Portable Sensor Motes as a Distributed Communication Medium for Large Groups of Mobile Robots

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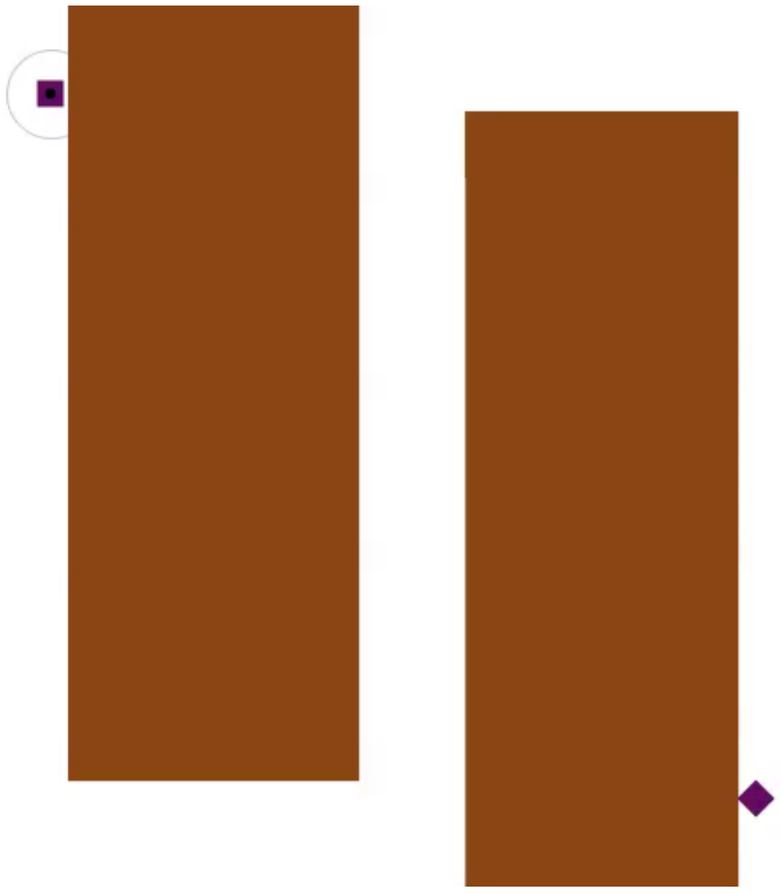


Multi-Robot Teams and Swarms

- **Robots are getting cheap**
- **Applications are increasing**
  - Self-driving vehicles
  - Fulfillment warehouses
  - Surveillance and Defense
  - Disaster relief
  - Robot Soccer!

- **Our Research**
  - Swarms of UAVs (drones)
  - Training Robot Teams Together
  - Robot Team Task Allocation
  - **Collaborative Construction**
  - **Communication/Collaboration Methods for Very Large Teams**

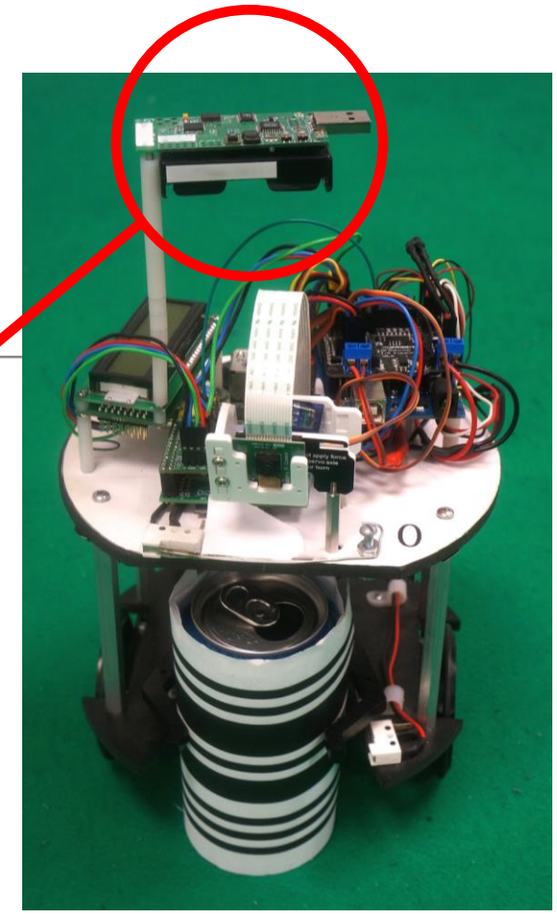
Why We Use Wireless Sensor Motes

- Global communication modes (broadcast, centralized) **don't scale** to very large numbers of agents
  - Bounded resource (wireless, etc.)
  - Too much load on agents
- Common Alternatives
  - Local signaling to neighbors
  - Local line-of-sight communication
  - **Indirect communication** (leaving information in the environment)
    - Breadcrumbs, RFID tags, roadsigns, **Wireless sensor motes**

How We Use Wireless Sensor Motes

- Robots can **deploy, move,** and **retrieve sensor motes**

- Robots can **identify local sensor motes** and can **read** and **write** information to them.



Tmote Sky Sensor Mote

- *At right:*
  - One sensor mote for each bar-coded can
  - Each robot also has one sensor mote which it uses to communicate with the cans' motes

