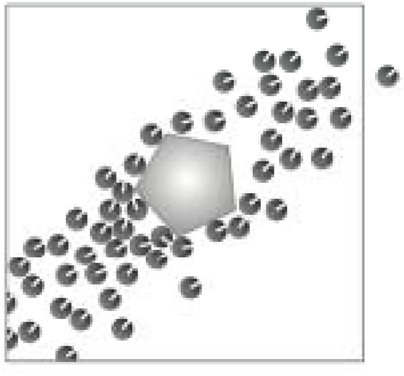
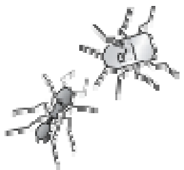
Swarm Robotics



Lecturer: Roderich Gross



Outline

Why swarm robotics?

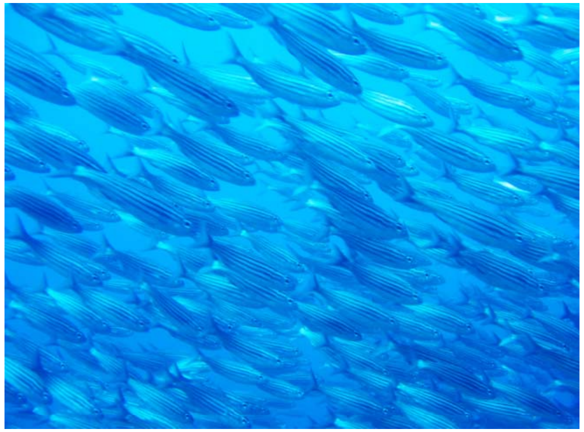
Example domains:

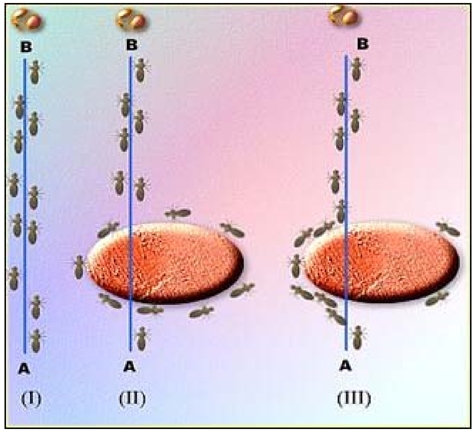
- Coordinated exploration
- Transportation and clustering
- Reconfigurable robots

Summary

Stigmergy revisited

Sources of Inspiration

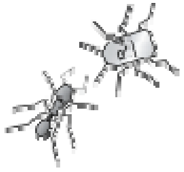




Example

Key Properties

- Composed of many individuals
- The individuals are relatively homogeneous.
- The individuals are relatively incapable.
- The interactions among the individuals are based on simple behavioral rules that exploit only local information.
- The overall behavior results from a self-organized process.



Technological Motivations

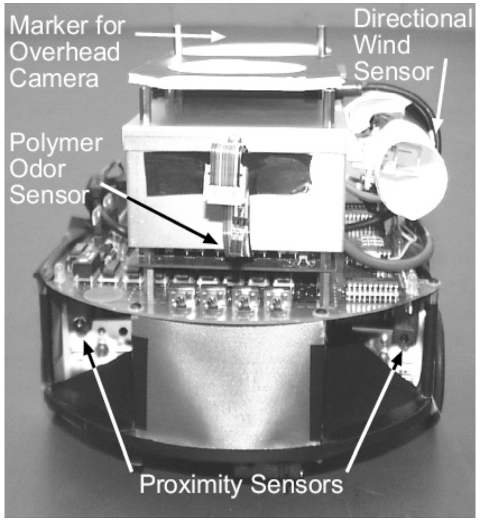
- Robustness
- Scalability
- Versatility / flexibility
- Super linearity
- Low cost?

Coordinated Exploration

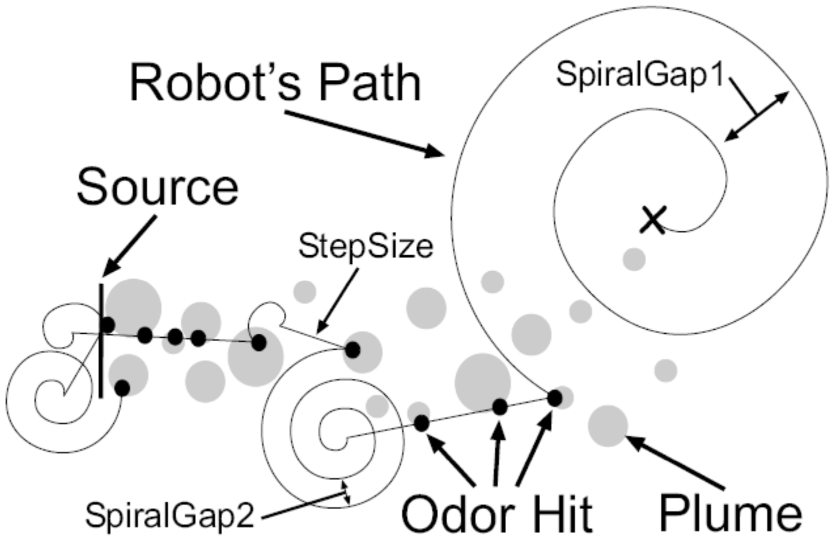
1. Environmental monitoring
2. Pheromone robotics
3. Chaining

Example 1: Environmental Monitoring

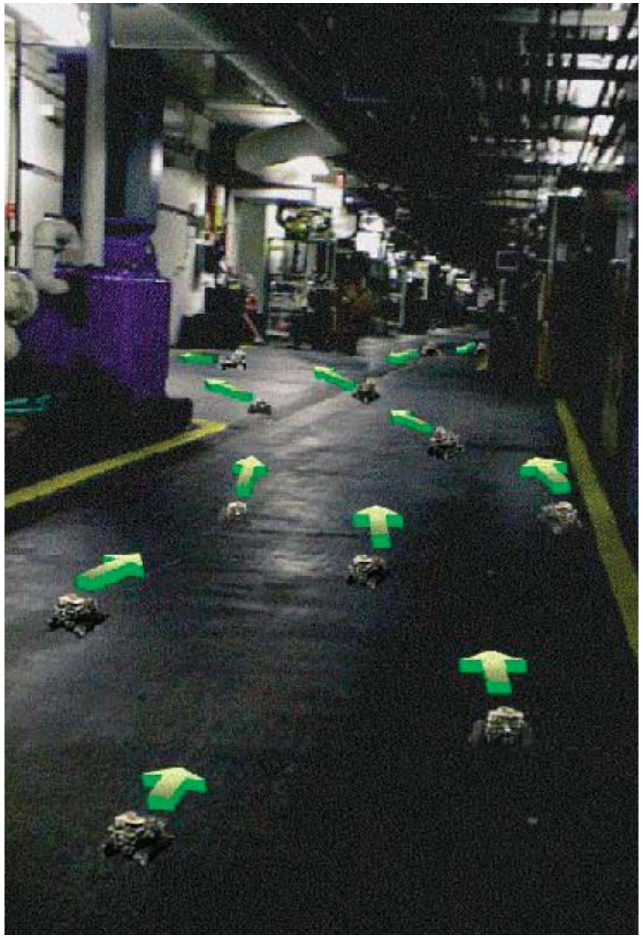
- Swarm of mobile robots for localizing an odor source
- Simple behaviors based on odor and wind detection
- Communication can help to increase the efficiency.



