# Lecture 2

# Ants

# Investigation of Self-Organization and Complex Systems

# CBN Text Website

- Visit Flake CBN textbook website for errata, software, etc.:

http://mitpress.mit.edu/books/FLAOH/cbnhtml

# Ants

*Think about the value of having computers, networks, and robots that could do these things.*

# Why Ants?

- Ants are successful:
  - 30% of Amazon biomass is ants and termites
  - Dry weight of social insects is four times that of other land animals in Amazon
  - Perhaps 10% of Earth's total biomass
  - Comparable to biomass of humans
- Good source: Deborah Gordon: *Ants at Work* (1999)

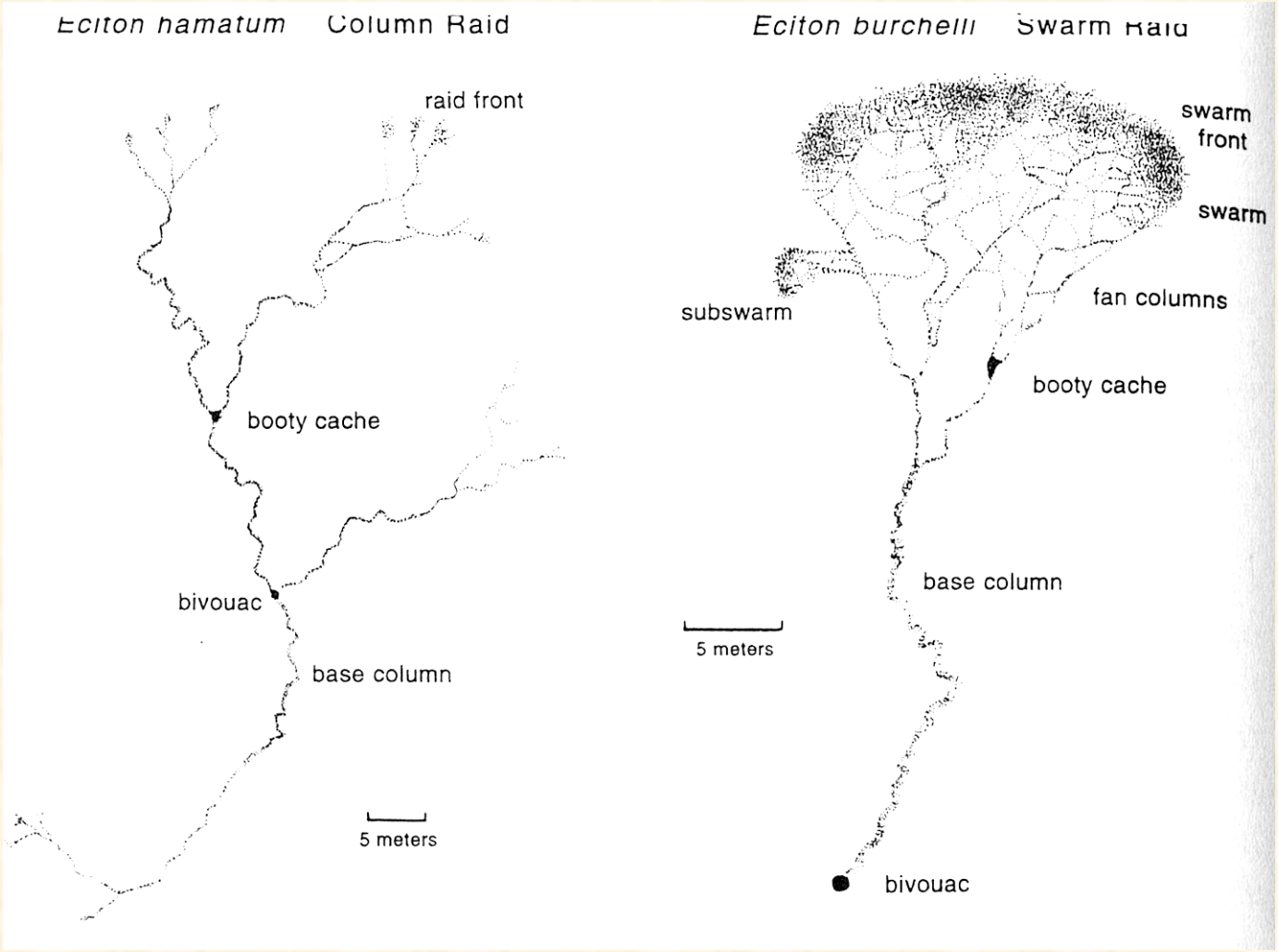
# Intelligent Behavior of Harvester Ants

- Find shortest path to food
- Prioritize food sources based on distance & ease of access
- Adjust number involved in foraging based on:
  - colony size
  - amount of food stored
  - amount of food in area
  - presence of other colonies
  - etc.