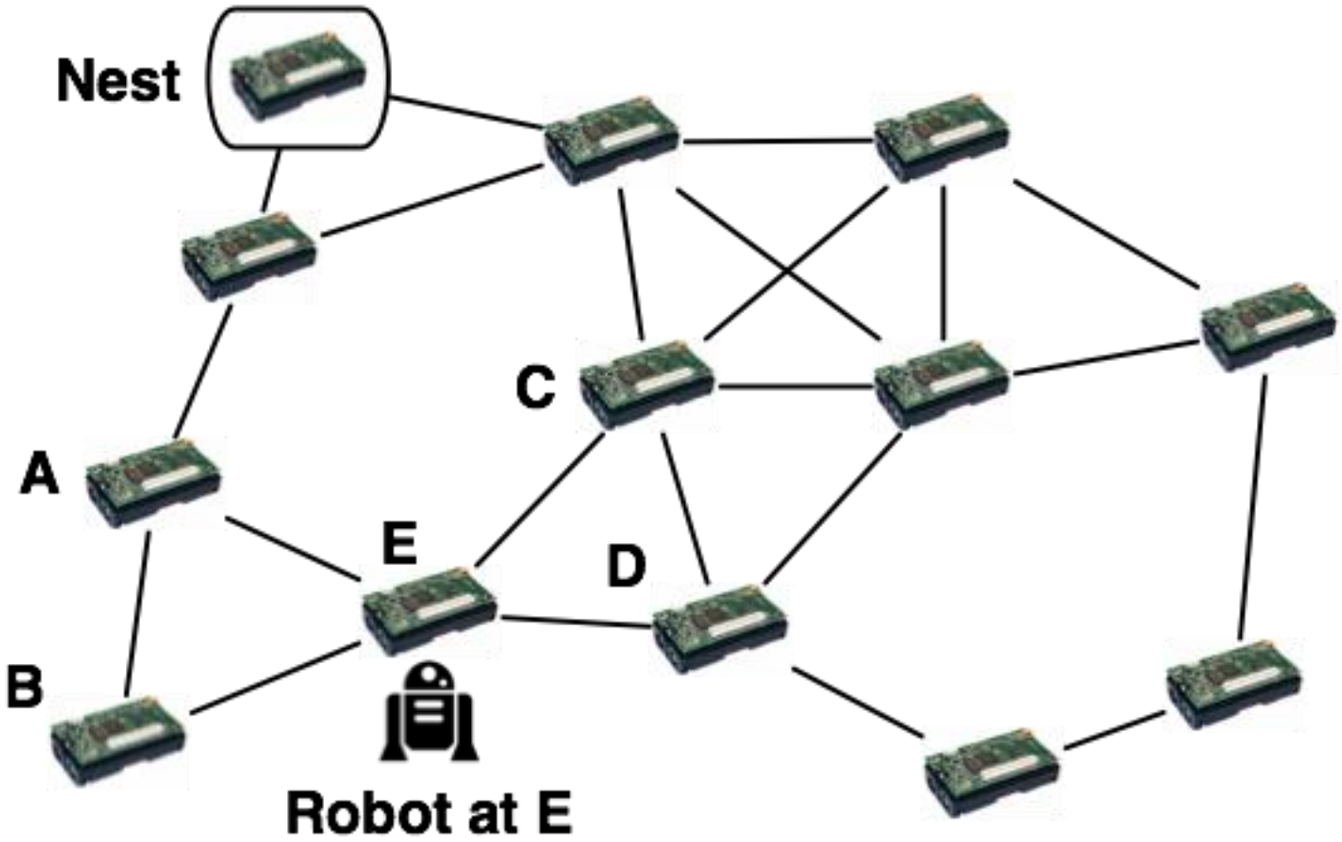
Indirect Communication Model: Ant **Pheromones**

- Robots **only talk** to freestanding motes
  - Freestanding motes **do not** talk to one another: **no network**
  - Robots **do not talk** to one another
- Each mote can store *pheromone values* (real-valued numbers), one per *pheromone type.*
- Robots deploy motes, then wander from mote to mote.
  When at a mote, a robot can talk to its neighboring motes.
  - Robots *read* pheromone values at nearby motes.
  - Robots *write* pheromone values to their current mote.

Building and Following Pheromone Gradients

- Robots gradually embed *gradients,* one per pheromone type, into the graph.

- Some pheromones at some locations are *fixed* to a high value. They form the peaks of the gradients.

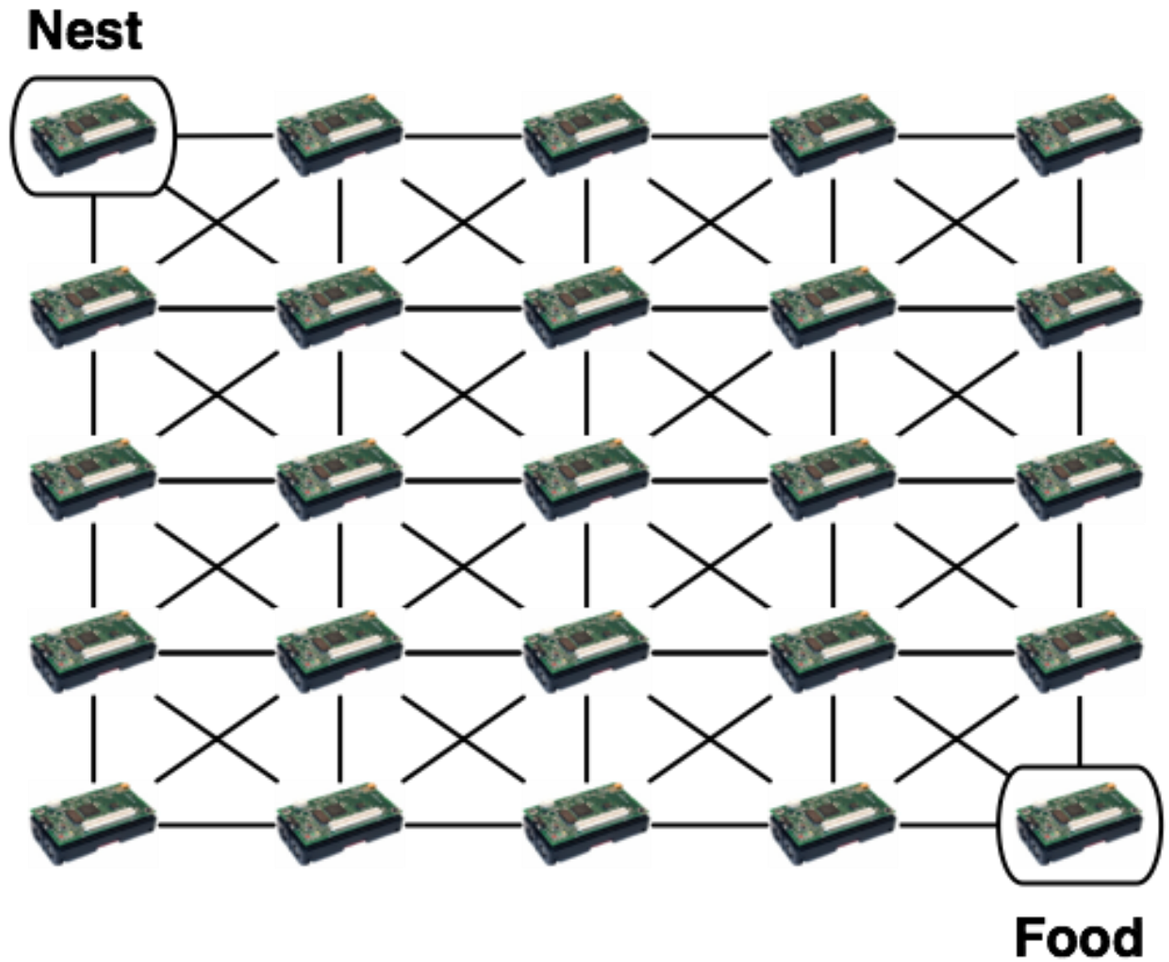


- **Updating Pheromone *P***
  Pheromone *P* at sensor mote *E* is updated to $\max_P(A, B, C, D, E) \times 0.9$

- **Following Pheromone *P***
  Robot moves to the mote in {A, B, C, D, E} with the highest *P* value