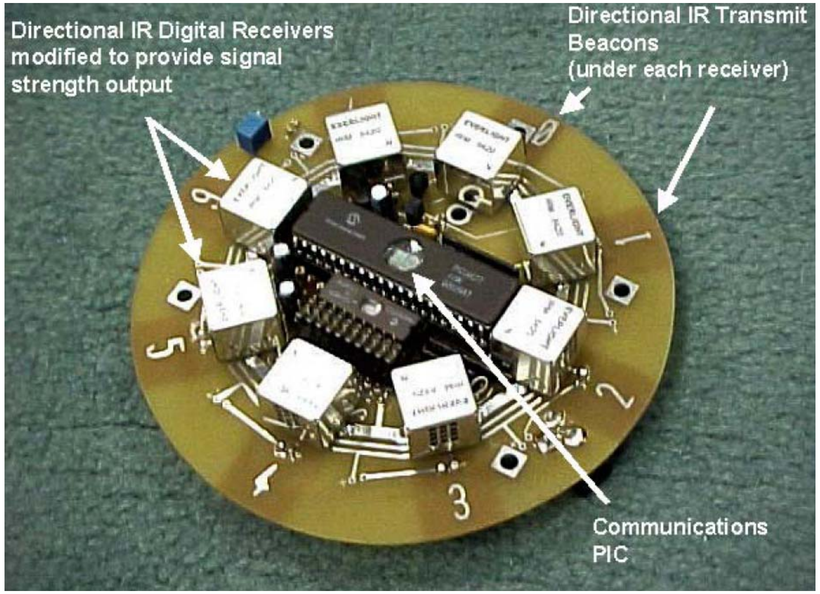
Hayes et al., 2002



Example 2: Pheromone Robotics



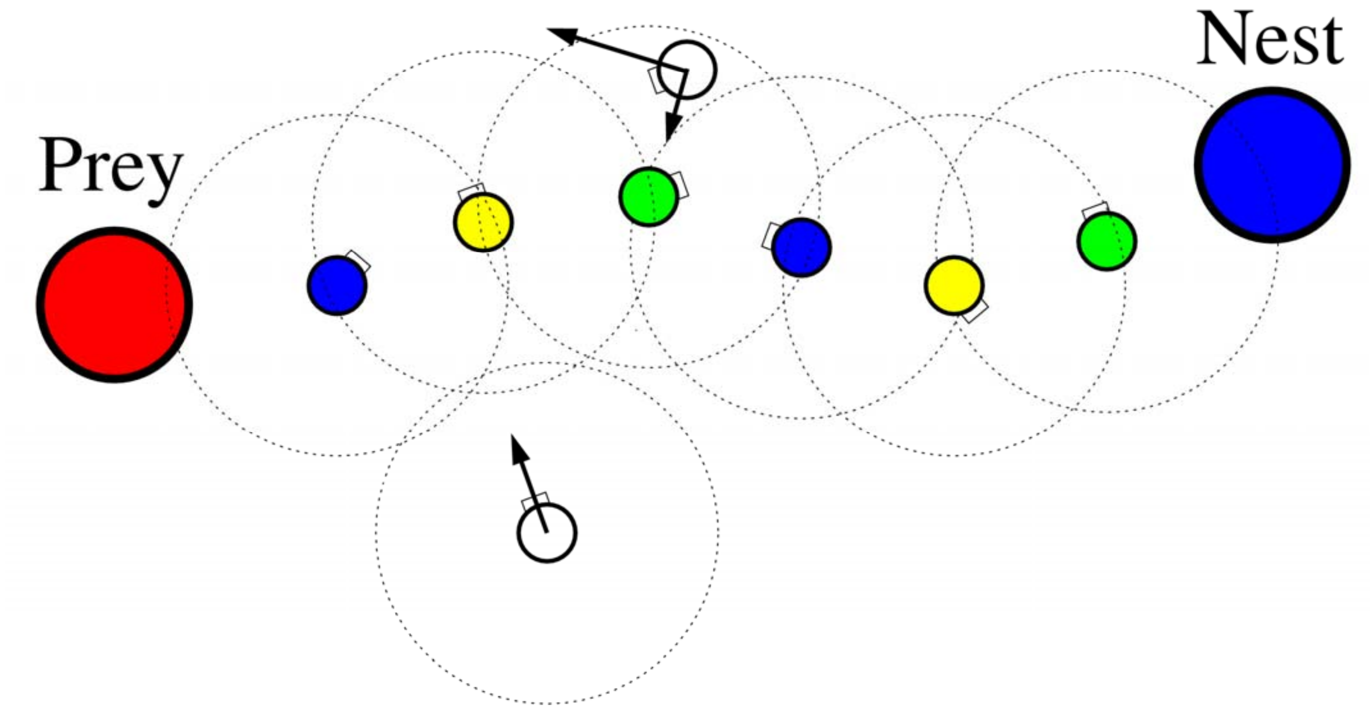
Payton et al., 2005



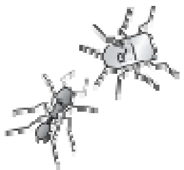
- robot dispersion
- gradient (via hop counts)
- shortest path
- pheromone diffusion / evaporation

Example 3: Chaining

- Limited sensing range
- Signaling of colors (directional chains)

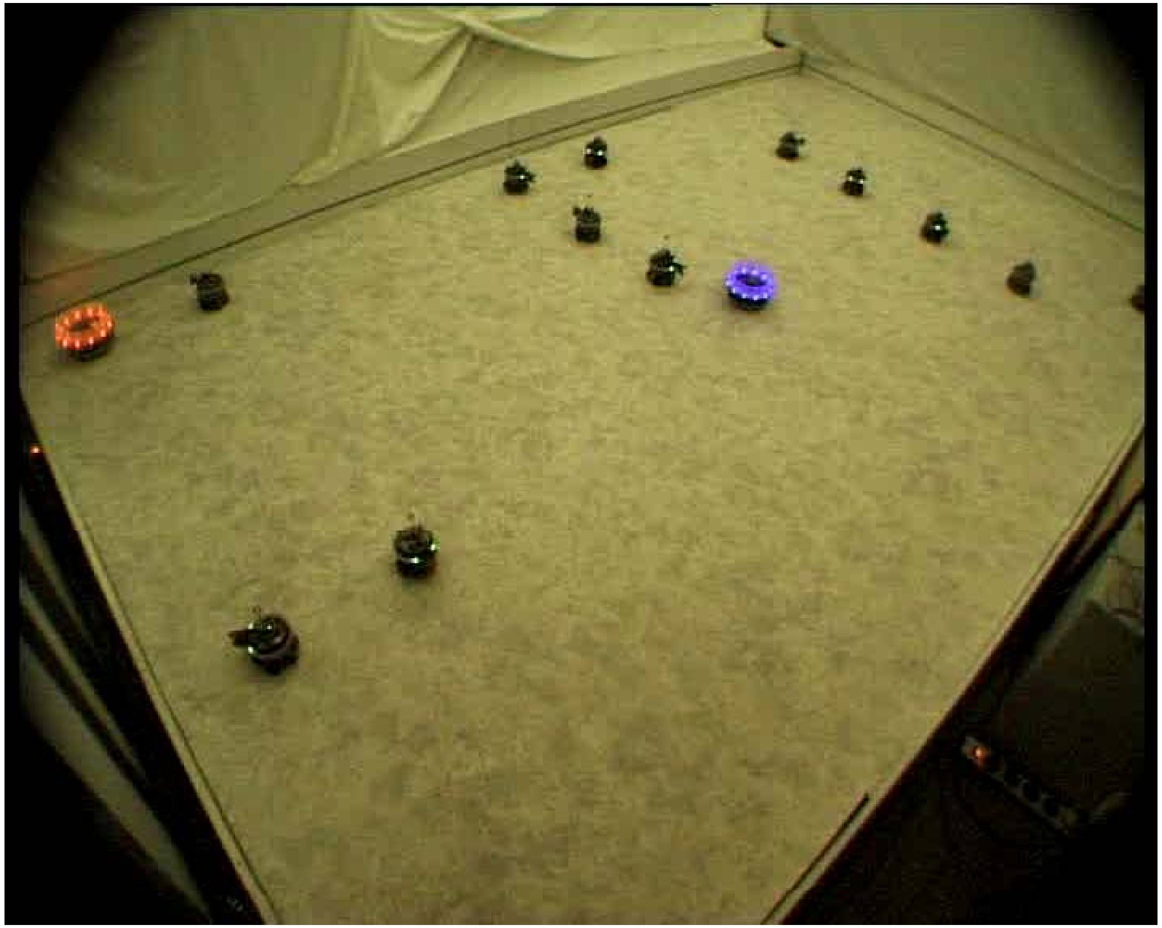


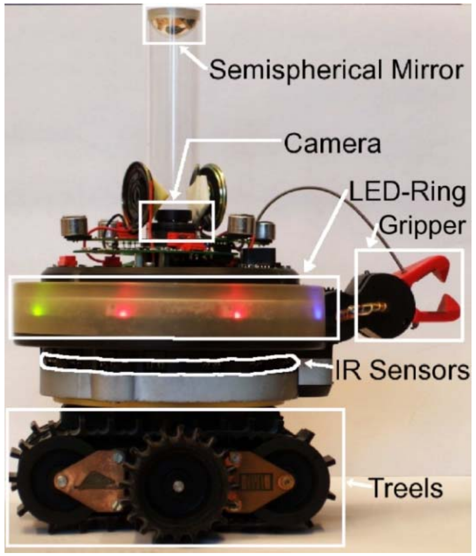
Nouyan et al., 2009



Example 3: Chaining (Cont.)