# Army Ants

- No permanent nest
- Create temporary “bivouacs” from bodies of workers
- Raiding parties of up to 200 000
- Act like unified entity

# Army Ant Raiding Patterns

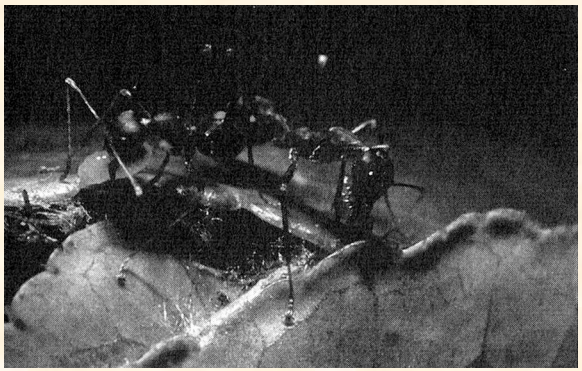




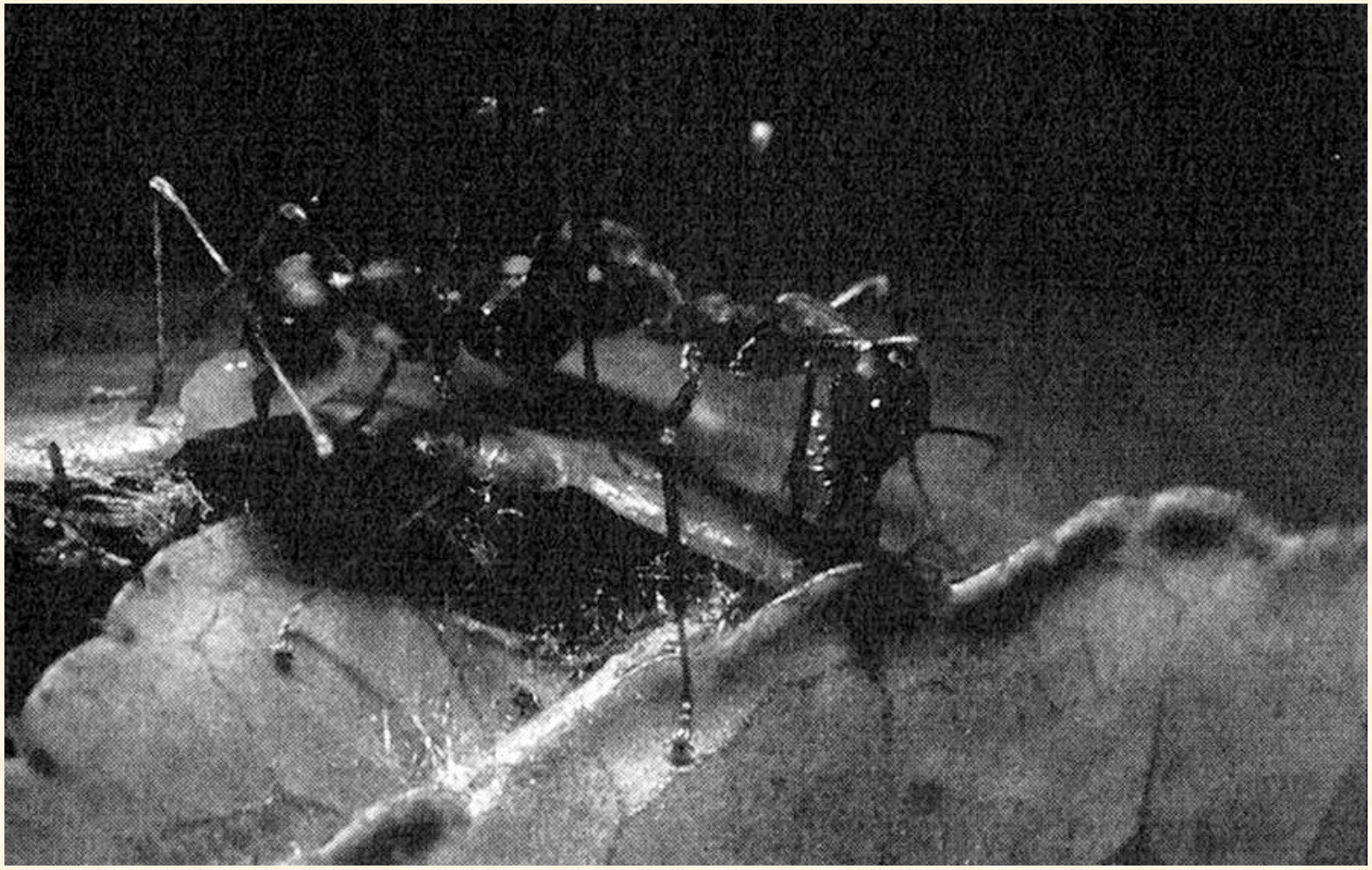

from Solé & Goodwin, *Signs of Life*

# Weaver Ants

- Form chains of bodies to bridge gaps
- Others may cross these bridges
- Use chains to pull leaf edges together
- Connect edges with silk from larvae held by workers

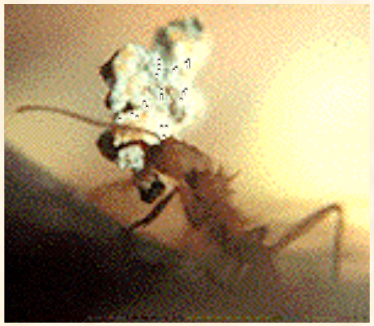


# Adults Using Larvae as “Glue Guns”



# Fungus Cultivator Ants

- “Cultivate” fungi underground
