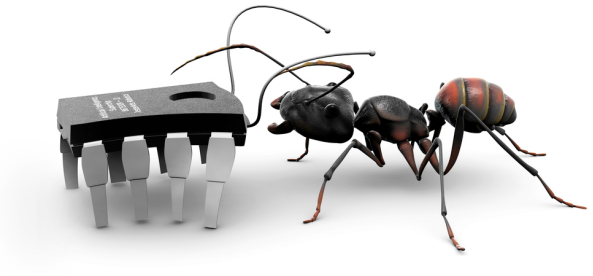


Swarm Robotics:

Biologically-inspired solutions to large-scale engineering challenges

Joshua P. Hecker

Moses Biological Computation Lab

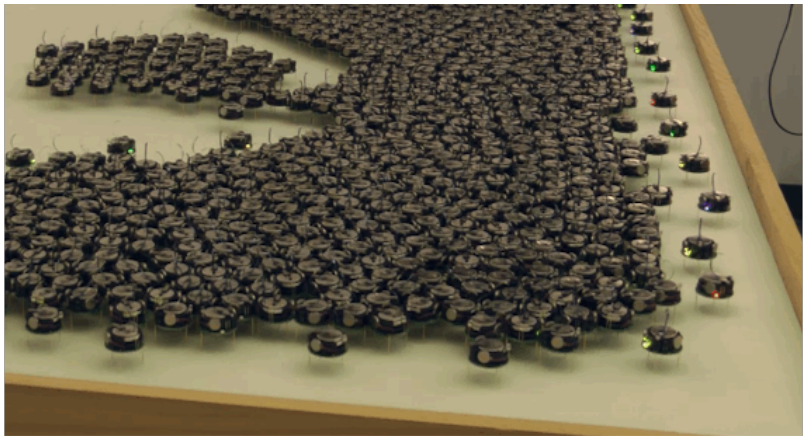
Postdoctoral Fellow, UNM CS

From Biology to Engineering

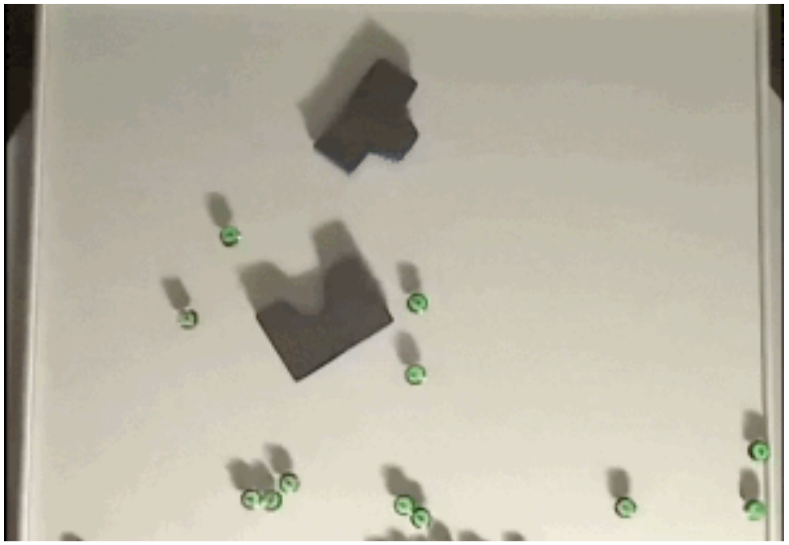
Inspiration

Implementation

Flocking



Collective Transport



Outline

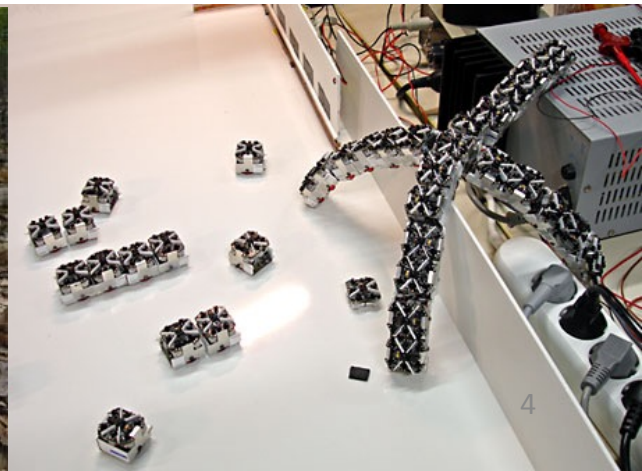
- Introduction to swarm robotics [Brambilla 2013]
  - What's a swarm?
  - Examples of collective behavior
- Open research topics:
  - Foraging
  - Construction
- UNM swarm testbeds:
  - iAnt Project
  - NASA Swarmathon

Swarm Robotics

“The study of how large numbers of relatively simple physically embodied agents can be designed such that a desired collective behavior emerges from the local interactions among agents and between the agents and the environment.”