Mondada et al., 2005





Chains in prey retrieval (division of labor)
Nouyan et al., 2009

Transportation and Clustering

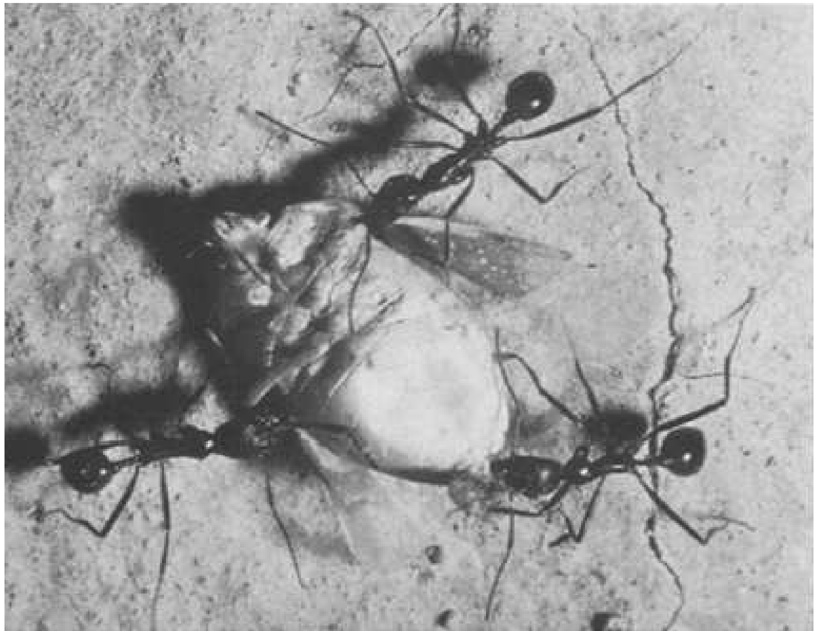
1. Coordinated box pushing
2. Blind bulldozing
3. Clustering
4. Cooperative Manipulation

Example 1: Coordinated Box Pushing

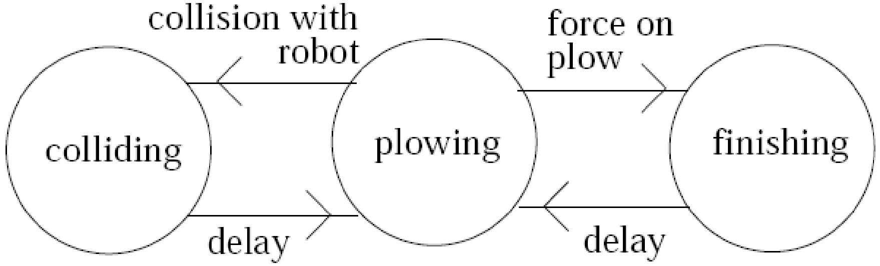
- Task requires cooperation
- No explicit communication
- Behavior-based approach
- Ant-inspired stagnation recovery mechanism

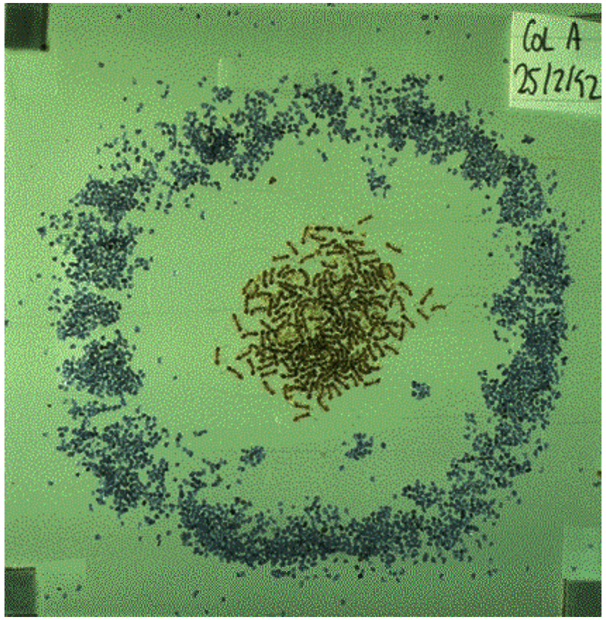
Kube and Zhang, 1993;
Kube and Bonabeau, 2000

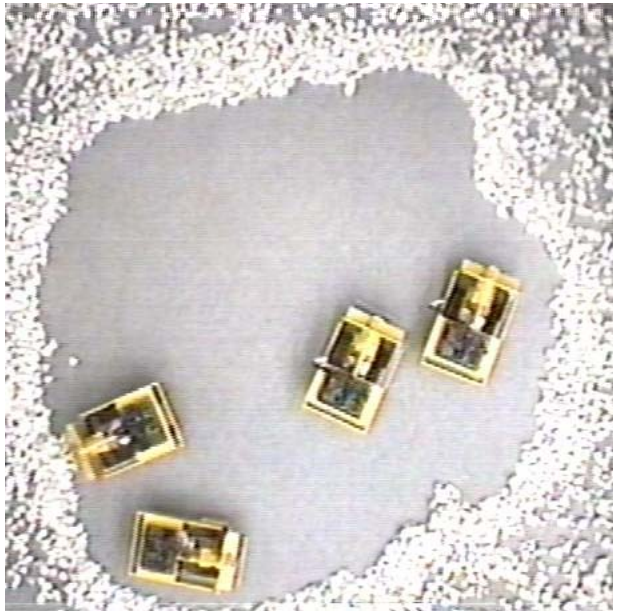
Hoelldobler et al., 1978



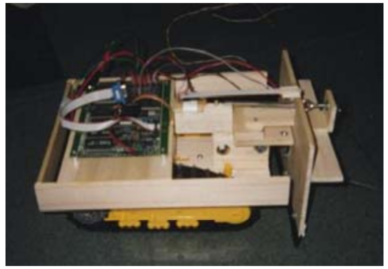
Example 2: Blind Bulldozing







Force sensitive plow



Nest construction by ants
Franks et al., 1992

Nest construction by robots
Parker et al., 2003

Example 3: Clustering

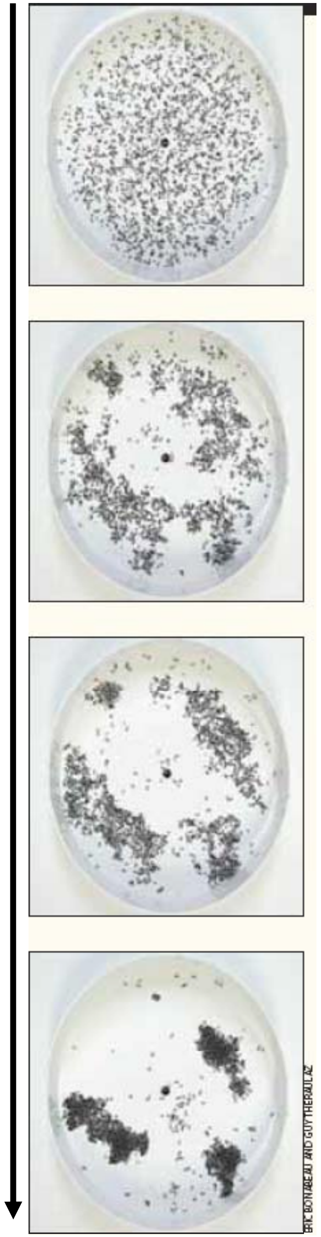
Clustering and sorting behavior can be observed in several ant species. Important mechanisms:

- stigmergic communication
- positive & negative feedback

Example rule (N = #objects experienced in a short time window):

1. Probability to pick up an object: inversely proportional to N
2. Probability to deposit an object: directly proportional to N

Cemetery clusters in *Messor sancta,* 26 hours in total, 1500 corpses



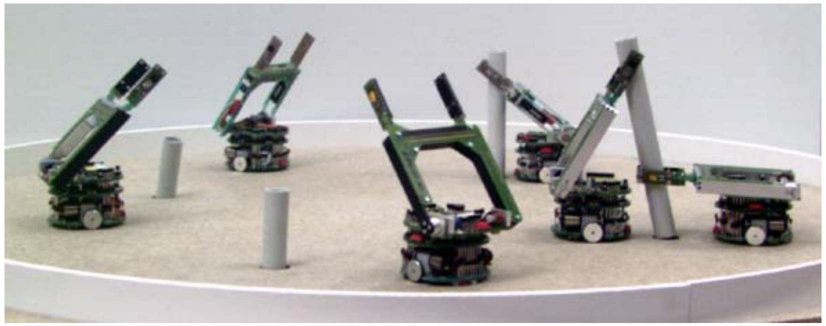
Example 4: Cooperative Manipulation

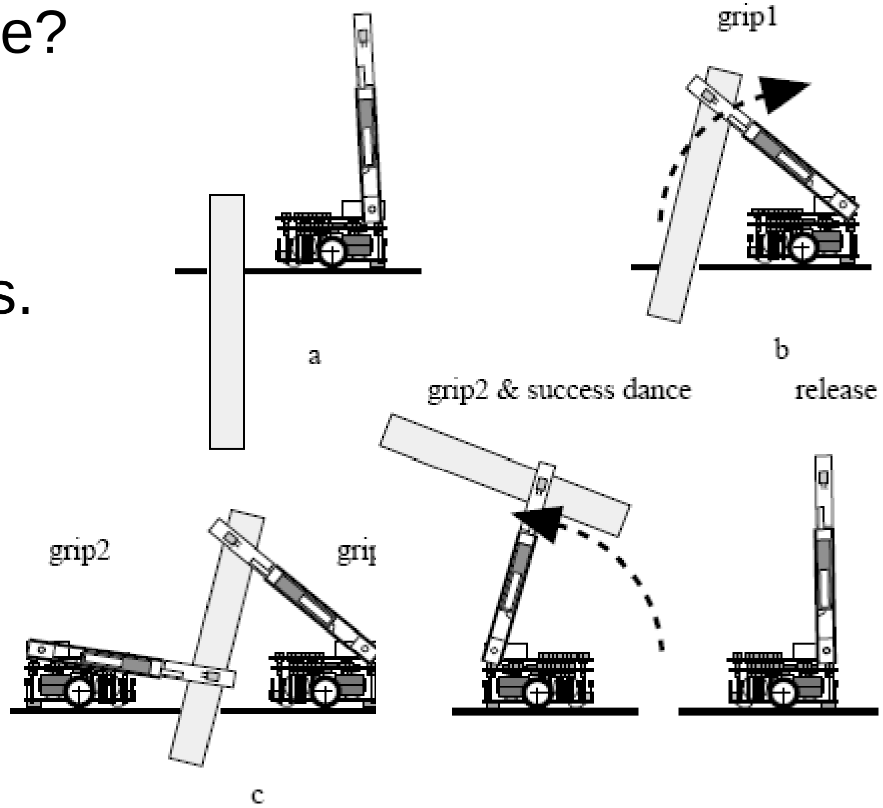
Desert ants cooperate to pull out of the ground long sticks (too long for a single ant). This behavior can be reproduced with a group of robots.