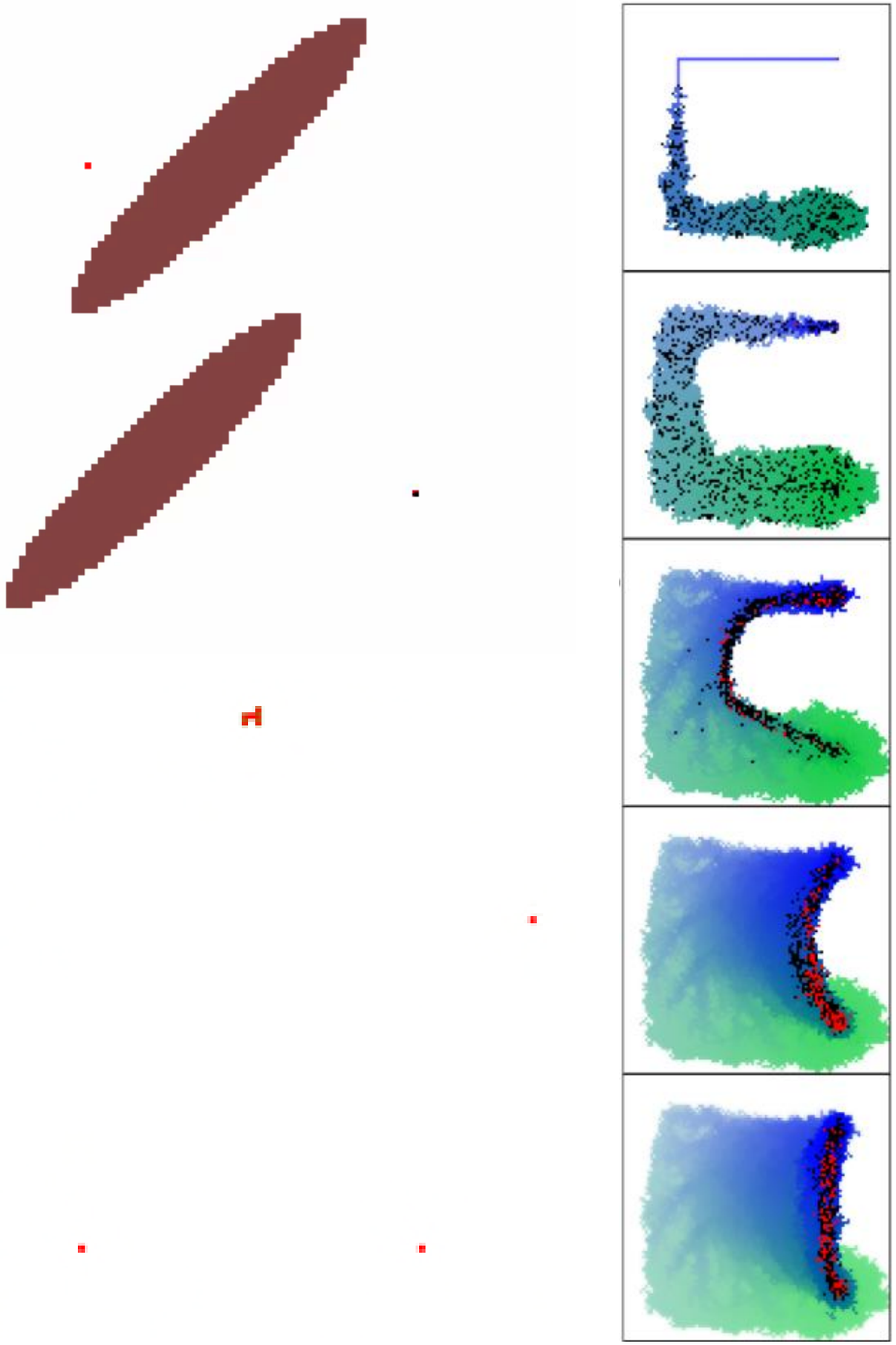
Simple Example: Two Pheromone Food Foraging

- 100 x 100 grid of **predeployed** sensor motes
- A *Nest* with fixed *Nest* pheromone
- A *Food Source* with fixed *Food* pheromone
- Other motes start at 0 for Nest and Food pheromones
- Obstacles
- Robots come out of the nest, find the food source and establish a trail
- Robots **do not move** the motes