— Erol Şahin

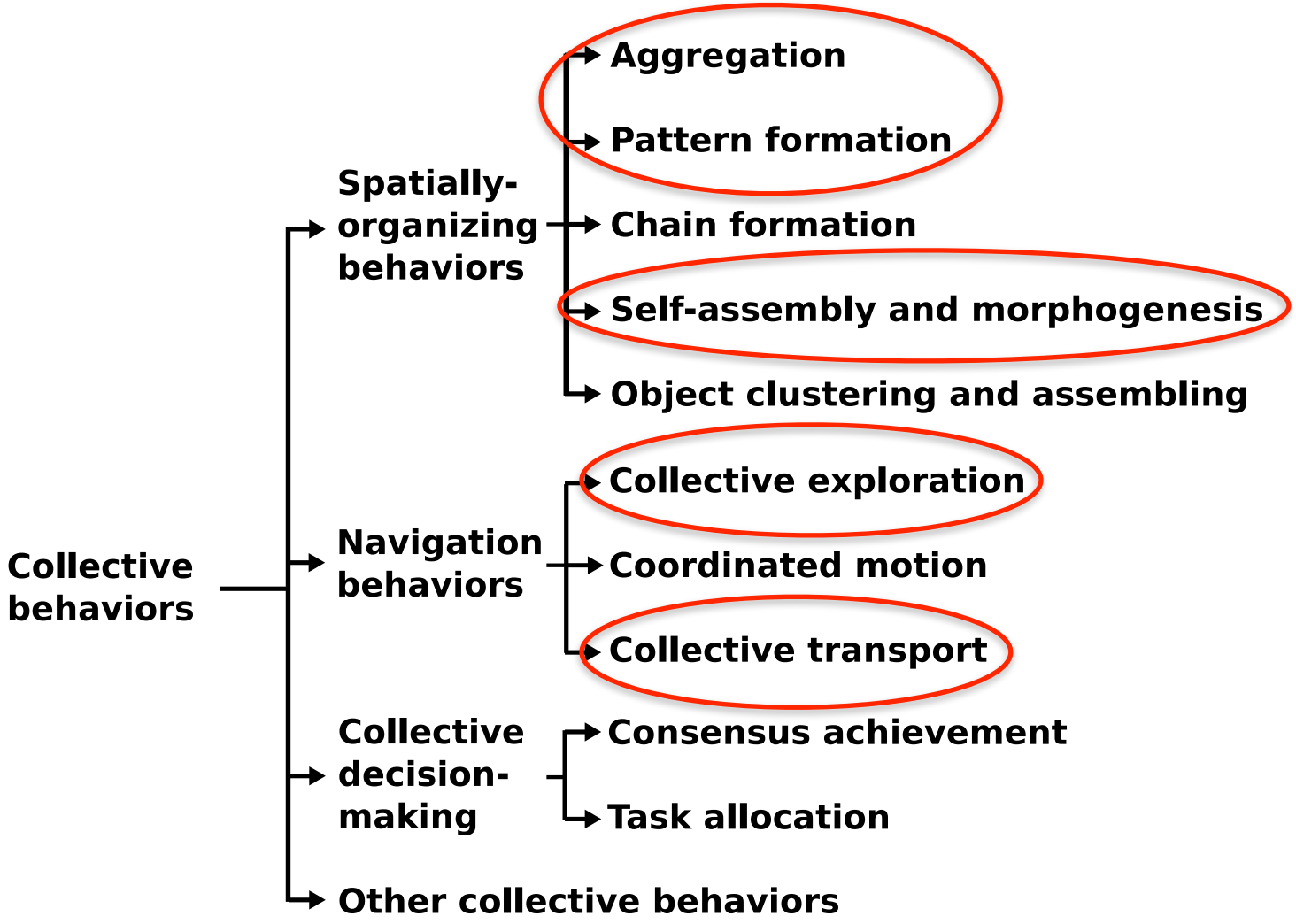




What's a swarm?