How long to wait for a teammate?

Super-linear performance:

sticks retrieved **per robot**
is optimal for ca. 6-robot groups.





Ijspeert et al., 2001

Reconfigurable Robots

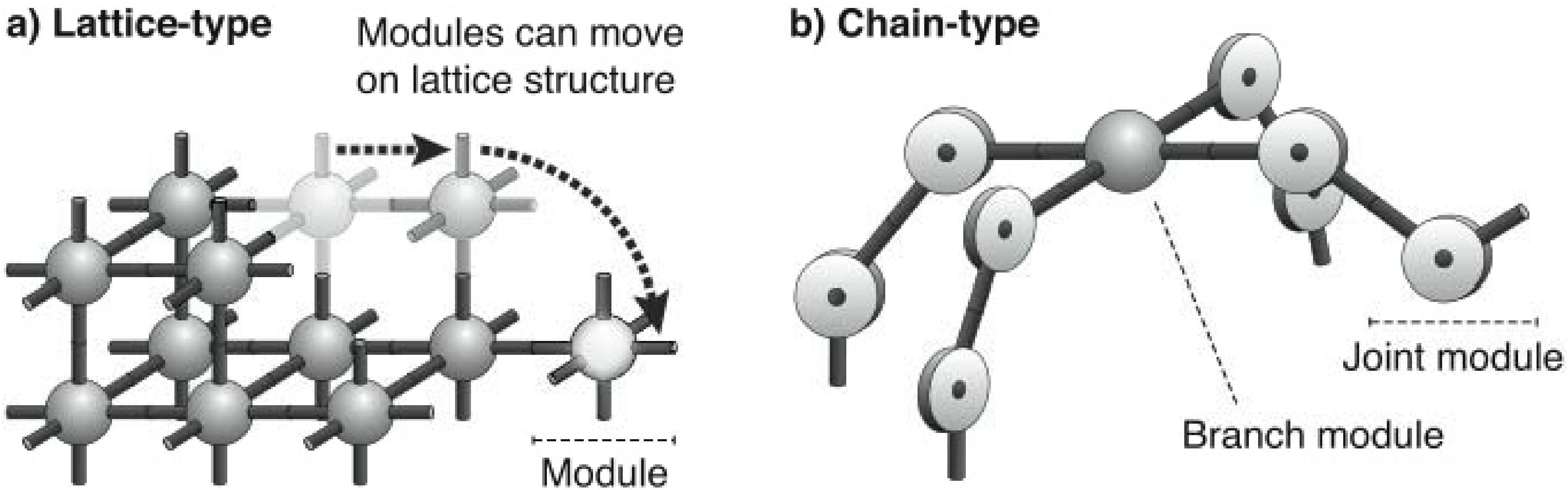
A modular robot, usually composed of several identical components, which can be re-organized to create morphologies suitable for different tasks.

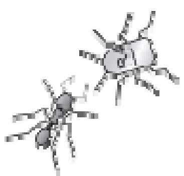
Inspiration:

- cells (cellular automata)
- individuals (swarm intelligence)

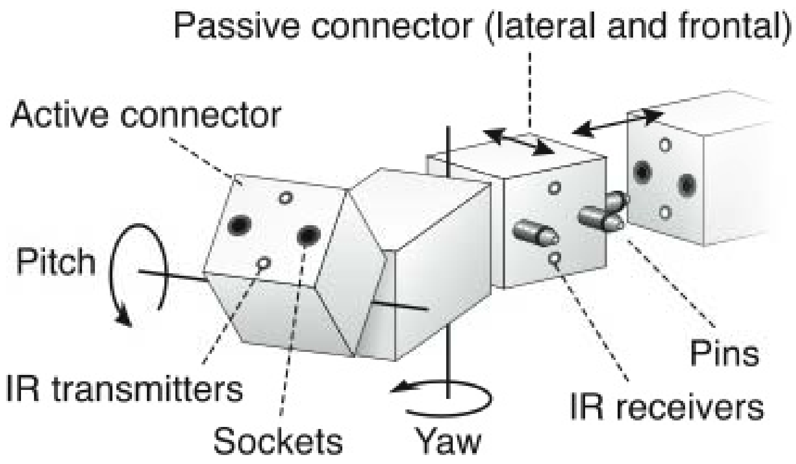
- Chain-type reconfigurable robots
- Lattice-type reconfigurable robots
- Mobile reconfigurable robots
- Further types of reconfigurable robots

Reconfigurable Robots

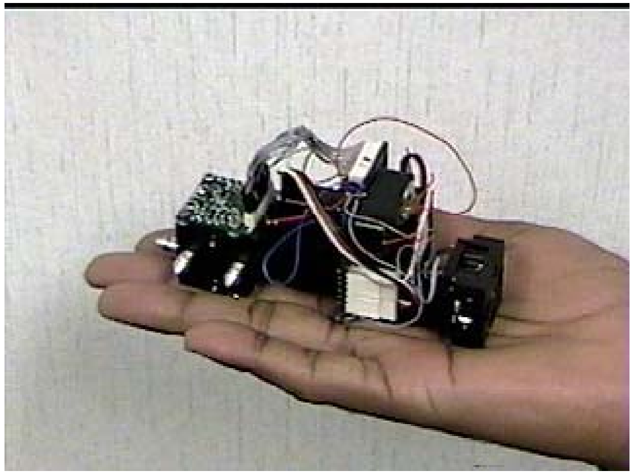




Chain Type Example: CONRO

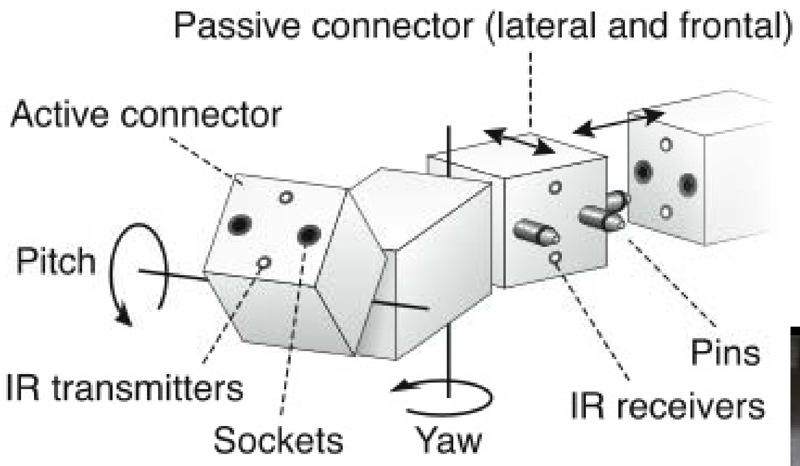


- Fully self-contained
- Pin-hole connector (+latch)
- Infrared-based guidance
- Docking relatively complex
- Good mobility