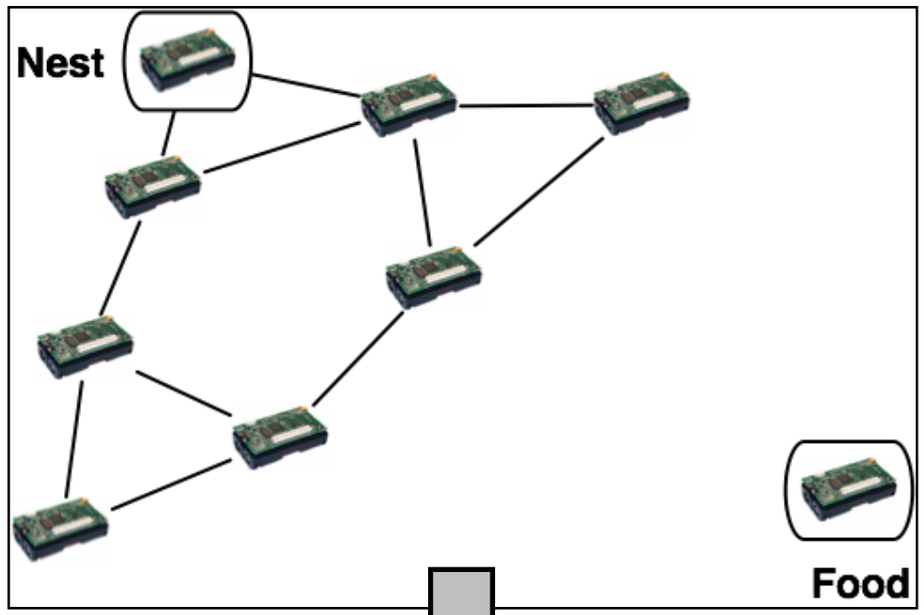


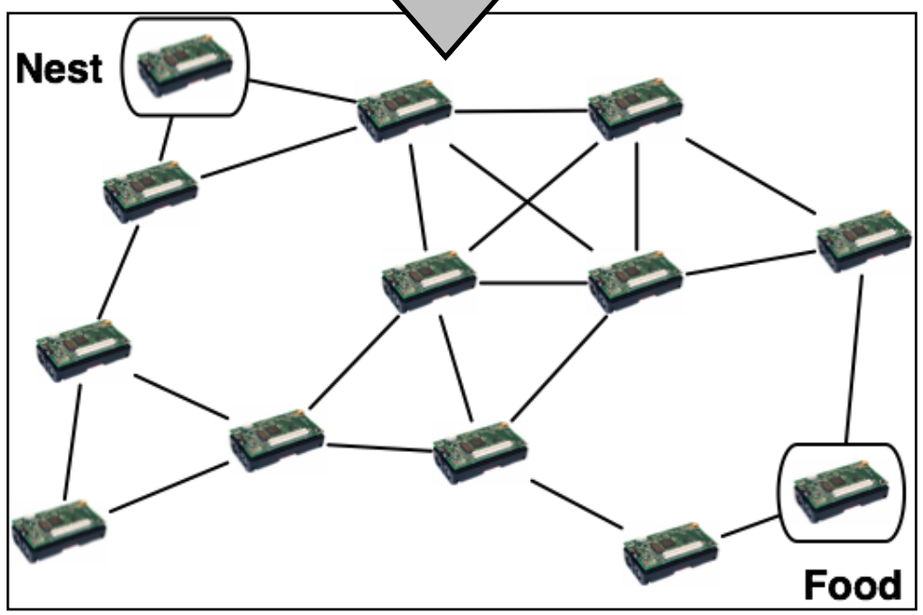
Simple Example: Two Pheromone Food Foraging

(in simulation)

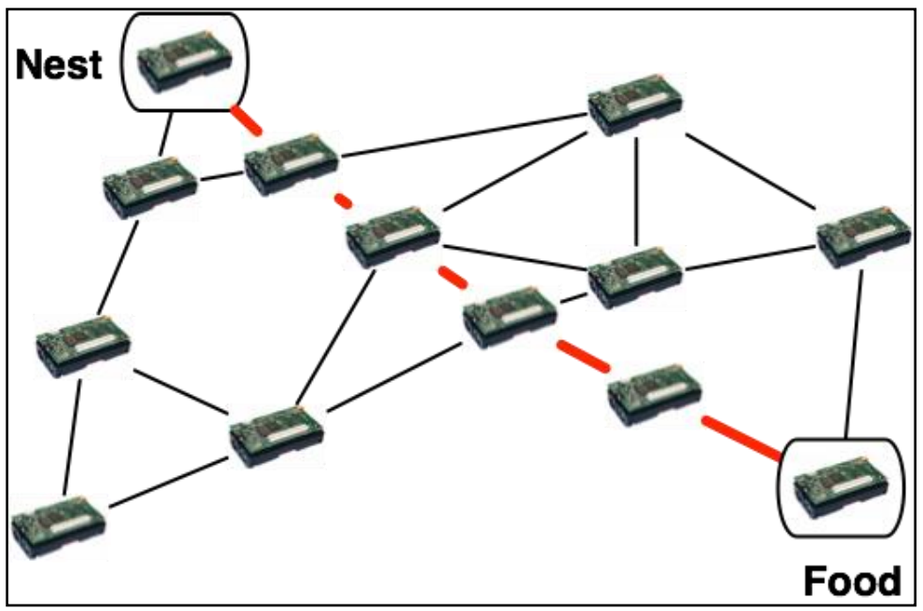


More Realistic Foraging: Two Pheromones, Deployable/Movable/Removable Sensor Motes