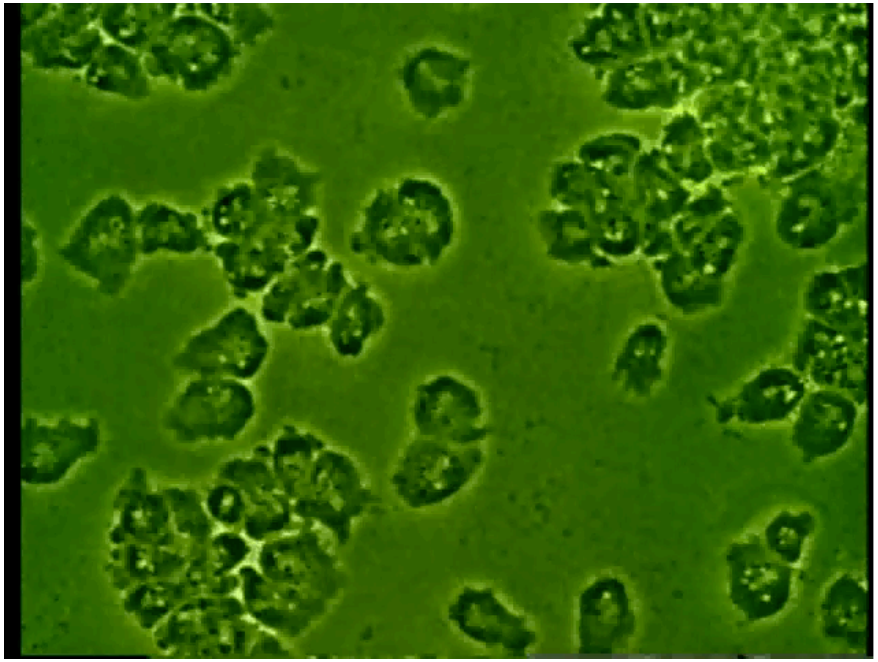
- Characteristics of a swarm robotics systems:
  - Robots are **autonomous**
  - Robots are **situated** in the environment and can act to modify it
  - Robots use **local sensing and communication** capabilities
  - Robots do not have access to **centralized control** or **global knowledge**
  - Robots **cooperate** to tackle a given task