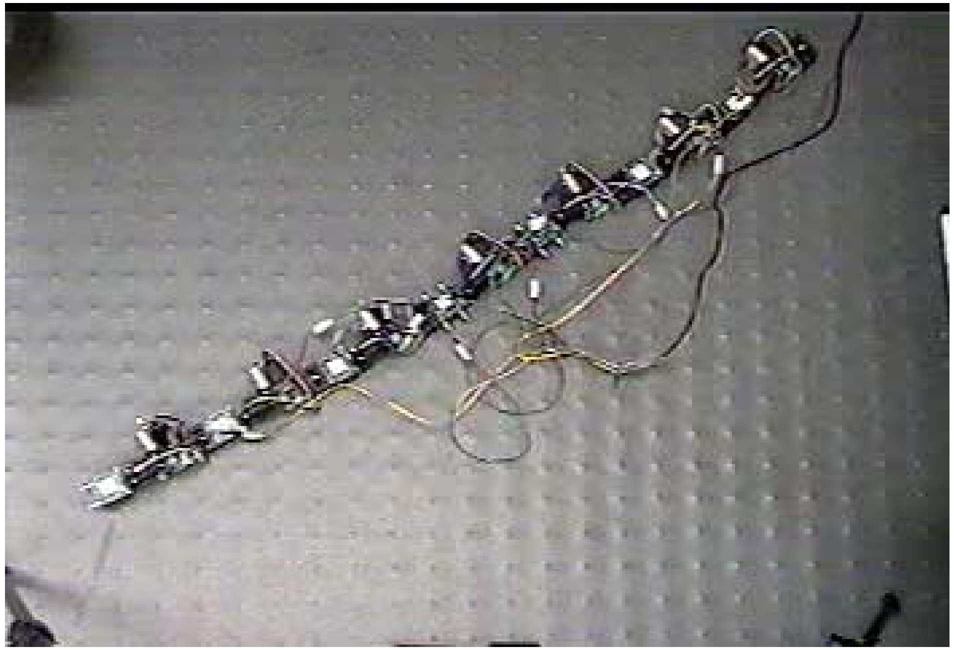


ISI, USC; Castano et al., 2000

Chain Type Example: CONRO

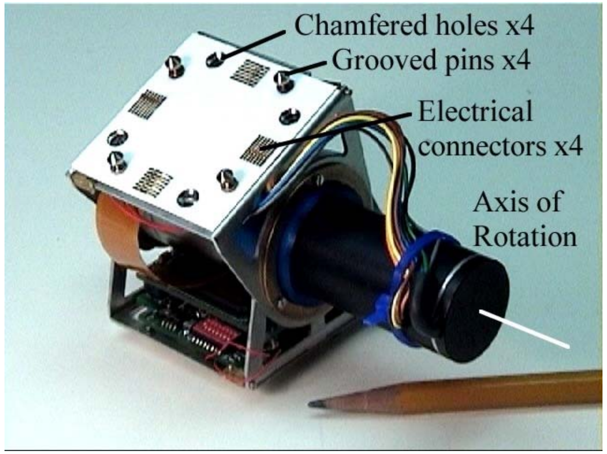


Control can cope with sudden changes in the robot's morphology.



AdapTronics Group & ISI, USC

Chain Type Example: PolyBot

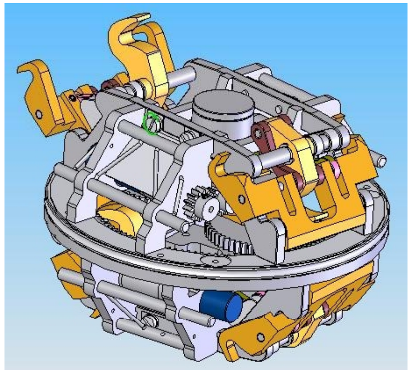


PARC, 2000; Yim et al., 2002

- 1 DOF module
- Power PC 555
- Externally powered

Self-reconfiguration of PolyBot

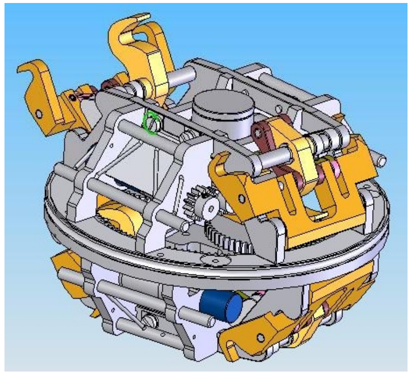
Lattice Type Example: A-TRON



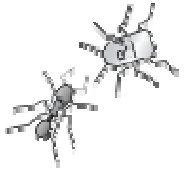
- Two half-spheres
- 4 male and 4 female connectors
- Self-docking is relatively simple.
- Self-reconfiguration can require many steps.

The Maersk McKinney Moller Inst., Univ. of Southern Denmark

Lattice Type Example: A-TRON

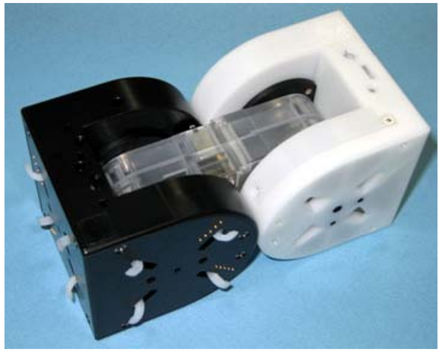


The Maersk McKinney Moller Inst., Univ. of Southern Denmark

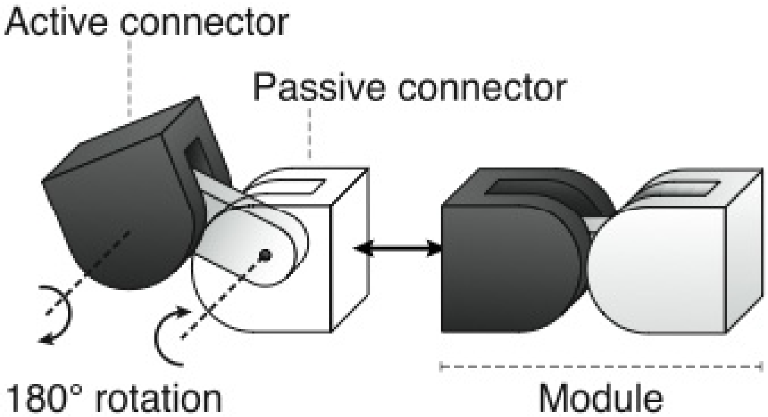


Hybrid Example: M-TRAN

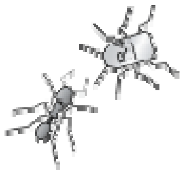
M-TRAN III (2005 -)



- Hybrid: lattice type & chain type
- Magnets or actuated mechanical hooks
- Cellular Automata rules

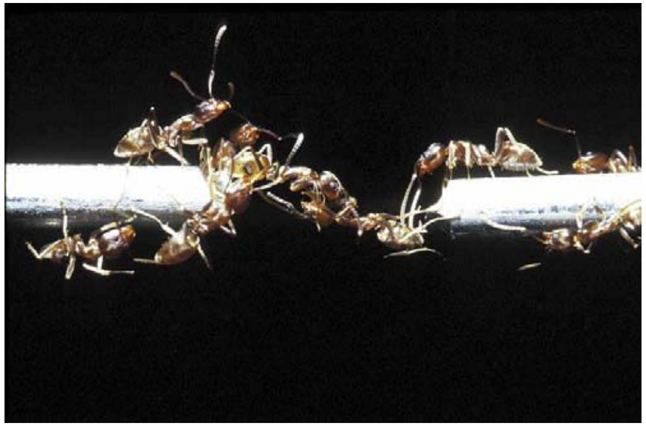


AIST; Murata et al., 2002



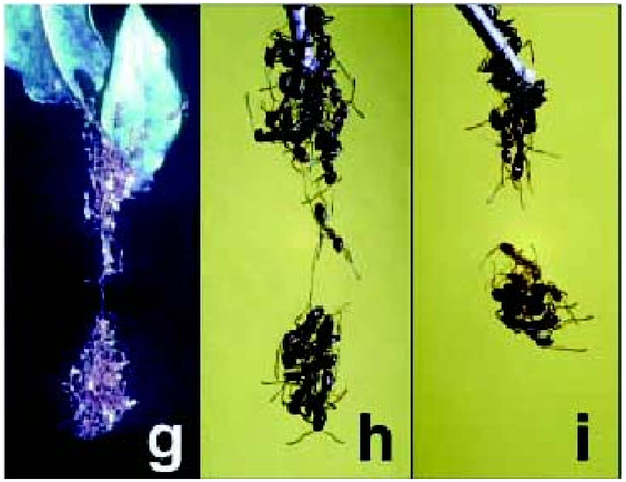
Physical Cooperation of Mobile Individuals

