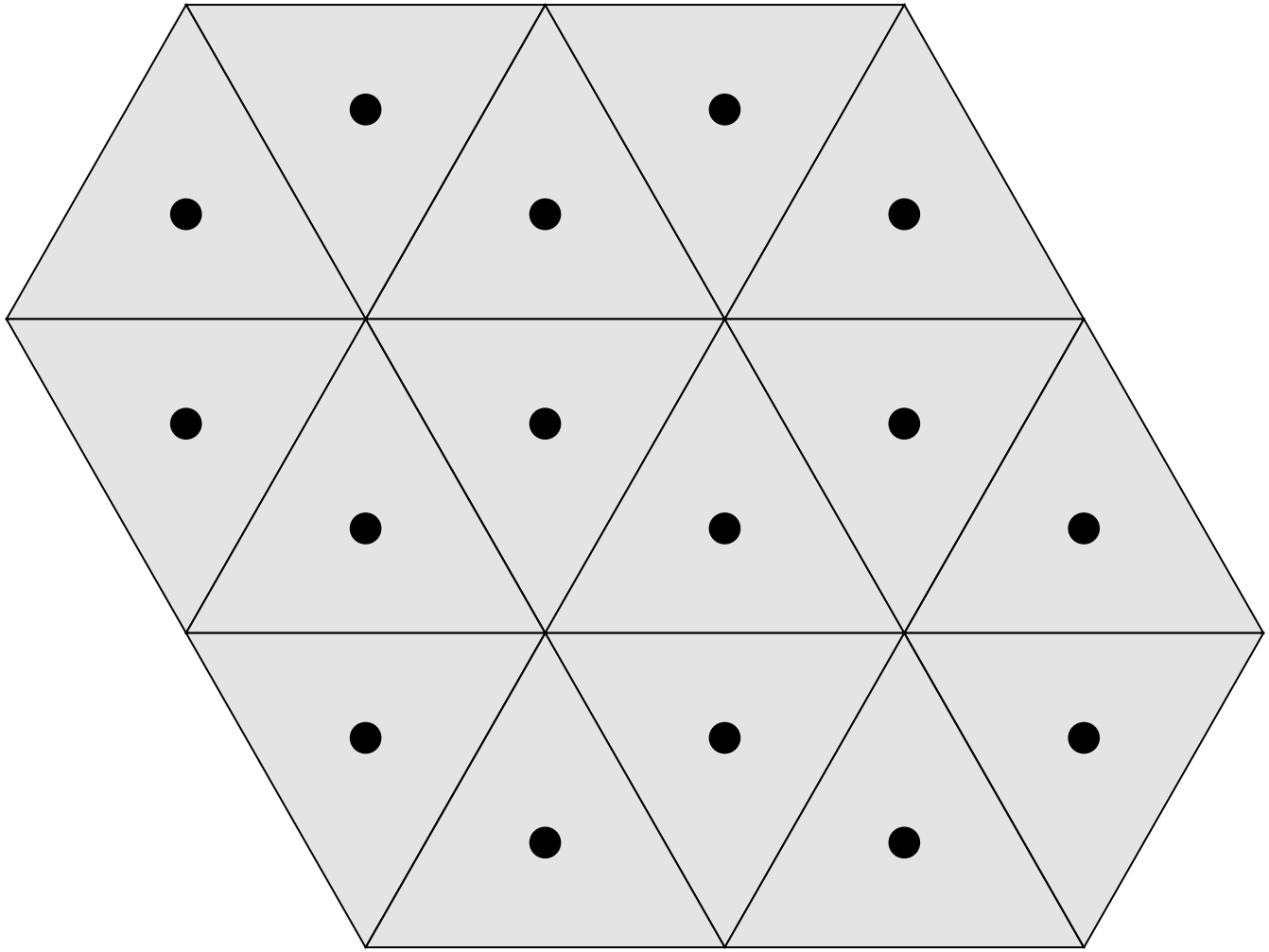
The Infrastructure Network



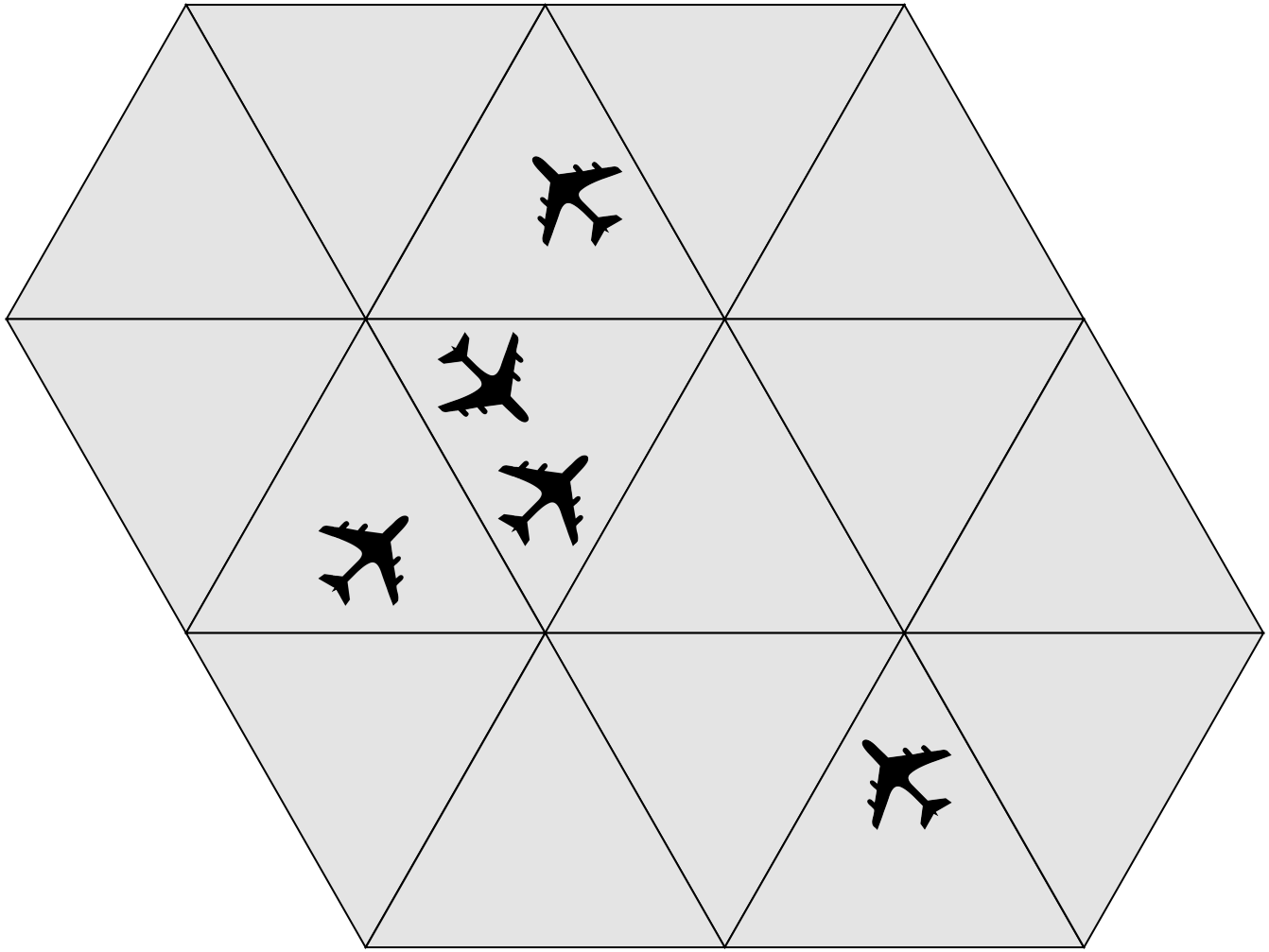
The Infrastructure Network



The Infrastructure Network



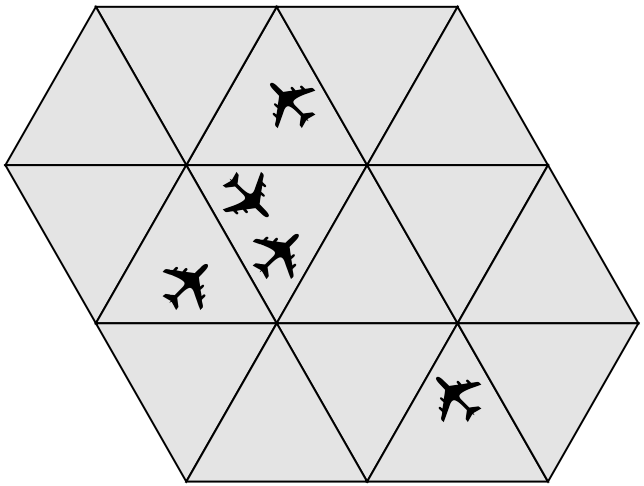
The Infrastructure Network



Two Views of the World

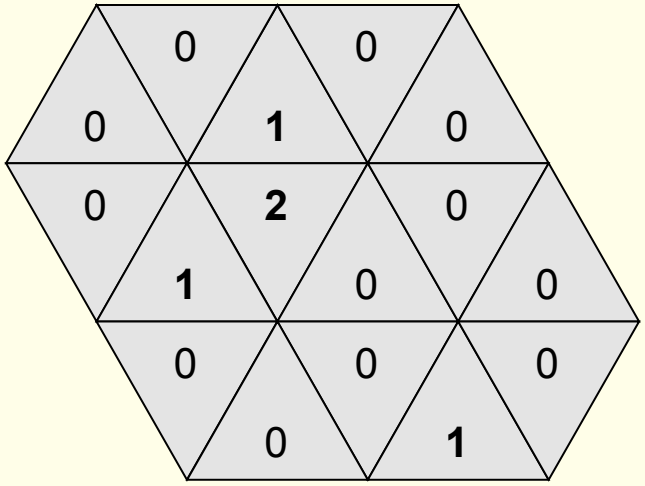
- Lagrangian