- Construct “gardens”
- Plant spores
- Weed out competing fungi
- Fertilize with compost from chewed leaves



# Maeterlinck on Ants

"What is it that governs here? What is it that issues orders, foresees the future, elaborates plans, and preserves equilibrium?"

# Emergent Aspects

- Colony size ~ $8 \times 10^6$

  *but no one is "in charge"!*

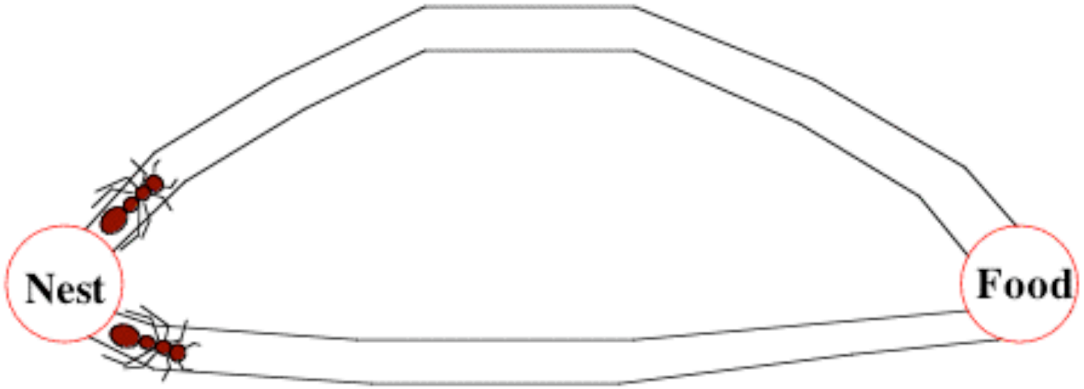
- Colony lifetime ~ 15 years
- Colonies have a "life cycle"
  - older behave differently from younger
- But ants live no longer than one year
  - Males live one day!