Passing a gap



Nest building

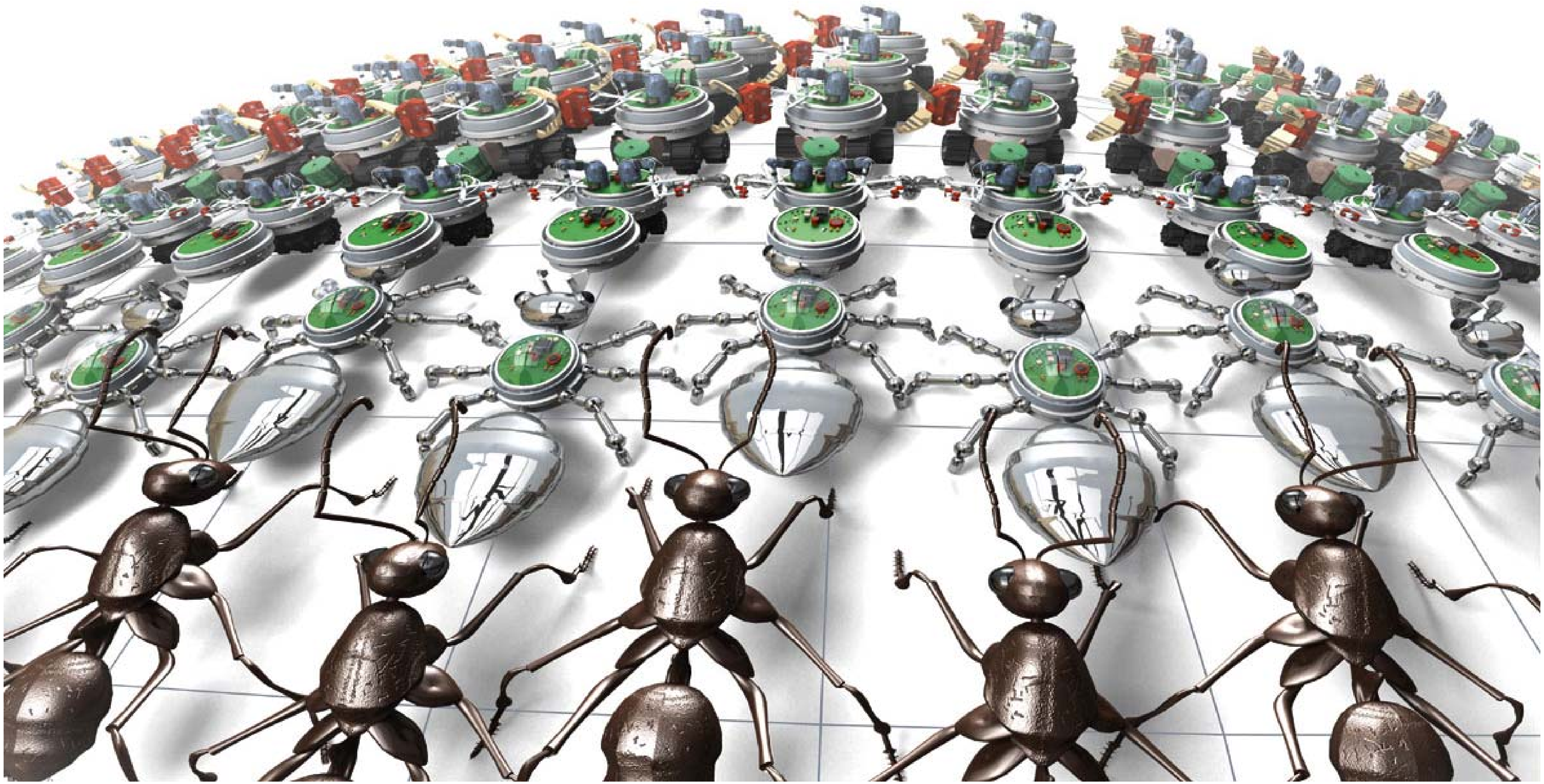
Grouped Fall



Plugging potholes in the trail

From Swarming Ants to Swarm-bots

Swarm-bots



Mobile Reconfigurable Robots

Mobile units assemble into connected entities that are larger and stronger than any individual unit.

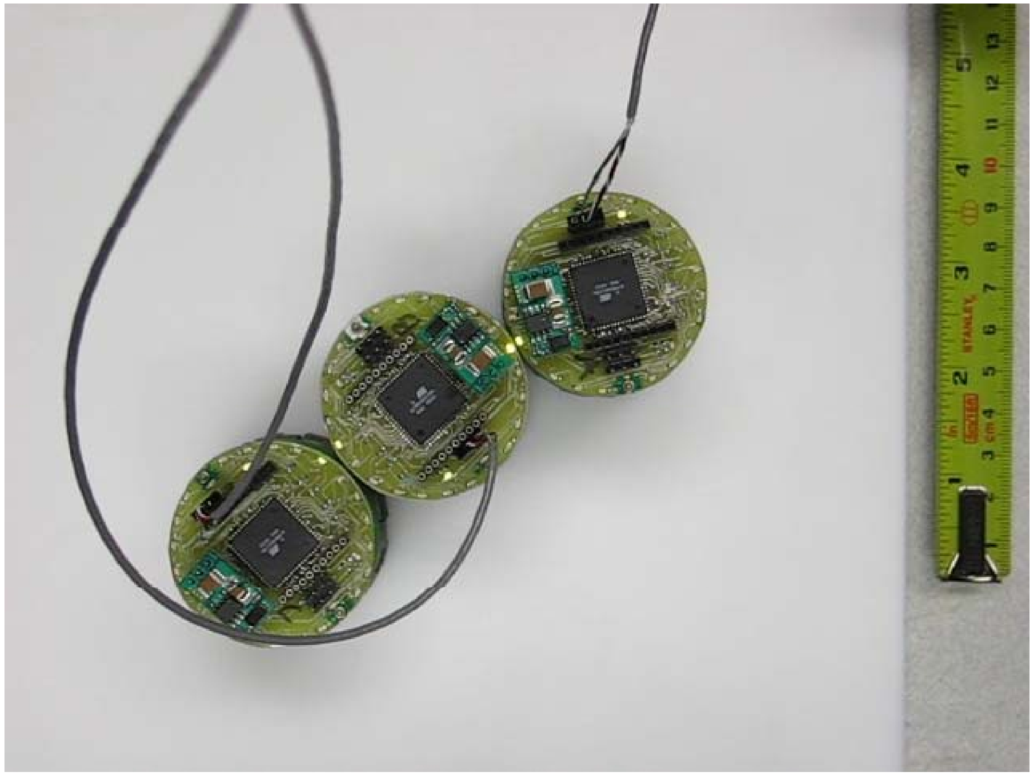

Mondada et al., 2005; Gross et al., 2006

Example: Search & Rescue

Example: Search & Rescue (Cont.)

Other Types of Reconfigurable Robots

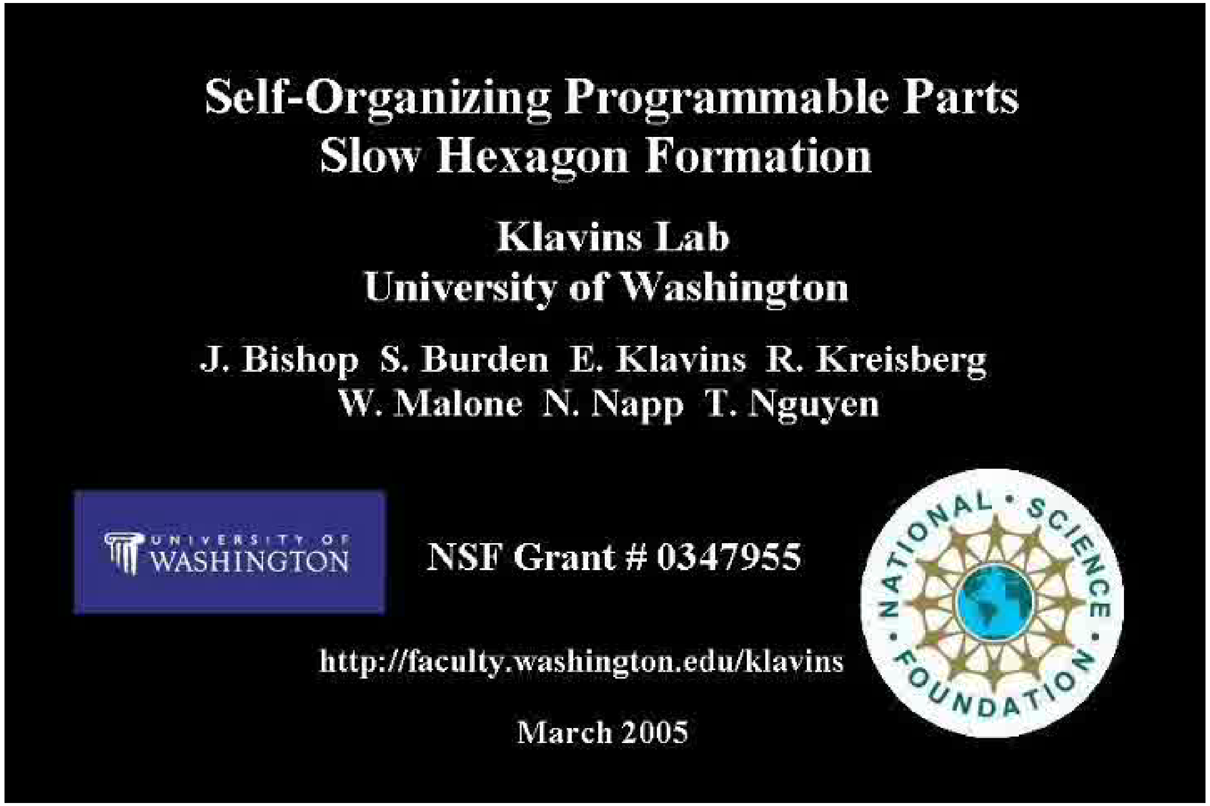
- Relative displacement without moving parts
- Electro-magnet rings
- Conversion of electrical to kinetic energy