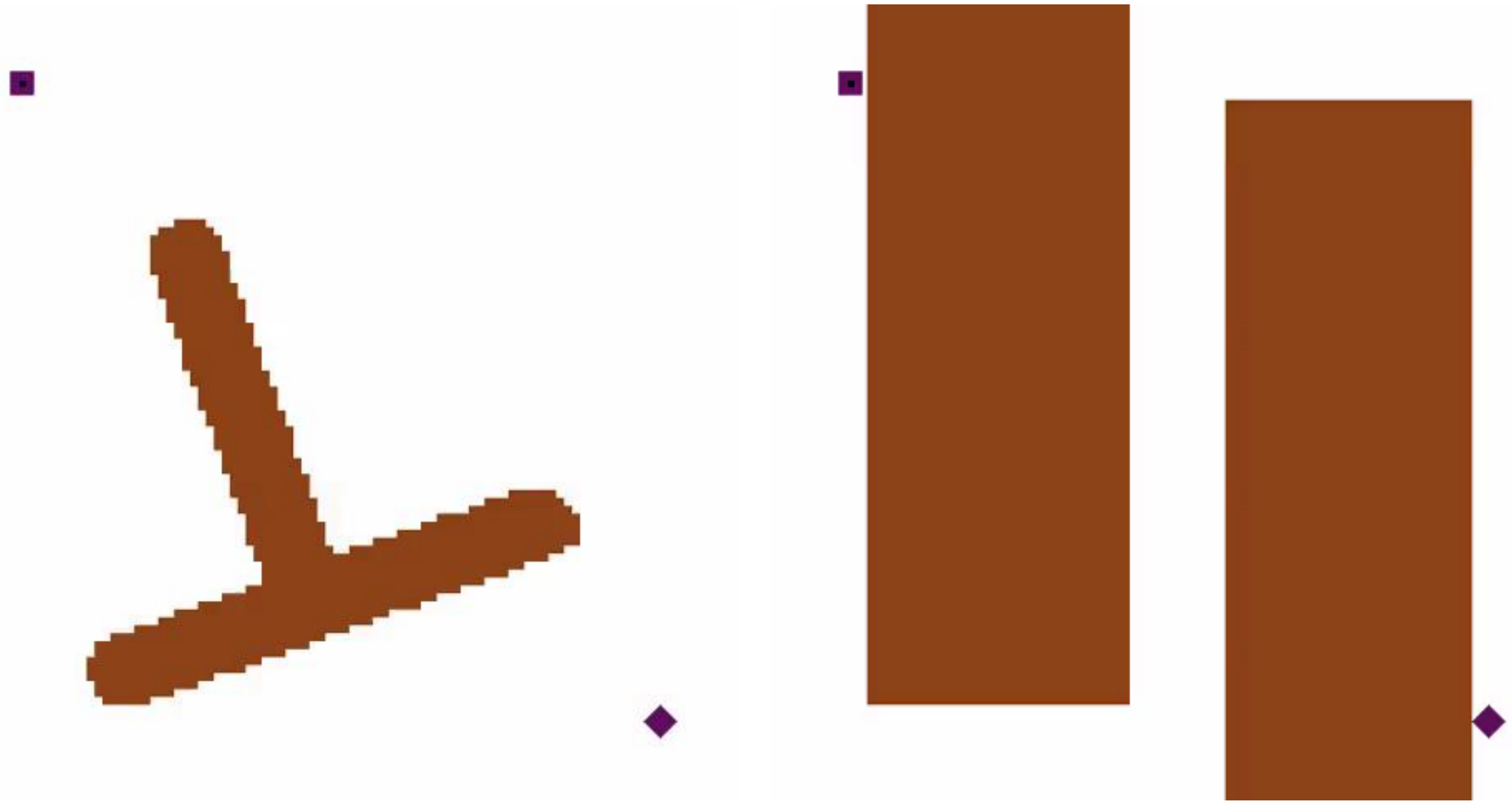


a



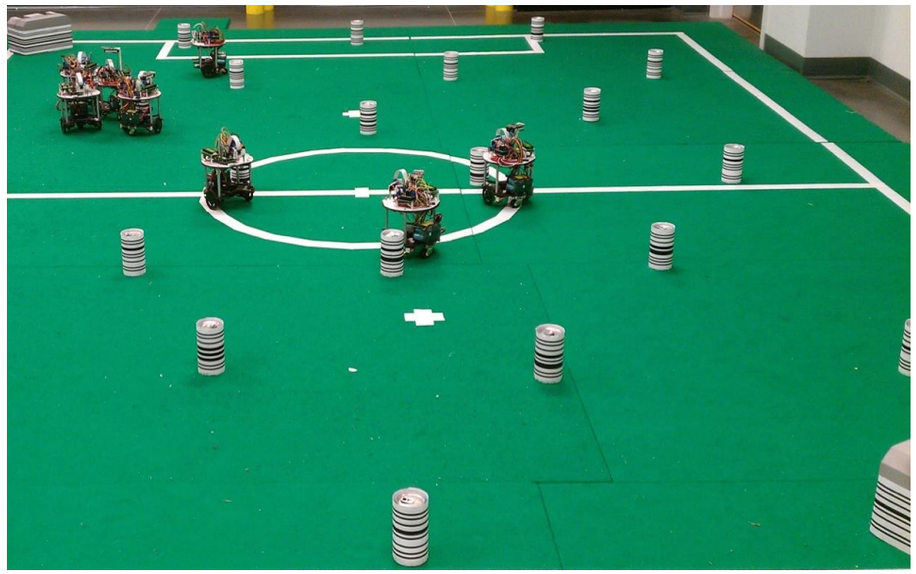
- Deploy motes to build the graph
- Develop the two-pheromone gradient
- Move and remove motes to create an *optimized path.*

More Realistic Foraging Model: Two Pheromones, Deployable/Movable/Removable Sensor Motes

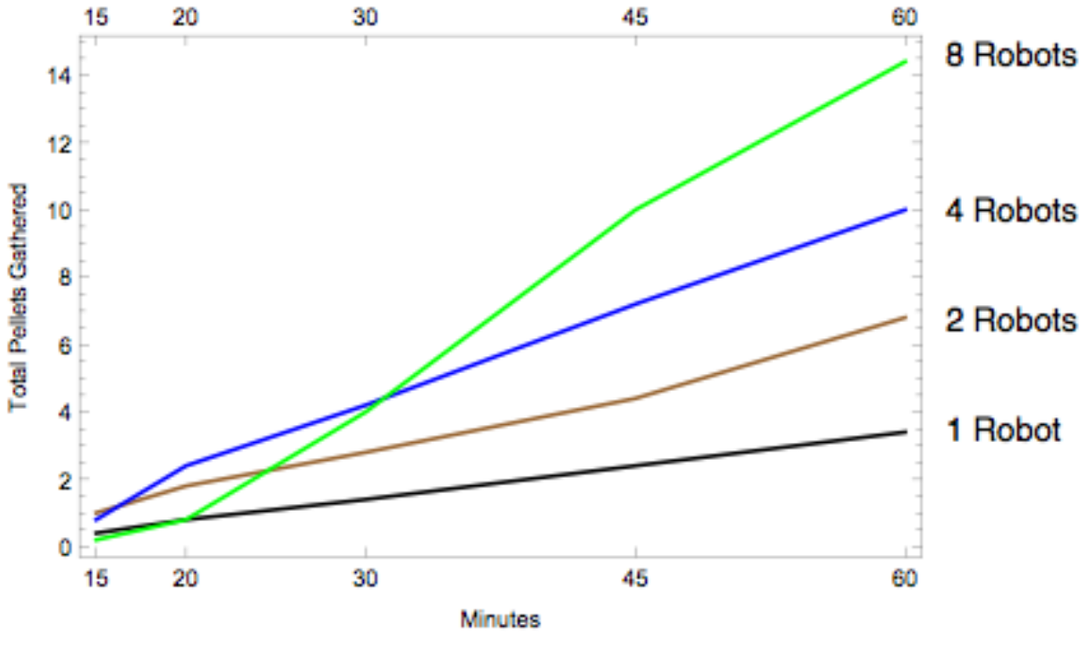


Deployment to Physical Robots

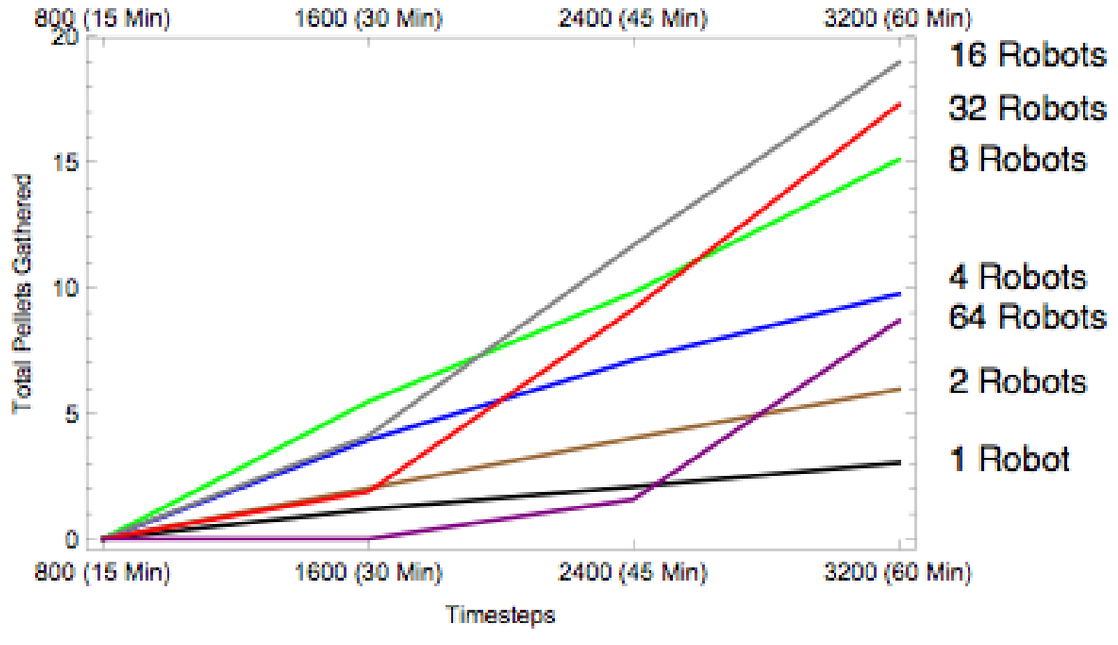
- Sensor motes associated with **cans with barcodes.**