# How do they do it?

- Semiochemically: deposit pheromones
  - 10-20 signs, many signal tasks
  - ants detect pheromone gradients and frequency of encounter
- Follow trails imperfectly
  - exploration
- Feedback reinforces successful trails
  - biased randomness

# Ant foraging

## Cooperative search by pheromone trails



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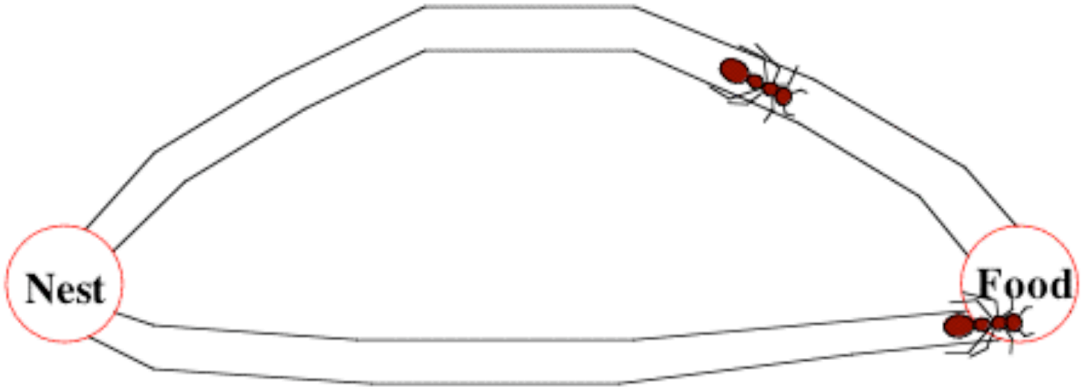

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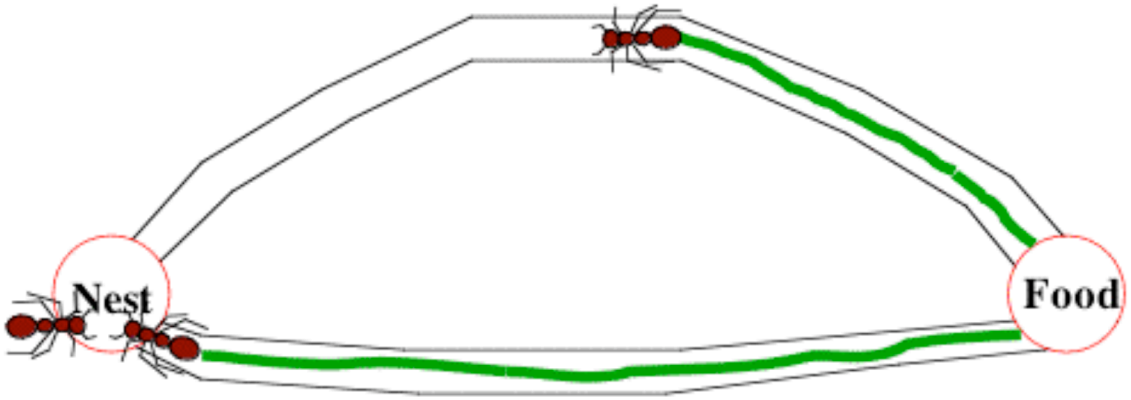

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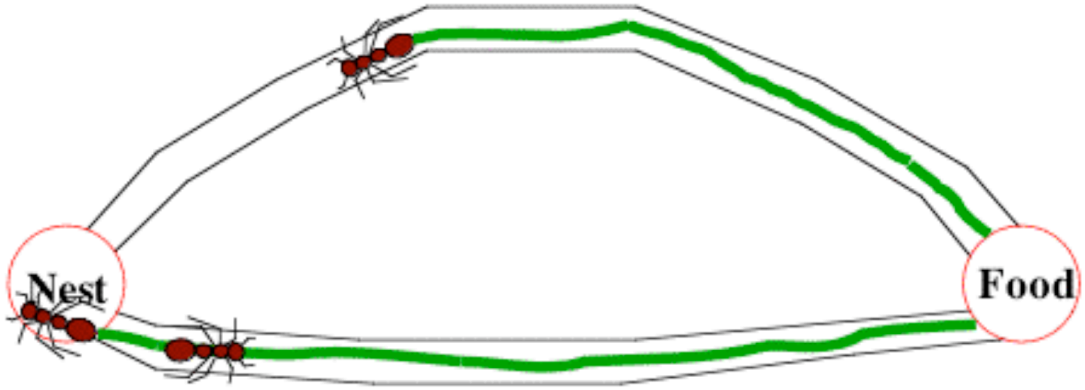