A Taxonomy of Collective Behavior



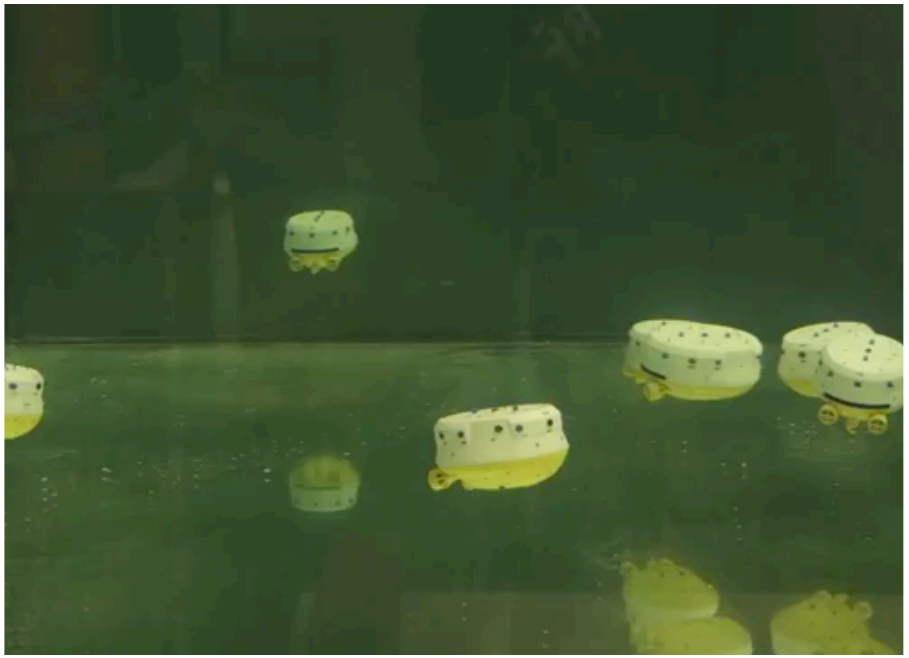
Aggregation

Biological inspiration



Cellular slime mold, The Cell image library

Engineering implementation

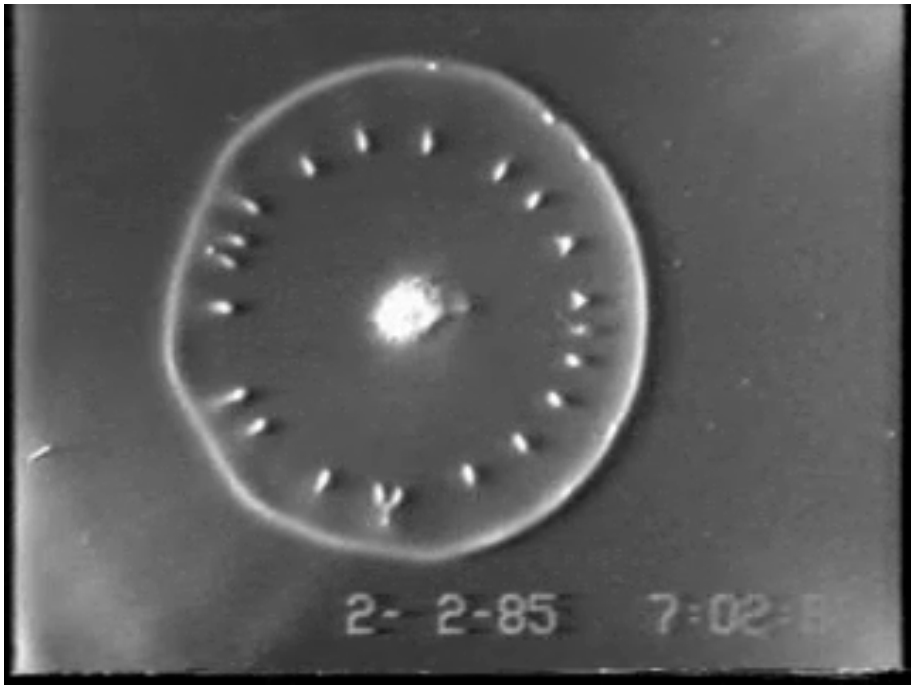


AUV swarm, CoCoRo lab, University of Graz

Individuals use local sensing and simple rules to locate neighbors, then taxis/actuation to collectively aggregate