Real Robots



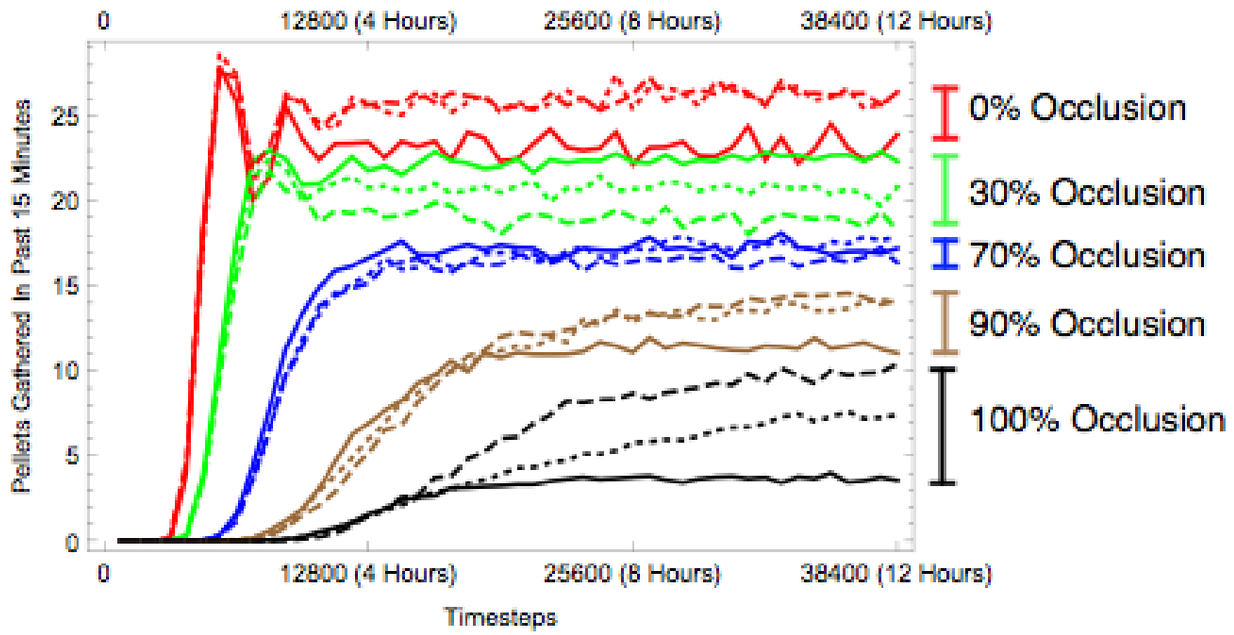
Simulation Validation



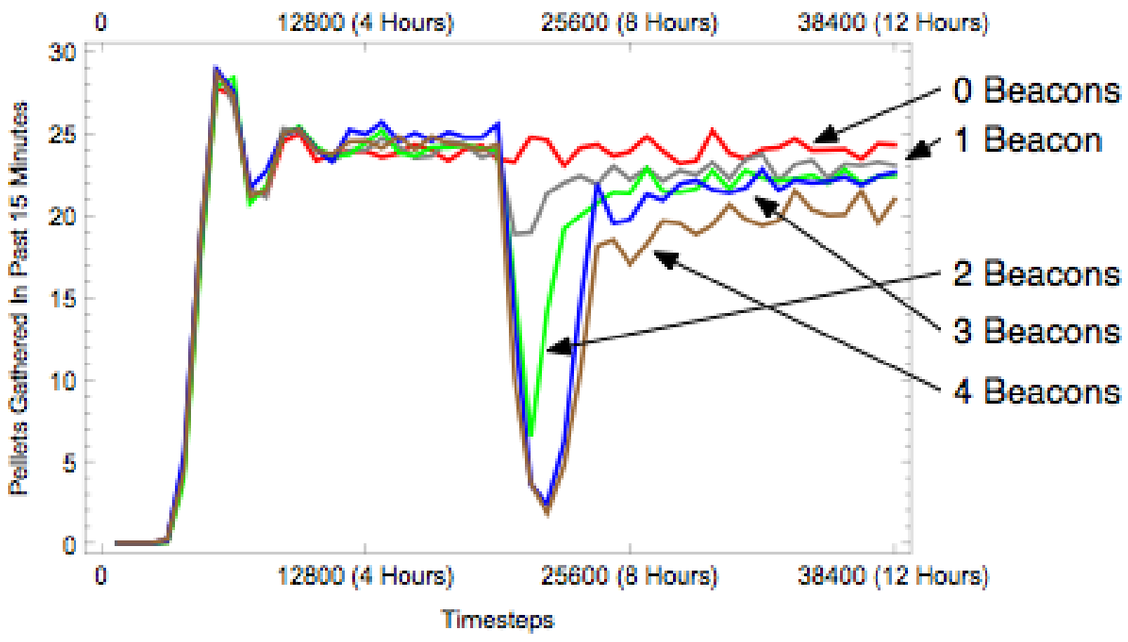
Deployment to Physical Robots

- Real robots/motes cause problems: **occlusion, sensor mote failure**