Claytronics
Goldstein et al., 2005

Other Types of Reconfigurable Robots

Stochastic reconfiguration of passively moving parts

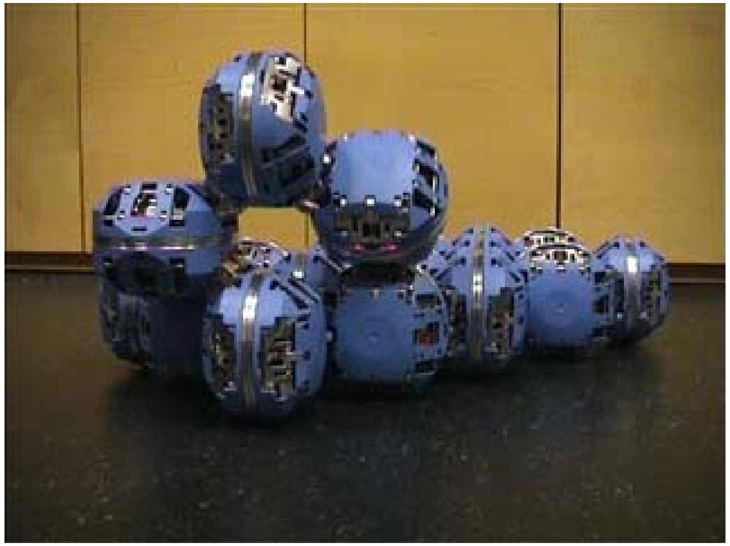


PPT

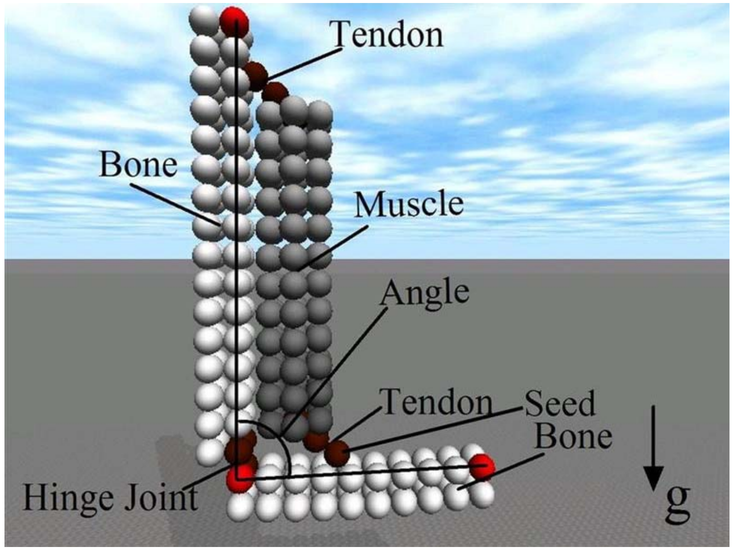
Univ. of Washington; Klavins et al., 2005

“Hierarchical” Organization

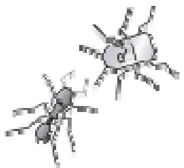
Meta-modules [1]



Anatomy-based [2]



[1,2] The Maersk McKinney Moller Inst., Univ. of Southern Denmark
[2] Intel Research Pittsburgh



Summary

Swarm Intelligence:
Key properties and technological motivations

Coordinated Exploration

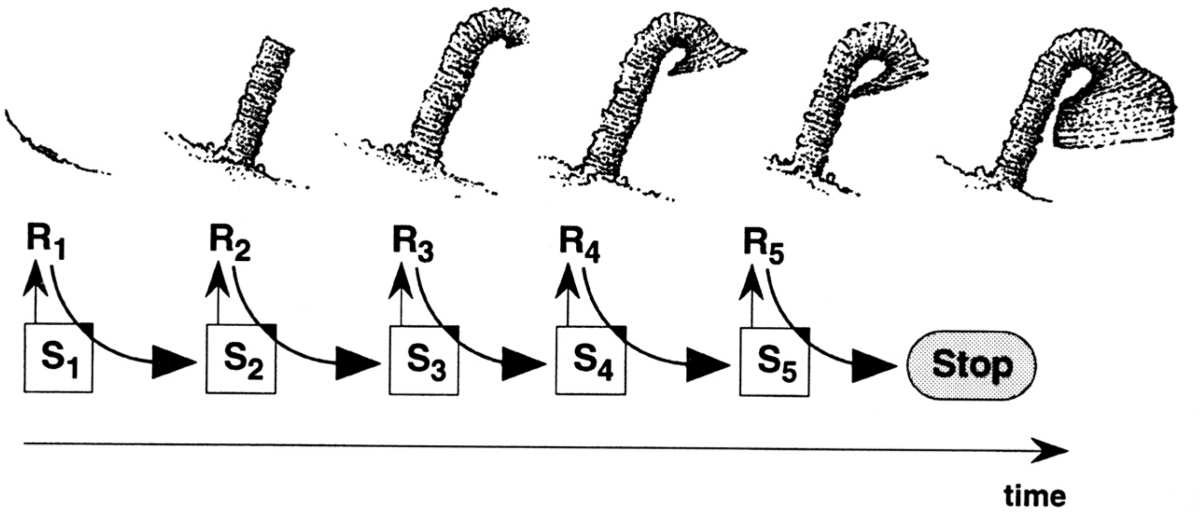
Physical cooperation in ants and robots

Reconfigurable robots

Stigmergy Revisited

Communication through modification of the environment. The result of work by an individual leaves a persistent sign that affects the actions of (possibly other) individuals.

Stimuli-response loop

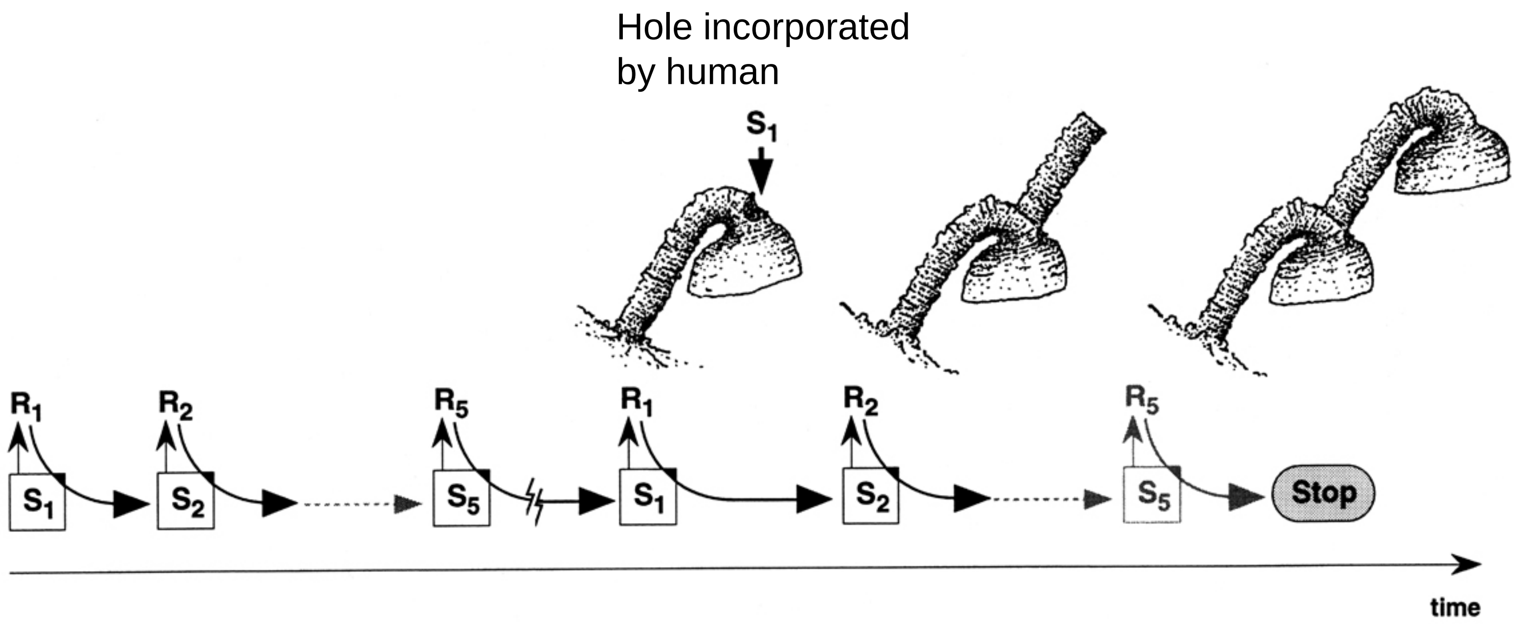


From Camazine et al., 2001 (Smith, 1978)

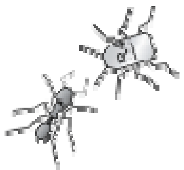
Stigmergy Revisited

Testing how building activities are coordinated.