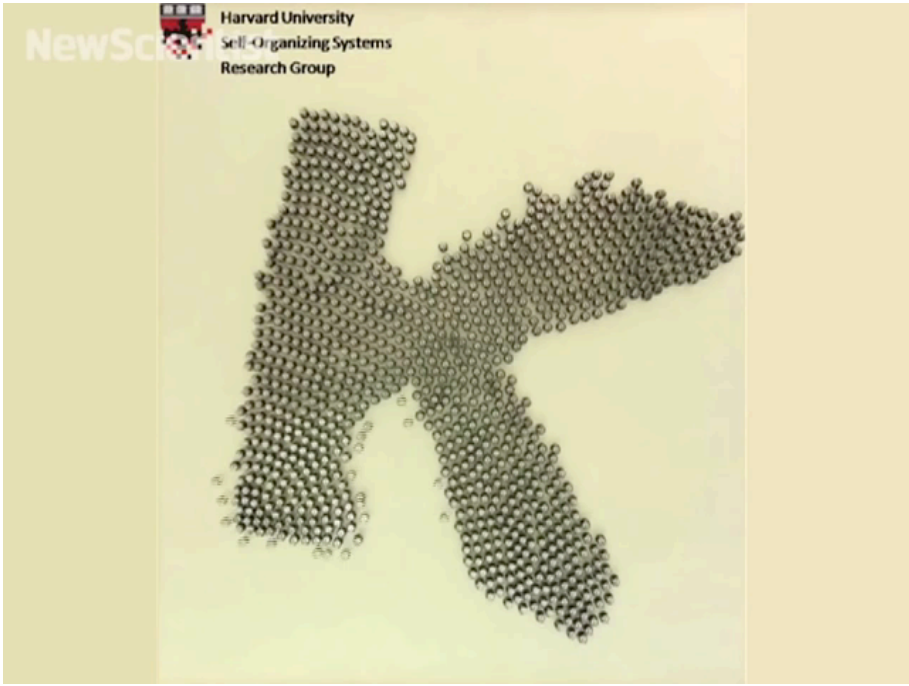
Pattern formation

Biological inspiration



Escherichia coli, Howard C. Berg, Harvard

Engineering implementation



Kilobots, SSR Research Group, Harvard

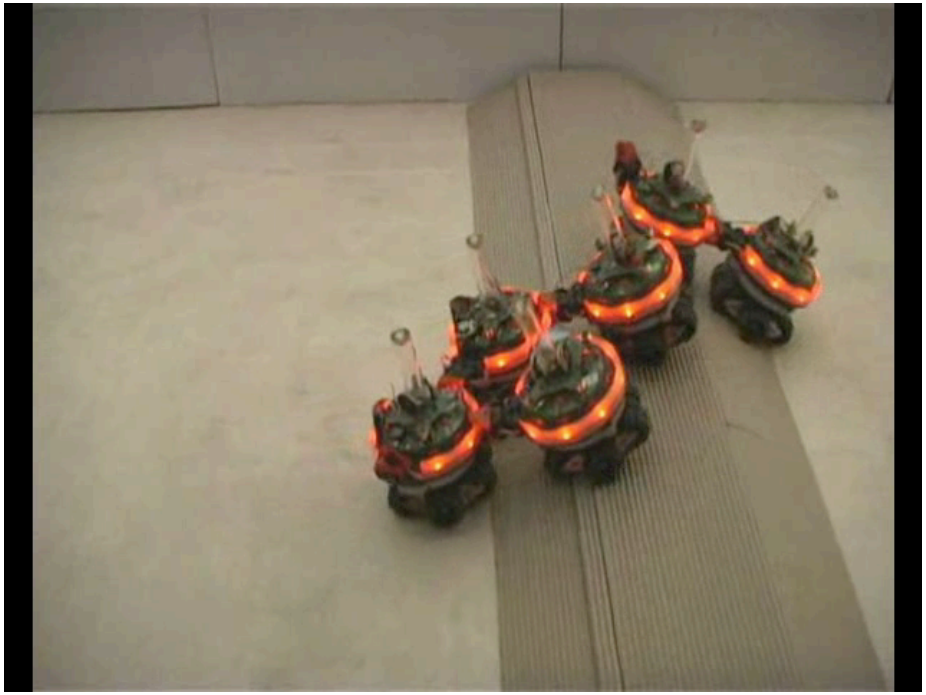
Individuals space themselves apart at specific distances; collective pattern can be emergent or, in robots, pre-specified

Self-assembly

Biological inspiration

Weaver ants, Department of Bioscience, Aarhus University

Engineering implementation



S-bot swarm, IRIDIA, Université libre de Bruxelles

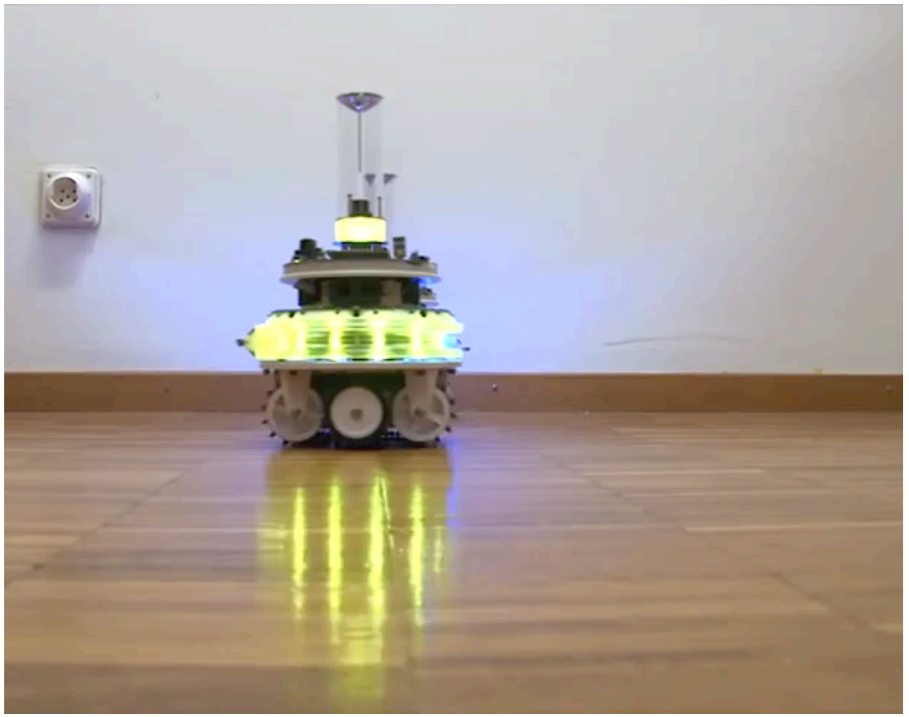
Individuals physically connect to each other to form a structure appropriate for accomplishing a specific task