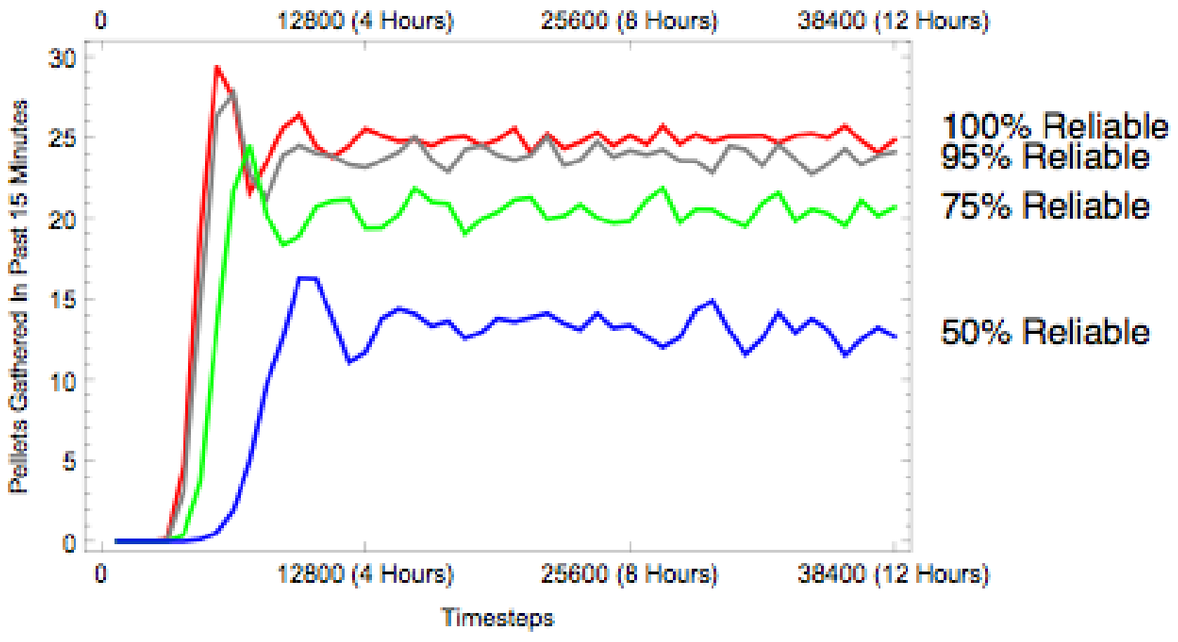
Beacon Occlusion



Wholesale Beacon Removal

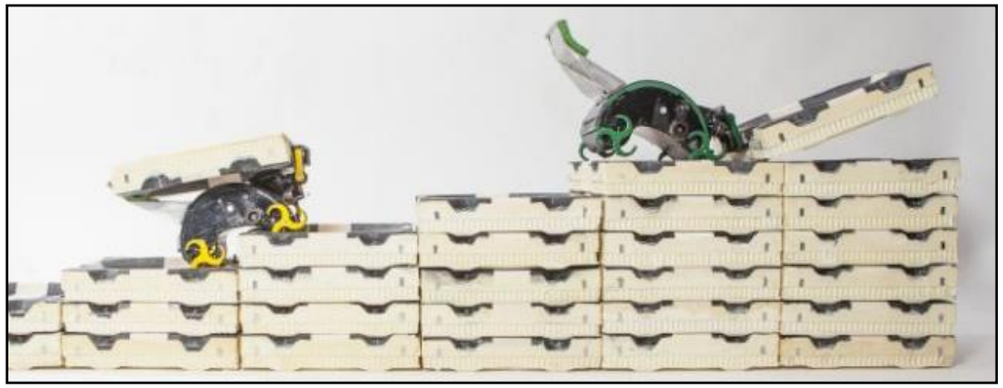


Beacon Reliability

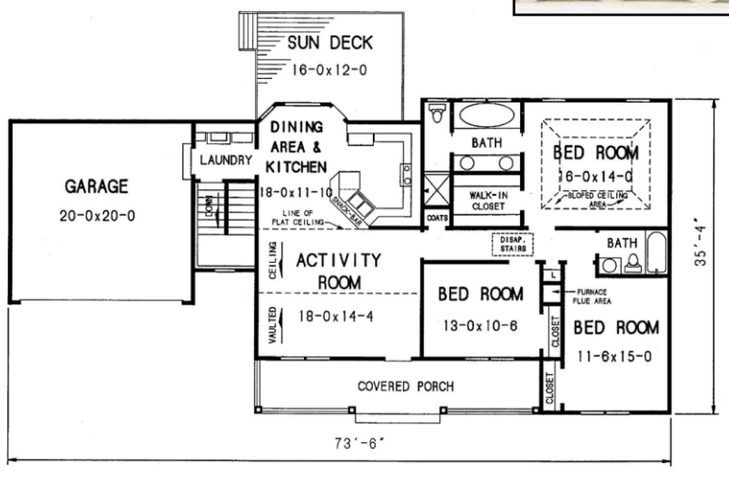


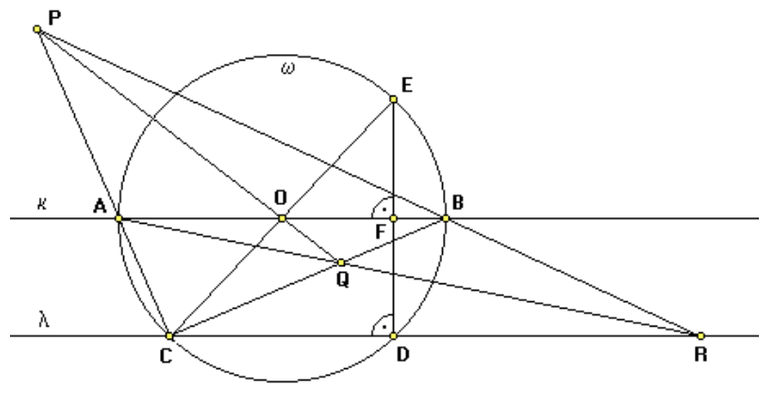
Beyond Foraging: Ant Geometry!