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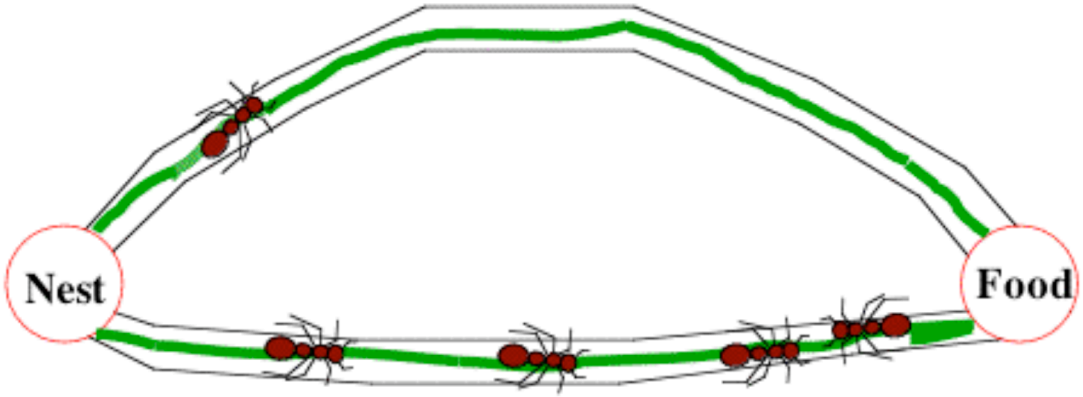

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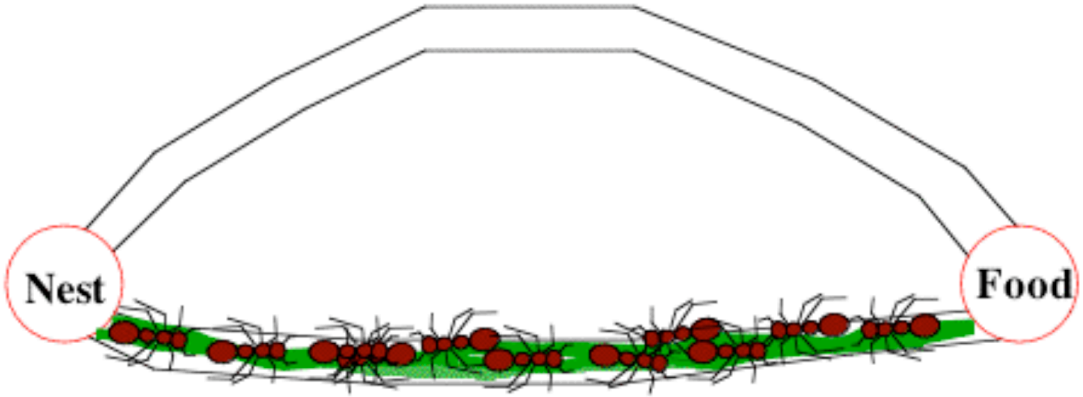
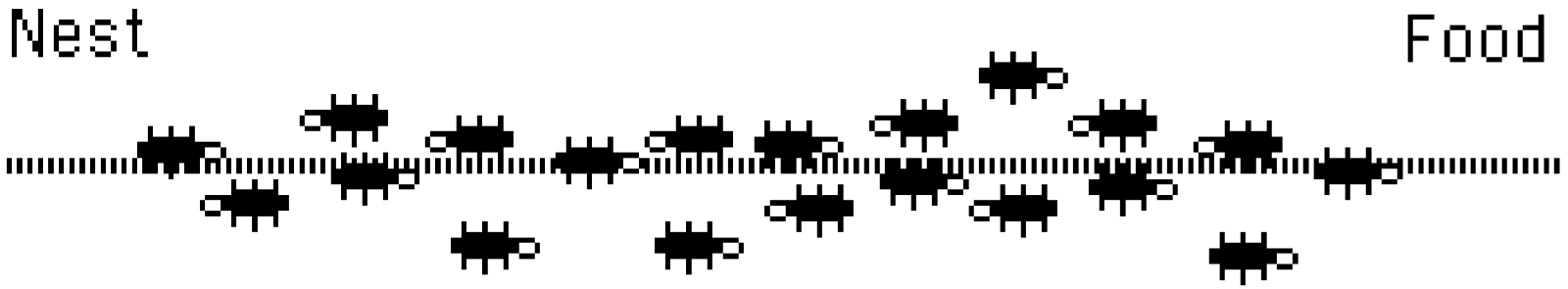