Collective exploration

Biological inspiration

Argentine ants, CRCA, University Paul Sabatier

Engineering implementation



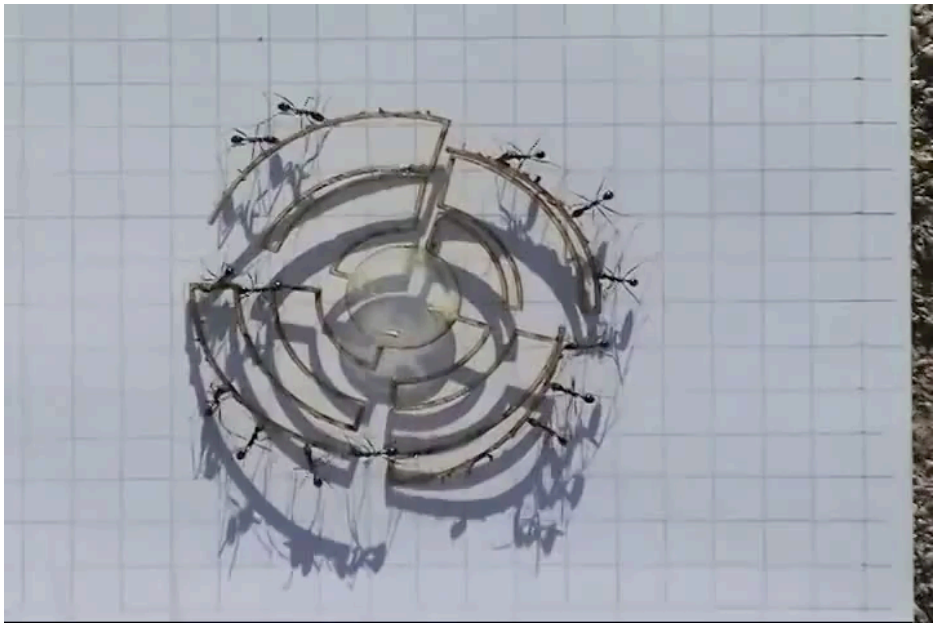
Swarmanoid, IRIDIA, Université libre de Bruxelles

Individuals focus on covering an area in search of resources, then use the discovered path(s) to exploit resources