$$\dot{x}_i = f(x_i, u_i)$$



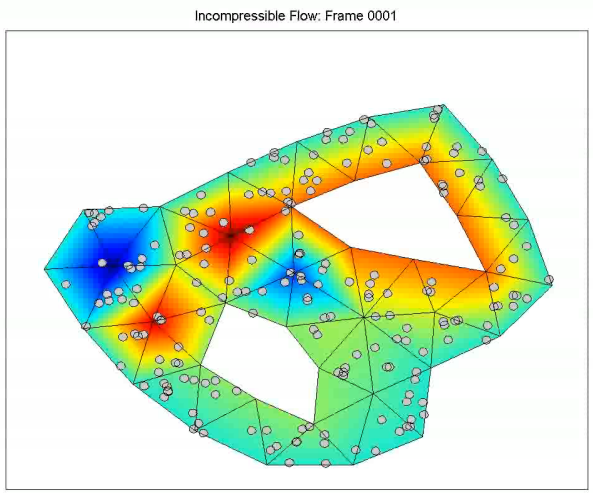
- Eulerian

$$\dot{m}_i = v_{ij}$$
$$\dot{m}_j = -v_{ij}$$

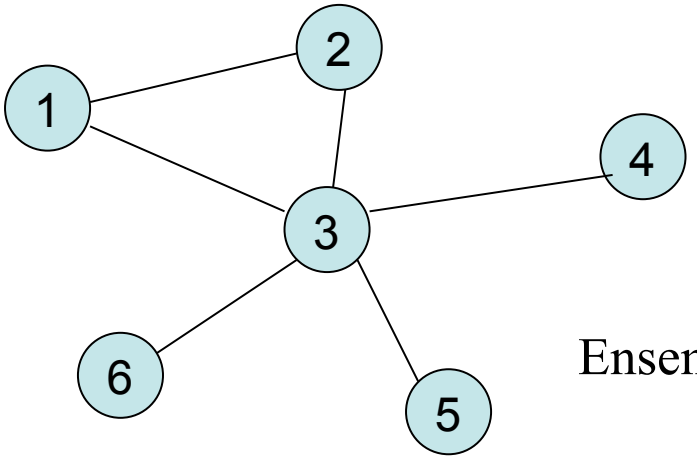


What We'll Do…

- Let users specify “flows” through the network
- Distribute the flows across the network so robots don't "pile up" anywhere
  - by solving a problem on the dual graph
  - in a distributed way.
- Produce, from these flows, continuous control laws
  - "no piling up”
  - collision avoidance
  - in a distributed way.



Controlled Laplacian Dynamics



Infrastructure Cell Dynamics

$$\dot{p}_i = -\sum_{j \in \mathcal{N}(i)} (p_i - p_j) + u_i$$

Ensemble dynamics

$$\dot{p} = -Lp + u$$

????