# Adaptive Path Optimization



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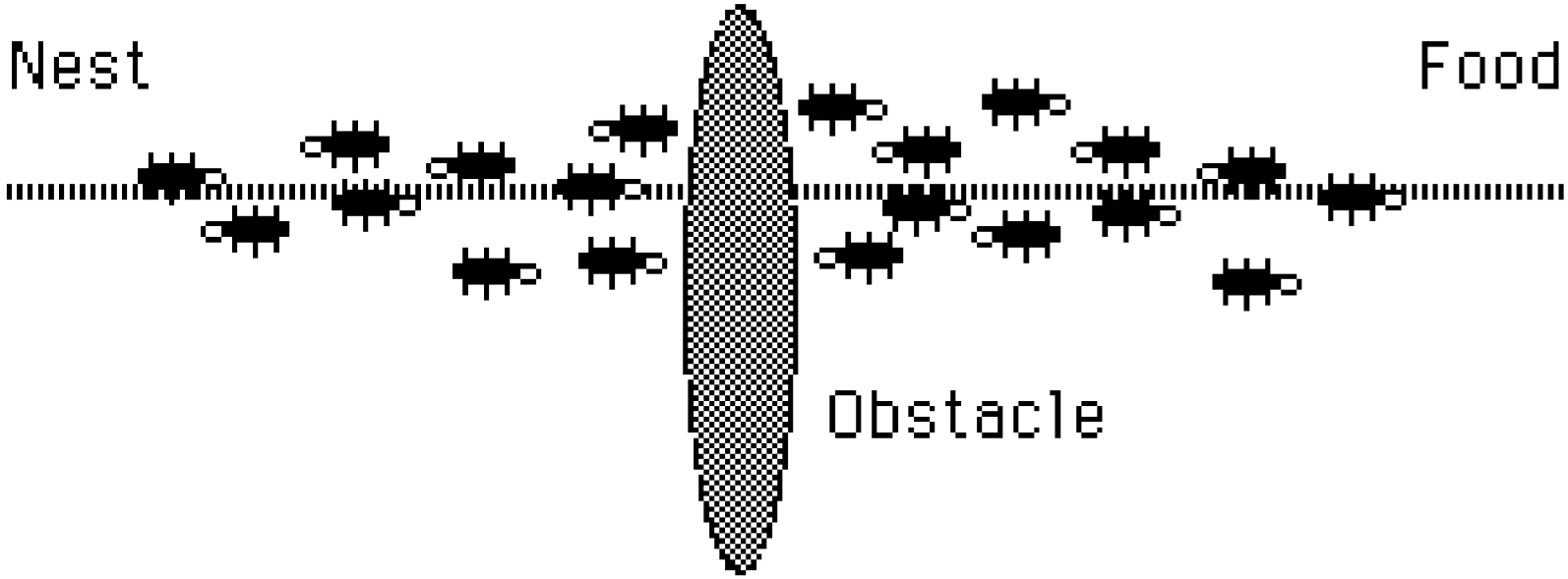