Redundant structures

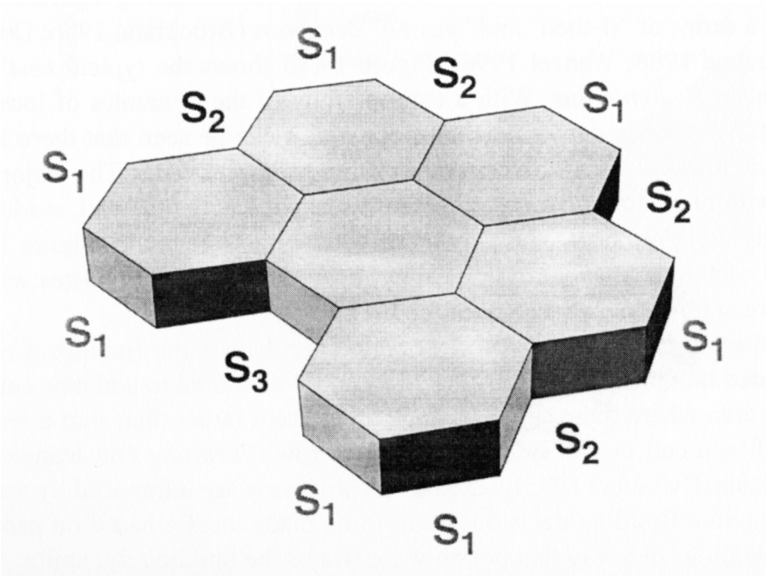


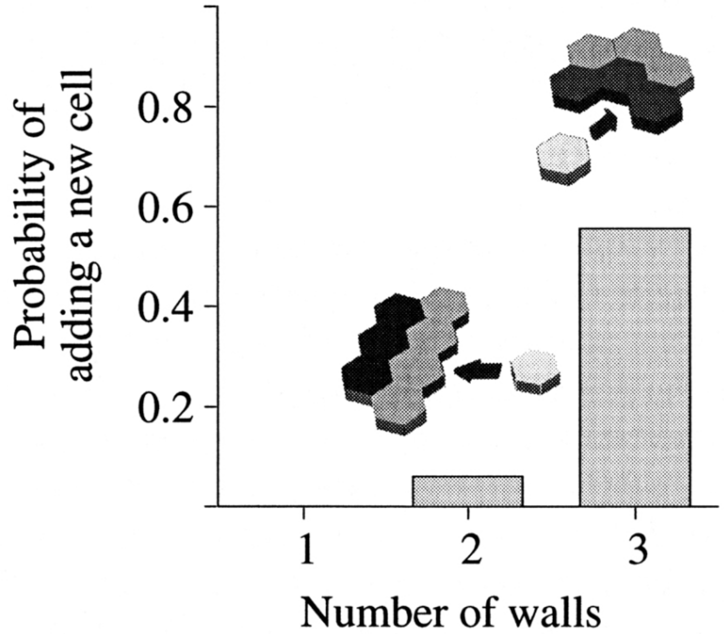
From Camazine et al., 2001 (Smith, 1978)



Stigmergy Revisited

Nest construction rules (wasp combs)





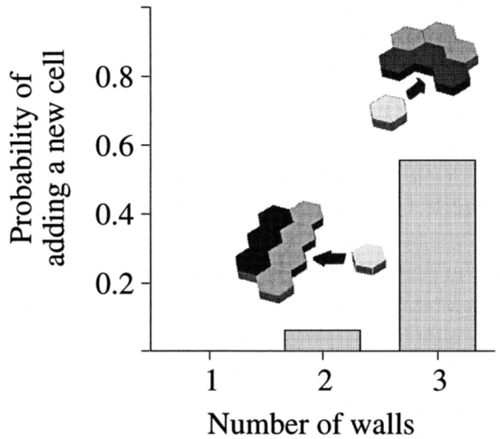
Camazine et al., 2001

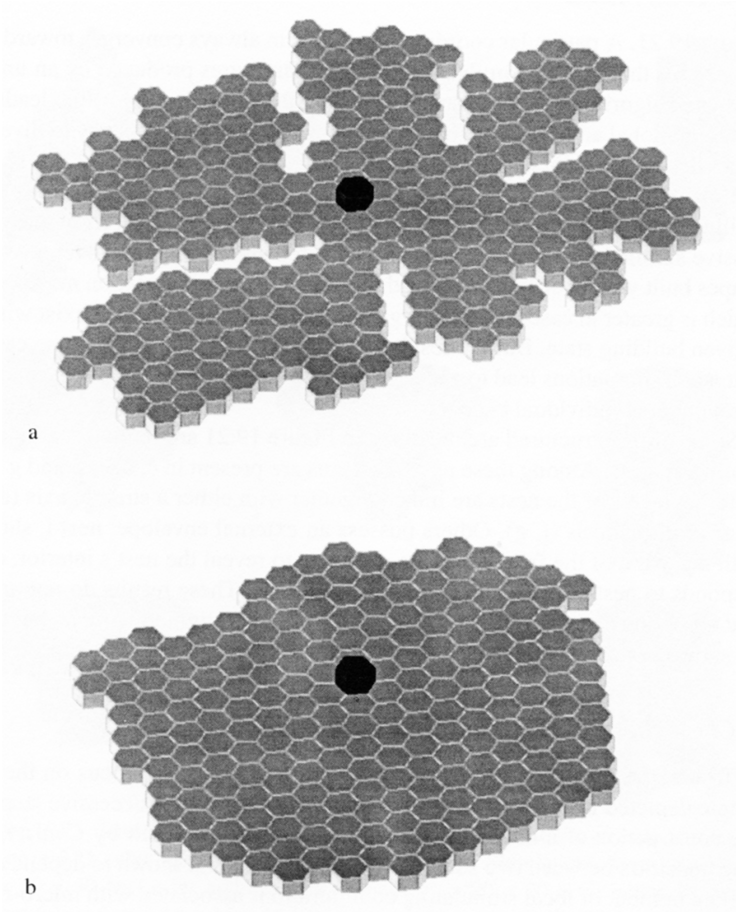
Stigmergy Revisited

Deterministic rule:

Add cell to corner area if 2 or 3 adjacent walls are present.

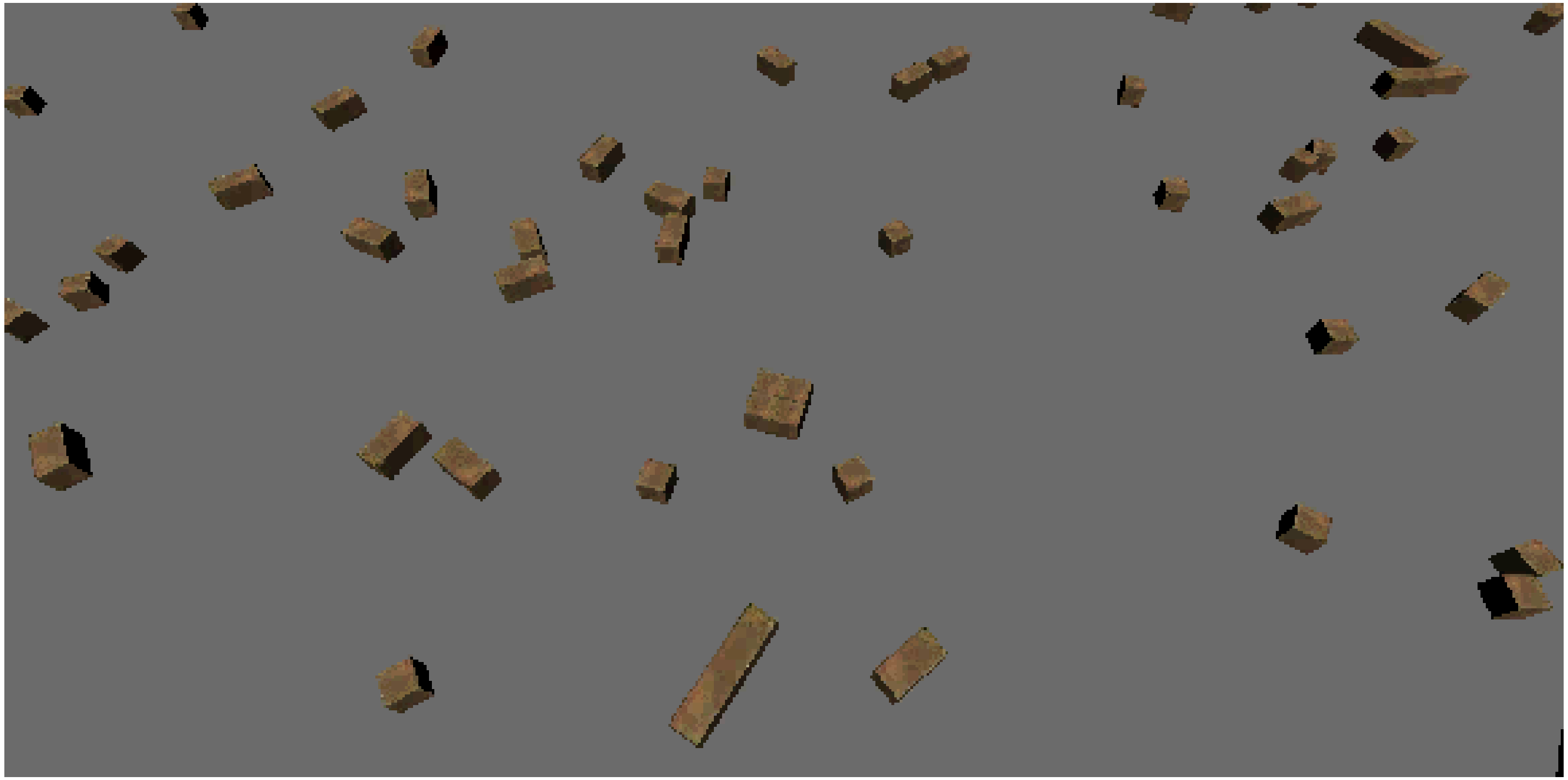
Probabilistic rule:





Camazine et al., 2001

Stigmergy – Distributed Construction



Grushin and Reggia, 2006

Termites Video

Attenborough (BBC)

http://www.youtube.com/watch?v=0m7odGafpQU