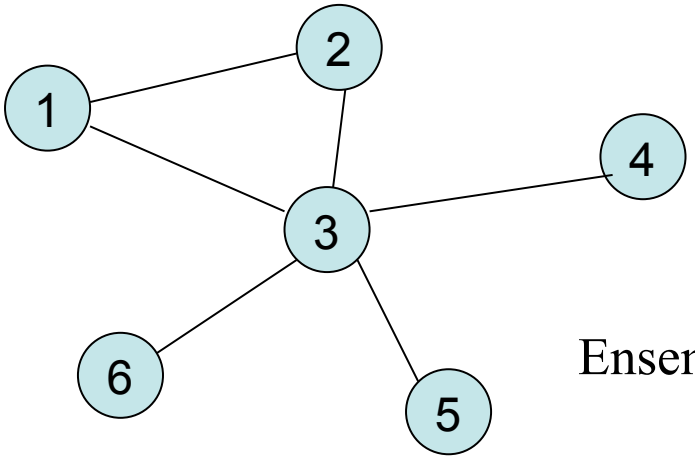
$$p = \begin{bmatrix} p_1 \\ \vdots \\ p_N \end{bmatrix}$$

$$u = \begin{bmatrix} u_1 \\ \vdots \\ u_N \end{bmatrix}$$

where L, the *Graph Laplacian*, is defined s.t.,

$$L_{ij} = \begin{cases} \deg(i) & i = j \\ -1 & j \in \mathcal{N}(i) \\ 0 & \text{o.w.} \end{cases}$$

Controlled Laplacian Dynamics



Infrastructure Cell Dynamics

$$\dot{p}_i = -\sum_{j \in \mathcal{N}(i)} (p_i - p_j) + u_i$$

Ensemble dynamics

$$\dot{p} = -Lp + u$$

????

edges

$$D = \begin{bmatrix} 0 & 1 & \\ 1 & -1 & \\ 0 & 0 & \cdots \\ -1 & 0 & \\ 0 & 0 & \end{bmatrix}$$

vertices

$$L = DD^T$$

Grammian

A Least Squares Interpretation

$$Ax \stackrel{?}{=} b$$

$$\min_x \|Ax - b\|^2$$

$$\frac{1}{2}\frac{\partial(\cdot)}{\partial x} = A^T Ax - A^T b$$

$$\underbrace{A^T A}_{\text{Grammian}} x = A^T b$$

$$D^T p \stackrel{?}{=} f$$

$$\min_p \|D^T p - f\|^2$$

$$DD^T p = Df$$

$$\dot{p} = -\frac{1}{2}\frac{\partial(\cdot)}{\partial p} = -DD^T p + Df$$

$$\dot{p} = -Lp + Df$$

The input!!