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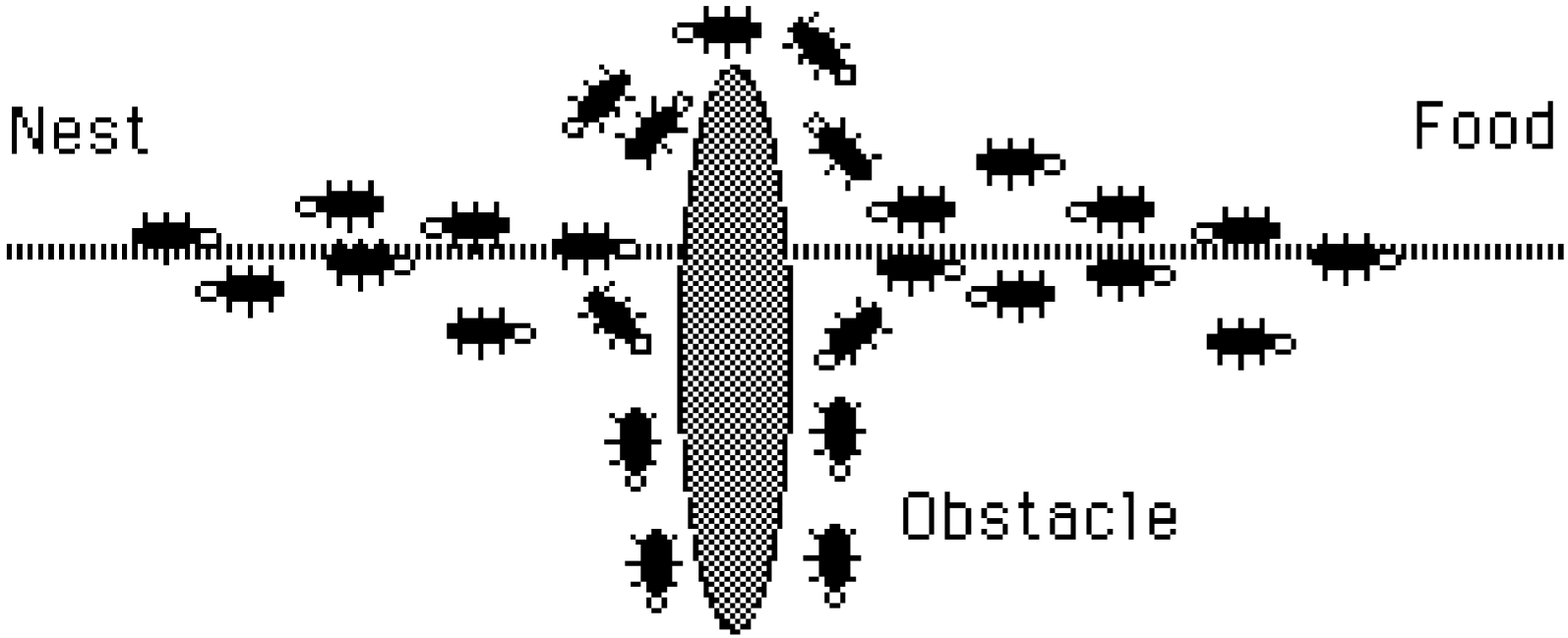