Collective transport

Biological inspiration

Engineering implementation



Aphaenogaster cockerelli, Pratt Lab, Arizona State University

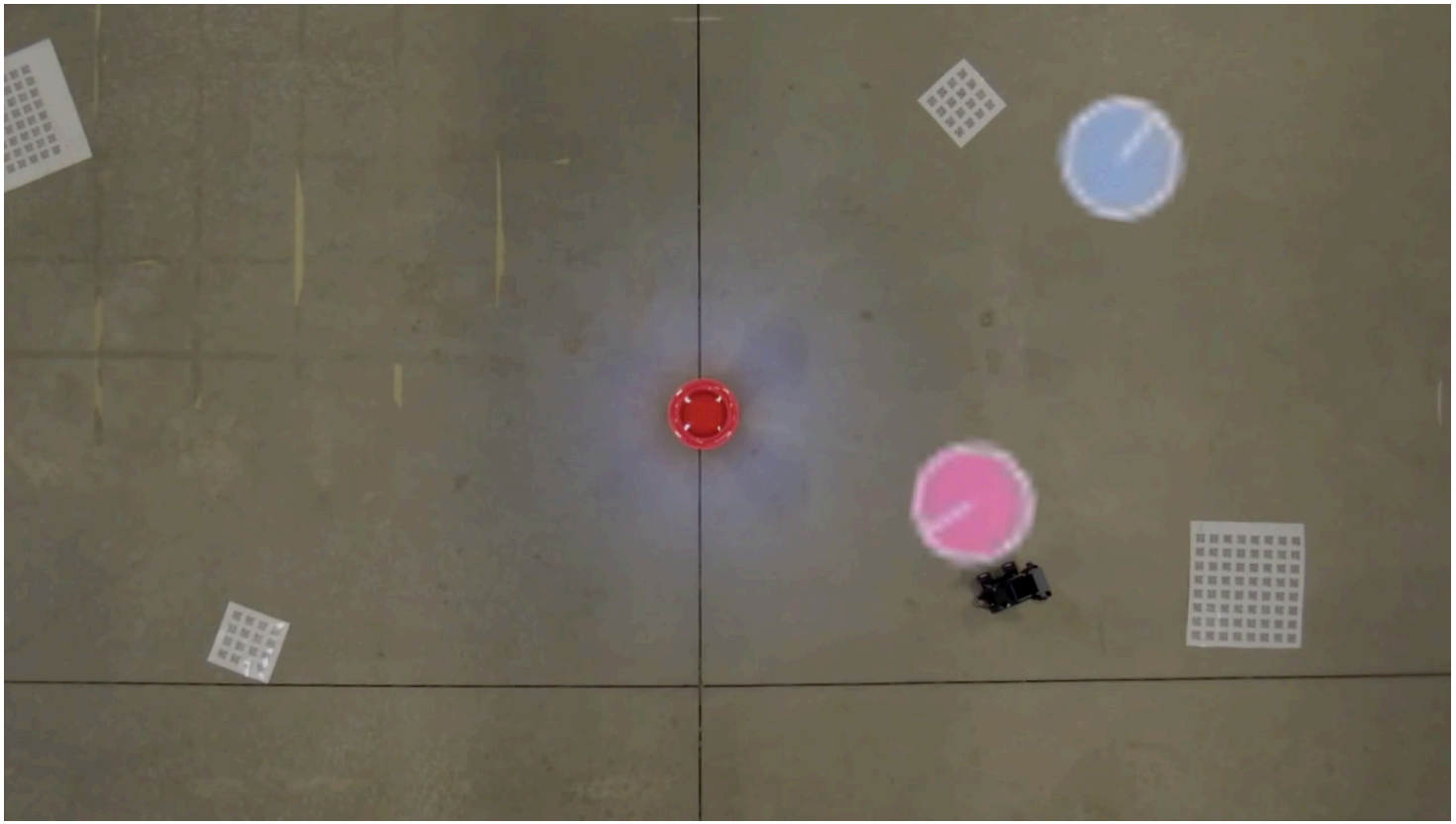
S-bot swarm, Mobots Group, EPFL

Individuals cooperate to transport a heavy object that cannot be moved by a single agent

Open research topics

- Testbed applications:
  - **Foraging** = collective exploration + collective transport + collective decision-making
  - **Construction** = object clustering + collective transport + collective decision-making
- **iAnt Project:**
  - Central-place foraging algorithm (**CPFA**)
- **NASA Swarmathon:**
  - In-situ resource utilization (**ISRU**)
  - Hands-on robotics education

Central-place foraging algorithm

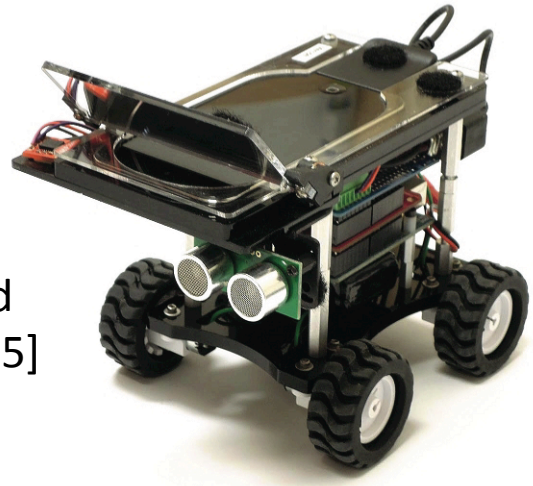


- Mimic foraging behaviors observed in desert seed-harvester ants
- Efficiently explore with correlated random walk
- Return via memory or communication
- Movement, memory, and communication tuned by GA

Why foraging robot swarms?

- Robot swarms are:
  - Relatively cheap
  - **Tolerant** of sensor errors
  - **Flexible** for multiple settings
  - **Scalable** to large swarm size

} [Hecker and Moses, 2015]