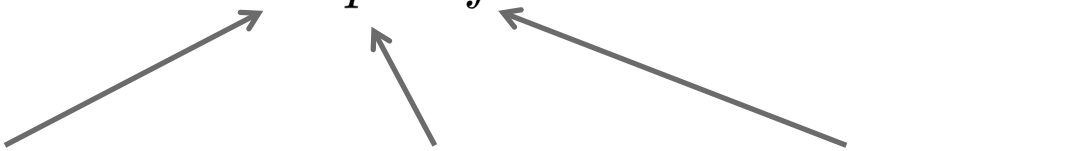
Punchline

- The forced consensus dynamics

$$\dot{p} = -Lp + Df$$

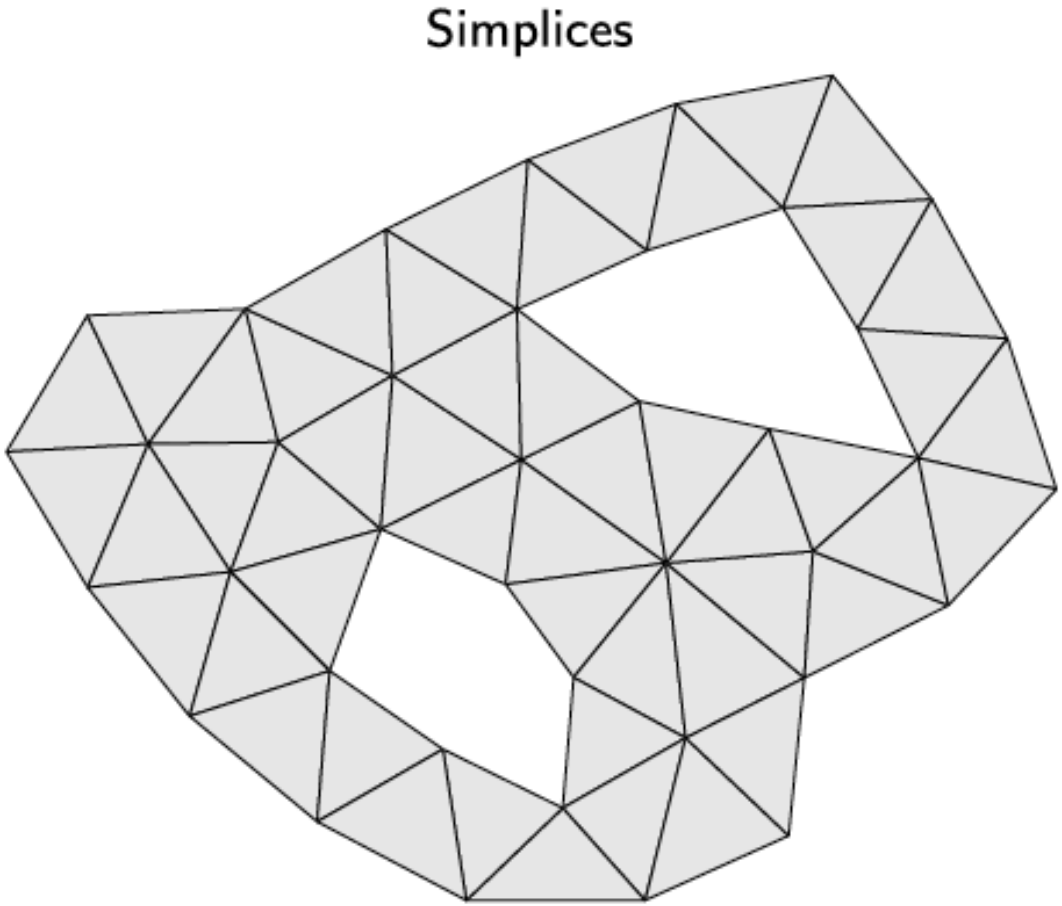
"solve"