- Swarm Robot Building Construction

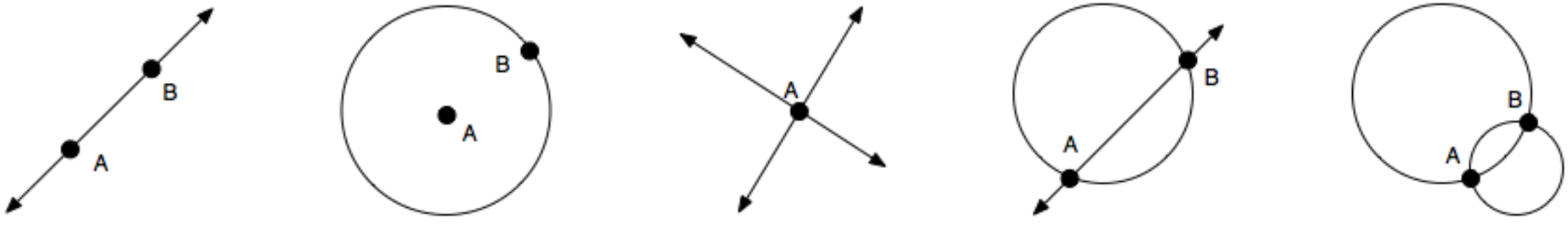


- Lay out the survey lines defining your building

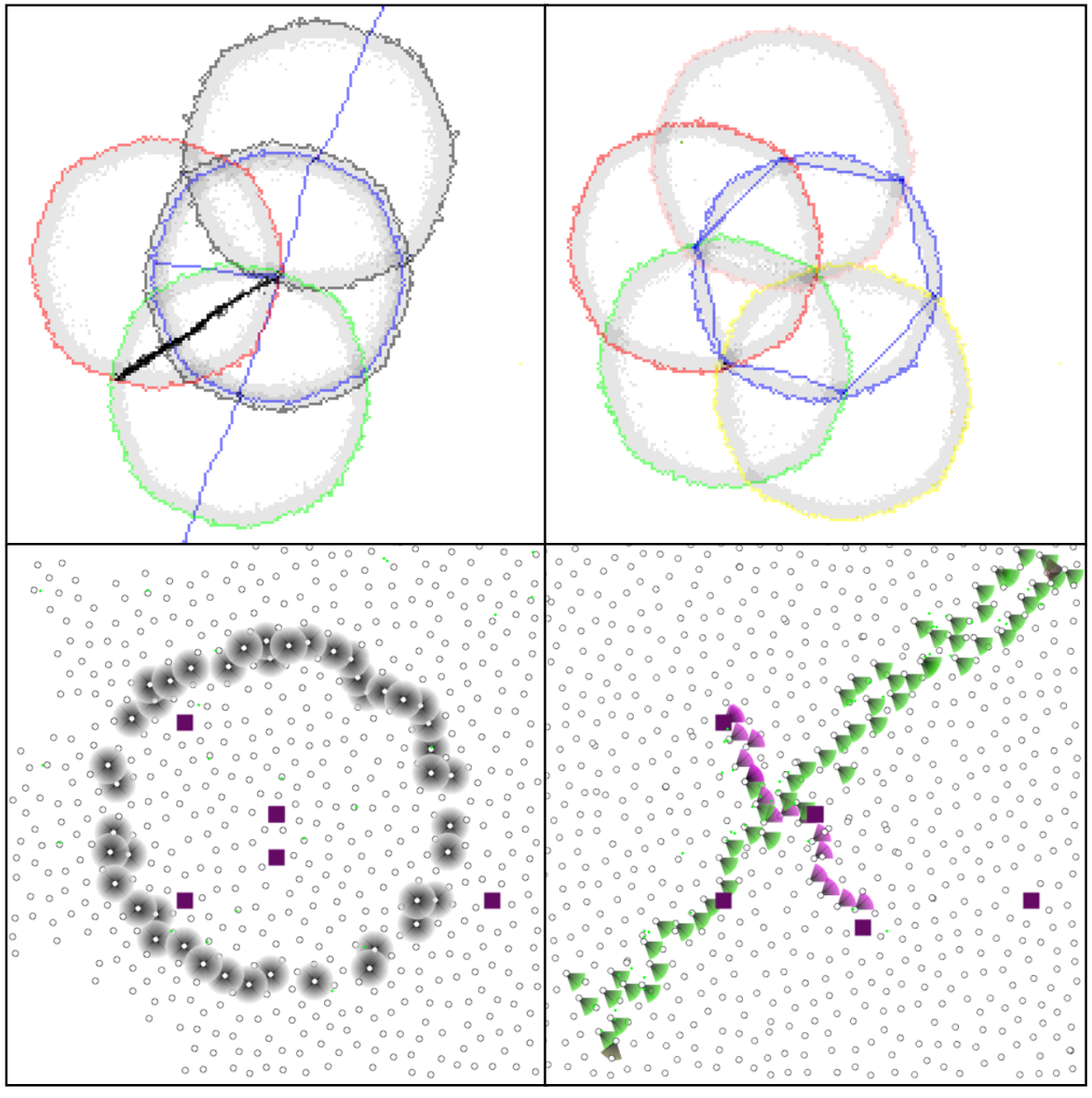




- Compass-Straightedge Geometry (Euclid)

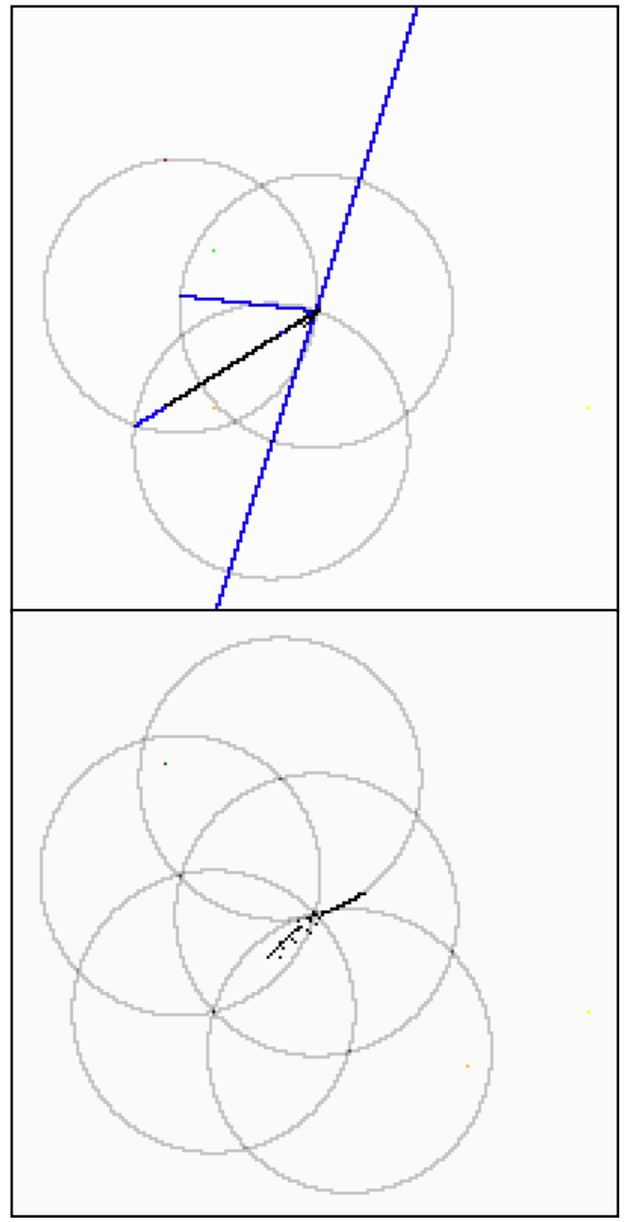


Compass / Straightedge Geometry (Euclid)



Next Steps (and What They Require)

- **Ad-Hoc Networks of Motes**
  Enables: planners distributing tasks throughout whole swarm,
  Enables: agents reporting events globally
  Constraint: tasks/events must be rare (scaling)
  Requires: **rapid, dynamically reconfigurable network topologies**



- **Motes as Local Broadcast Beacons**
  Enables: accurate shapes, fast drawing
  Requires: **distance** and **bearing to motes** (RSSI is terrible)

- **Sensor Motes' use of Sensors**
  Enables: sensor "foveation" (sensors provide low-resolution data, robots move to interest areas for more accurate sensing)

Where I Think Swarm Technologies Must Go

- **Ad-Hoc Networks of Motes**
  Enables: planners distributing tasks throughout whole swarm,
  Enables: agents reporting events globally

- **What is Wrong with the Classic Distributed Model of Swarms**
  - ***Sophisticated*** coordination has proven nearly impossible, due to lack of any control or communication with global reach

- Ultimately we will need to study hybrid models between fully distributed and fully centralized control
  - Hierarchies?
  - Swarms + Planners?

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