iAnt robot

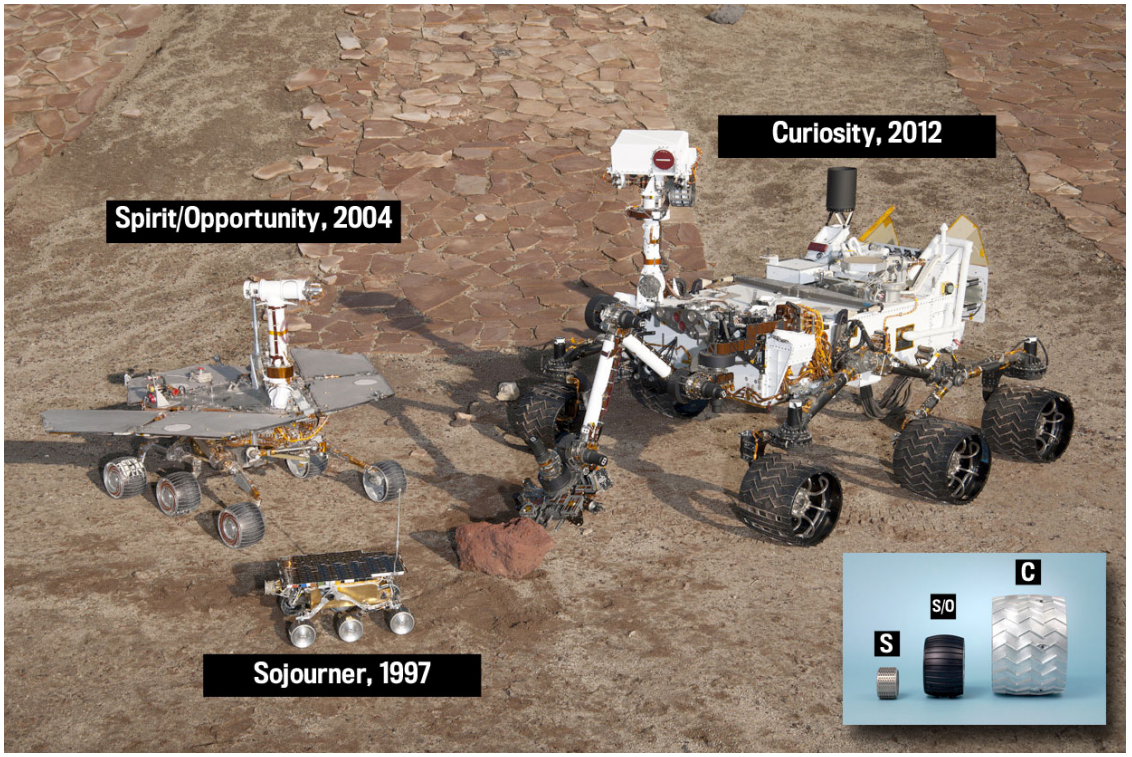
- Foraging swarms exemplify real-world tasks:
  - In-situ resource utilization
    - e.g. Lunar water
  - Environmental monitoring
  - Hazardous waste clean-up

Foraging iAnt robot swarm

Extraplanetary exploration

NASA rovers explore Mars (chiefly) via tethered control

- Pros:
  - Durable, long-lasting
  - Relatively flexible
  - Superb feat of engineering
- Cons:
  - Expensive (multibillion $$)
  - Many-to-one control
  - Monolithic
  - Redundancy ≠ scalability



Evolution of NASA's Martian rovers

Can we do better?

- Engineer autonomy to avoid single point of failure
- Use algorithms that adapt to change
- Reduce HW/SW/operator costs

Extraplanetary exploration

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NASA/UNM robot swarms

Can we do better?

- Engineer autonomy to avoid single point of failure
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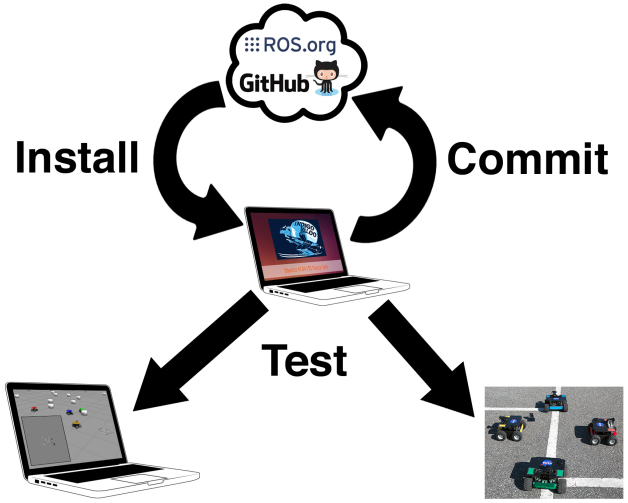
- Reduce HW/SW/operator costs

Yes! With foraging robot swarms…

JOIN THE SWARM

NASA Swarmathon

- 20 college teams, each given 3 robots at **no cost**
- Teams learn C++, ROS, git
- Winning algorithms balance global vs. local exploration and minimize collisions



Questions?