$$D^T p = f$$

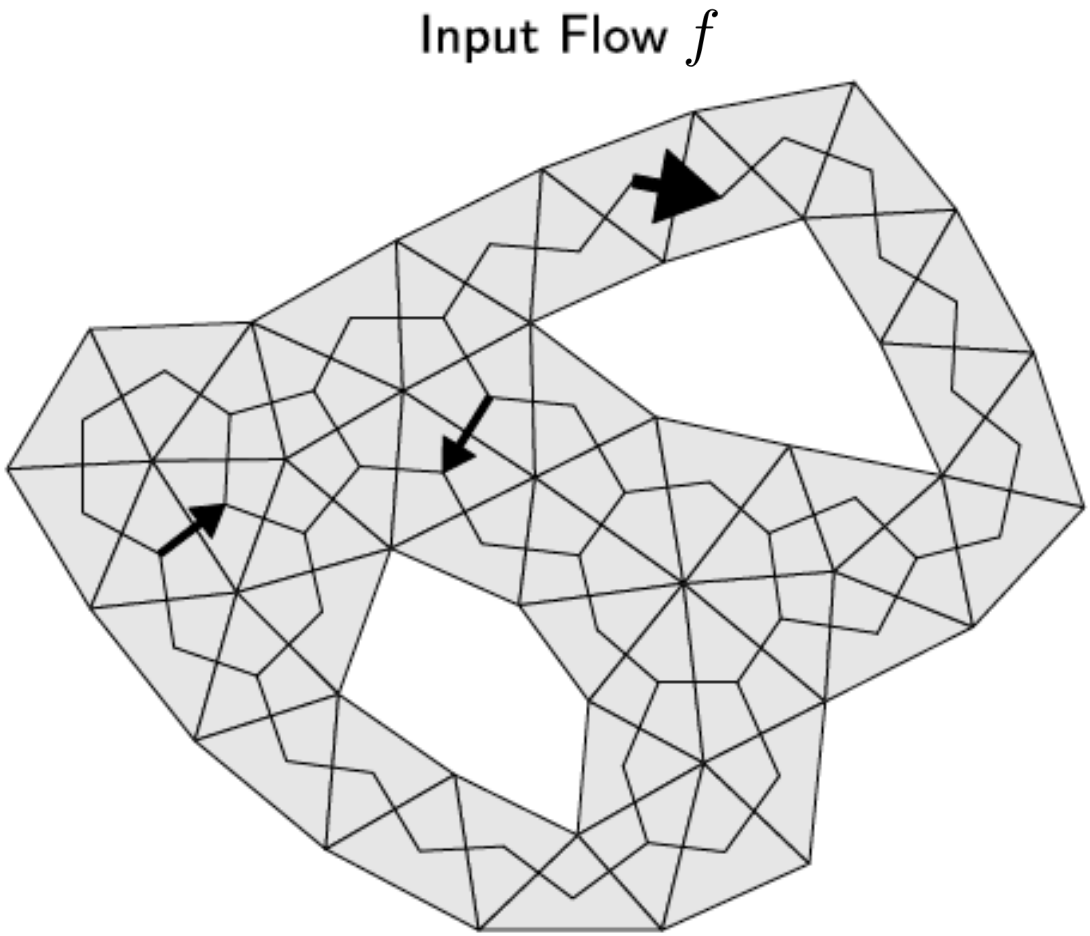


Computes differences across edges	Assigns a number to each vertex	Assigns a number to each edge
Gradient	**Scalar Field (PRESSURE)**	**Vector Field (FLOW)**

