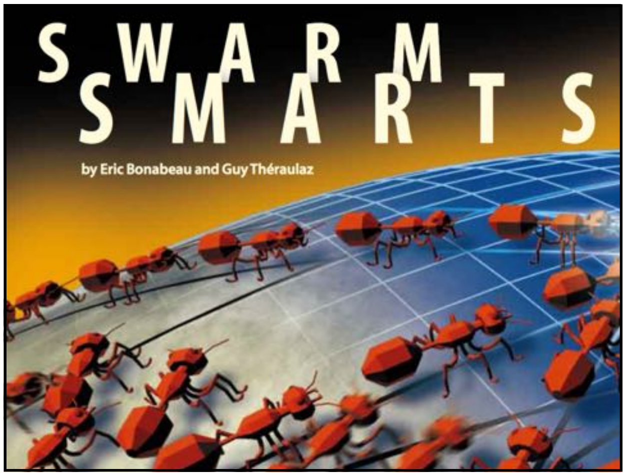
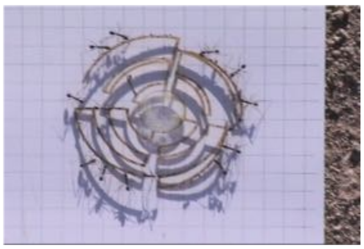


CS289: Collective Transport

Stephen Pratt, Arizona State University

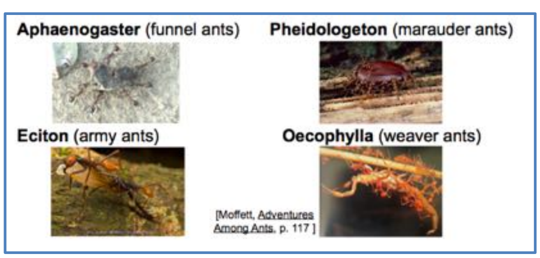
Stephen Pratt,
Spring Berman,
Arizona State University



Collective Transport in Ants

Evolved independently several times, but developed to much higher levels in some species.

Holldobler & Wilson, The Ants; Moffett, Adventures Among Ants; Exists in 40/283 genera



Why Evolve Collective Transport?

- Group raiders (e.g. army ants)
  - Massive colonies need large intake of fresh prey, high rates of prey capture, and efficient movement of large prey. Lifting big prey can be more efficient ("super-efficiency").
- Desert ants (e.g. Aphenogaster)
  - Not as aggressive, group retrieval is important to rapidly escape competition by other ants (cut and eat in secure home!)

Solution: "Distributed Consensus" Problem

- Most cases, if ants can agree on direction towards nest, and align forces, then they will be successful.

Key Open Question:

– How **"simple"** can ant be and still execute this behavior?
– How much **"coordination"** is required?

Discussion 1

What are the criteria and constraints for a successful cooperative transport algorithm?

On the "Global Goal"
(e.g. obstacle type, success metric, terrain)

On the "Agent"
(e.g. sensing requirements, actions, prior/global knowledge)

Collective Transport by Robots

Many Applications and Many approaches!

- Warehouses, automated construction, mining, manufacturing, disaster response….
- But unclear how sophisticated a robot needs to be?

Original
(Kube&Zhang, Maja Mataric)

Ant-Inspired
(e.g. swarmbot)

Control Theory
(e.g. caging, towing, etc)

Collective Transport by Robots

- Many Complexities
  - Manipulators: push-only, pull-only (towing), push-pull, lift
  - Global Knowledge: goal (localization), object details, localization
  - Communication and Sensing (neighbors, forces)

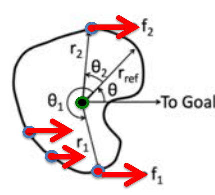
  Current paper has excellent Related Work section.

- **Ant-Inspired Approaches**
  - Box-pushing (e.g. Kube-Zhang, Maja Mataric), SwarmBot (e.g. Dorigo)
    At the time, no mathematical understanding
  - **Recent (e,g, current paper) Mathematical proofs**
    - Proof that you can often get away *with little to no coordination*!
    - Impacts both robots and biology.

- **Control Theory approaches**
  - Caging, Towing, Lifting (e.g. Kumar Upenn)
  - More industrial focus: *precision* manipulation (& analyzable)
  - Often assumes object shape/parameters is fully known in advance.

Modeling Collective Transport: Part 1

Proof Structure! For collective behavior
1. **Make simplifying assumptions** on agents and problem.
2. **Predict composite action for *dt time step*** [composite *Translation and Rotation*]
3. **Prove convergence** [i.e. for every time step, distance to goal *strictly decreases*]



What If every agent can always see/orient and apply force in the direction of the nest?

Can the agent act without any knowledge of mates or object shape?

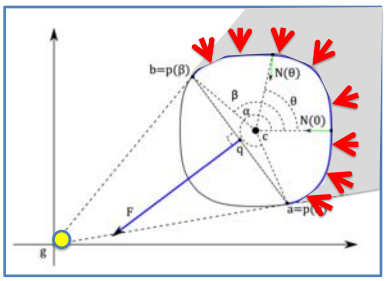
Rubenstein et al, "Collective Transport of Complex Objects by Simple Robots: Theory and Experiments", AAMAS 2013

Key Results: *(video)*
- Can predict **minimum agents** and **velocity scaling** from object properties (mass.friction)
- **Agnostic!** (agent position, shape/COM, doesn't matter)

Modeling Collective Transport: Part 2

Proof Structure! For collective behavior

1. **Make simplifying assumptions** on agents and problem.
2. **Predict composite action for *dt time step*** [composite *Translation and Rotation*]
3. **Prove convergence** [i.e. for every time step, distance to goal *strictly decreases*]



What If agents can only push? And they can't see the nest if the object is in front of them….

Can the agent act without any knowledge of mates or object shape?

Today's Reading 2

Videos

More Discussion/Project Topics

- Explicit communication between robots
  - When/how would this help?
- Humans
  - What mechanisms do we use? Is explicit communication (talking) necessary?
- Complex Terrains
  - Ants/Robots navigating terrains with obstacles.
  - Ants climbing up walls