Example

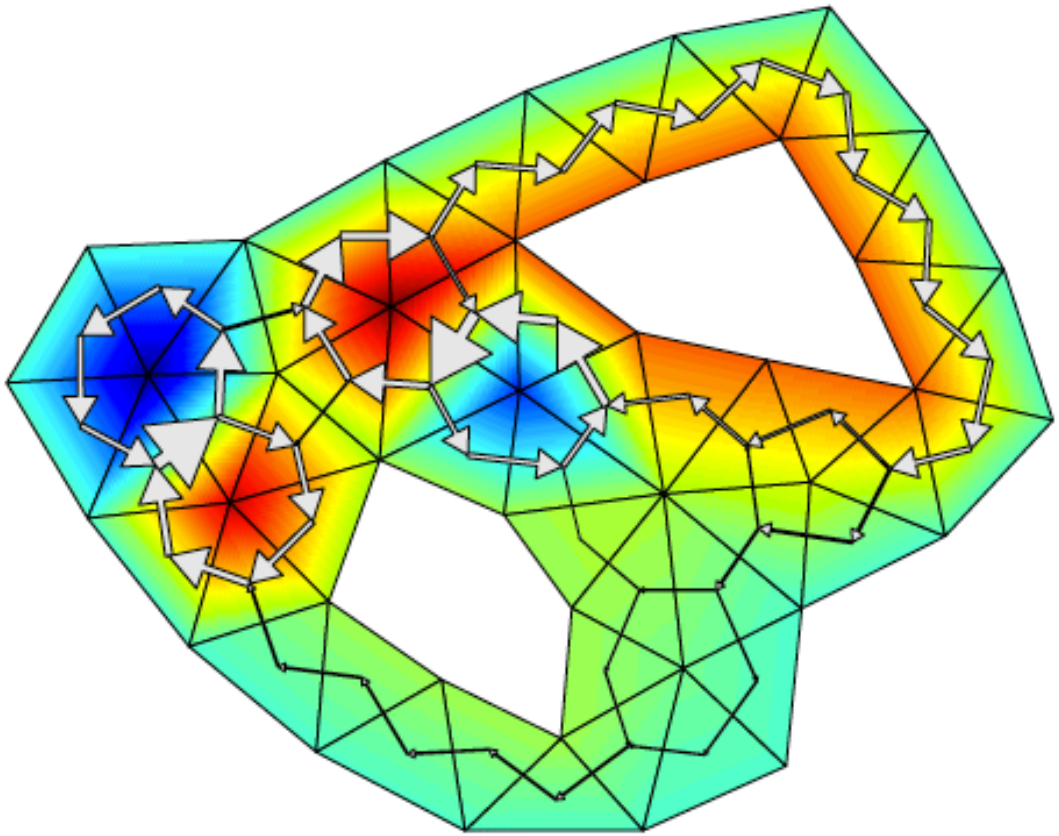


Example



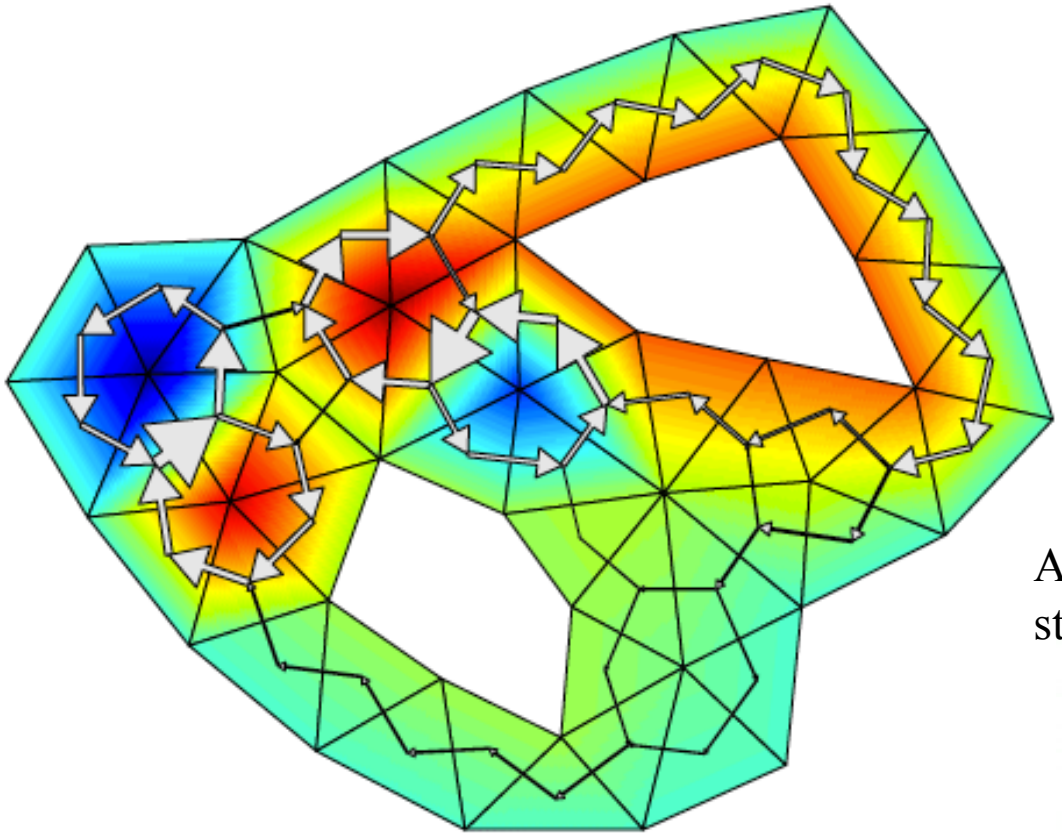
Example

Resulting Flow $D^T p$

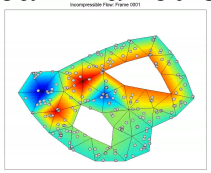


Example

Resulting Flow $D^T p$



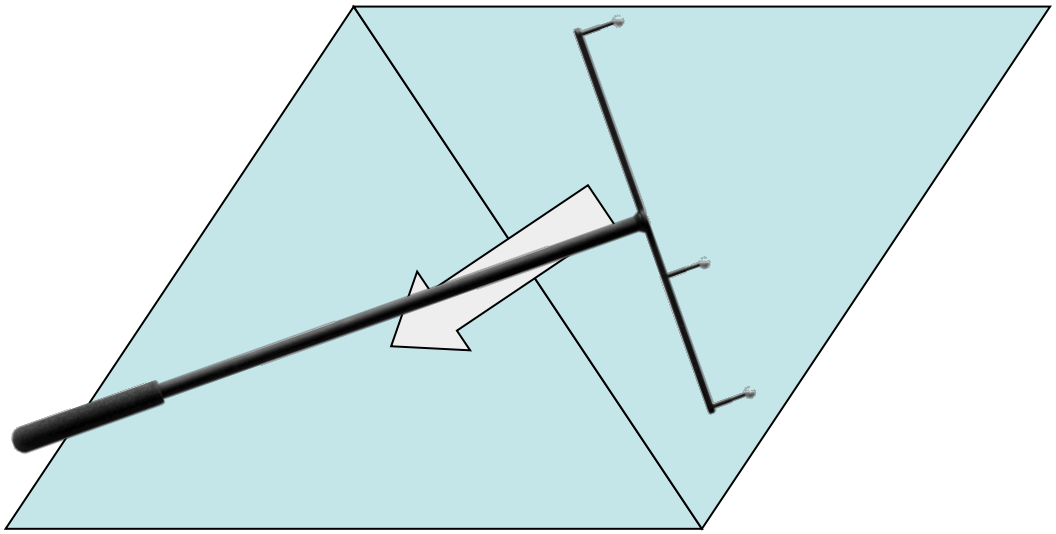
Add local, hybrid stream functions



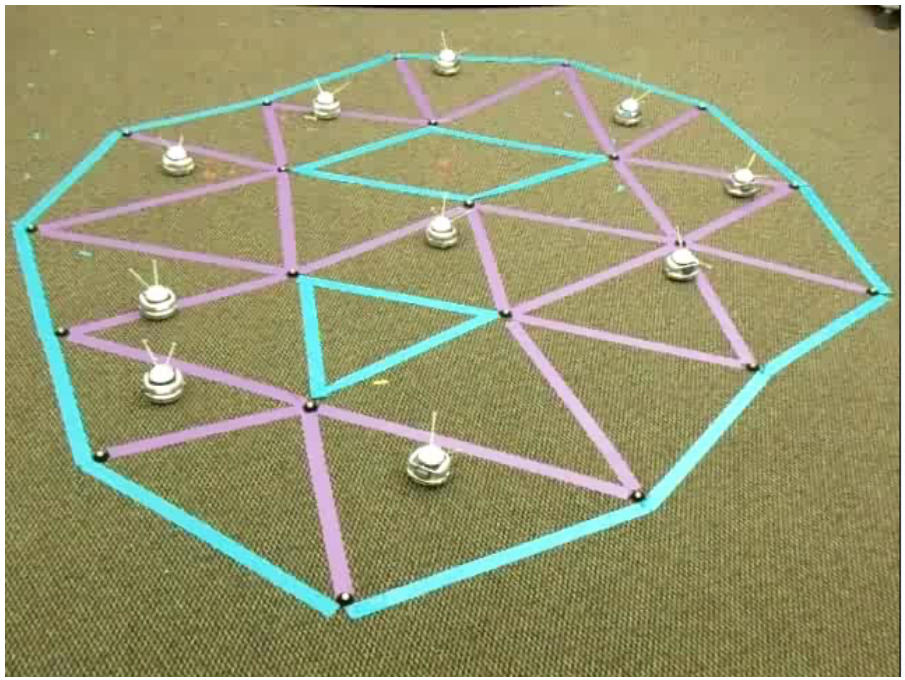
But, What About This Picture?

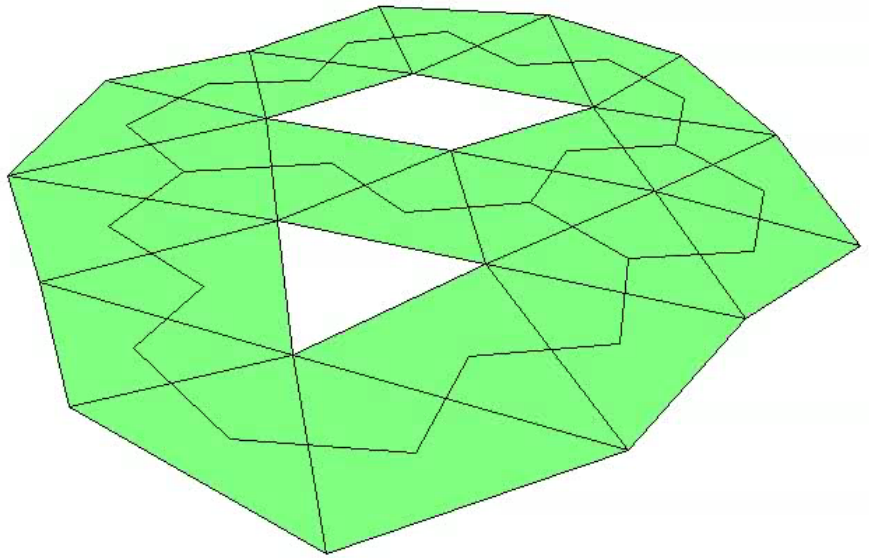
Swarm Conducting

- Interface: Motion capture wand



Swarm Conducting





THANK YOU!

Peter Kingston