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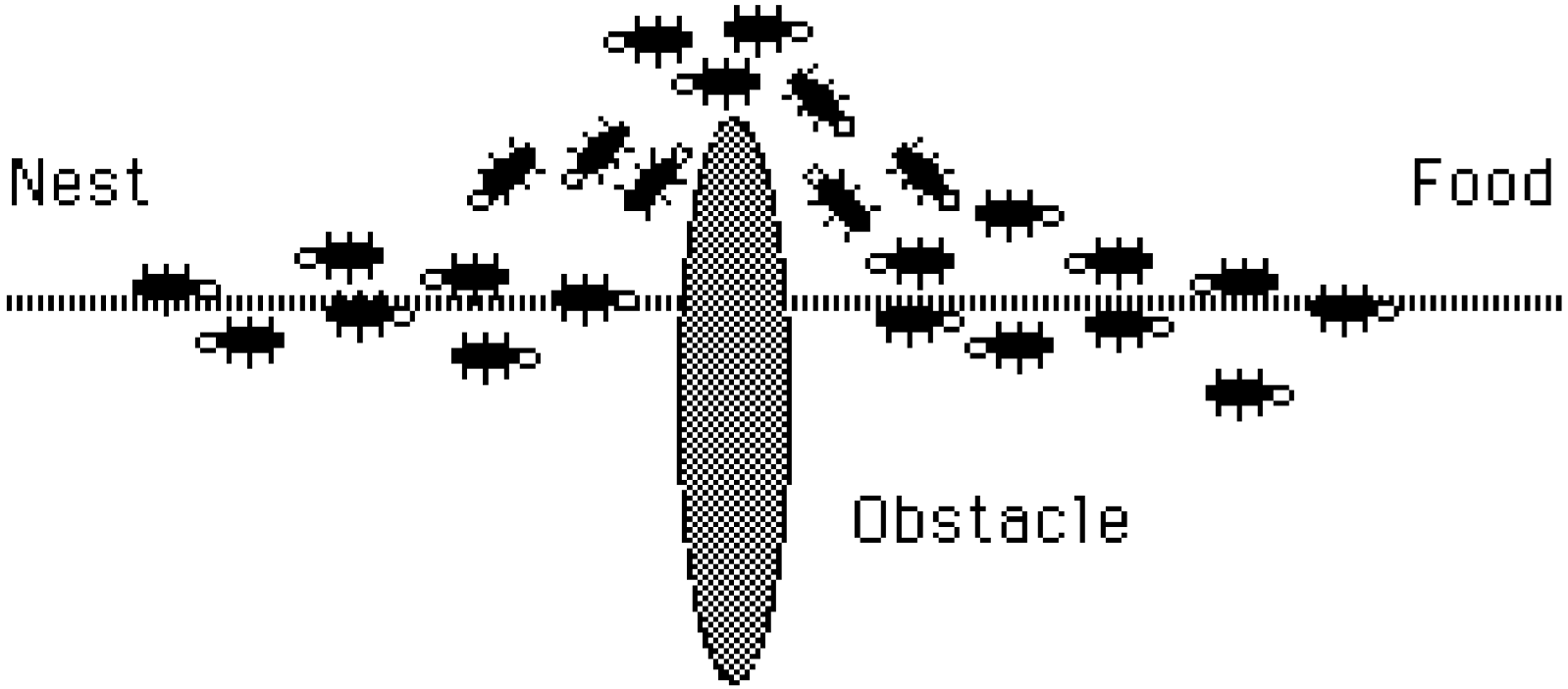
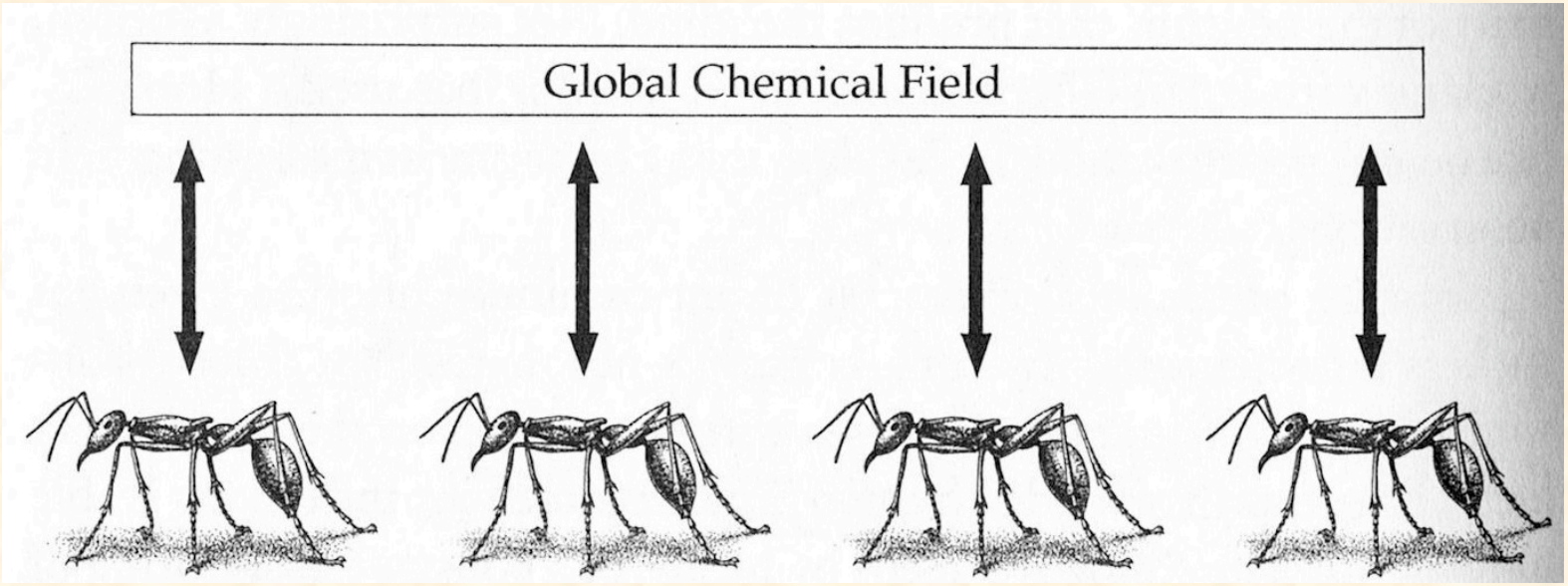


# Circular Causality

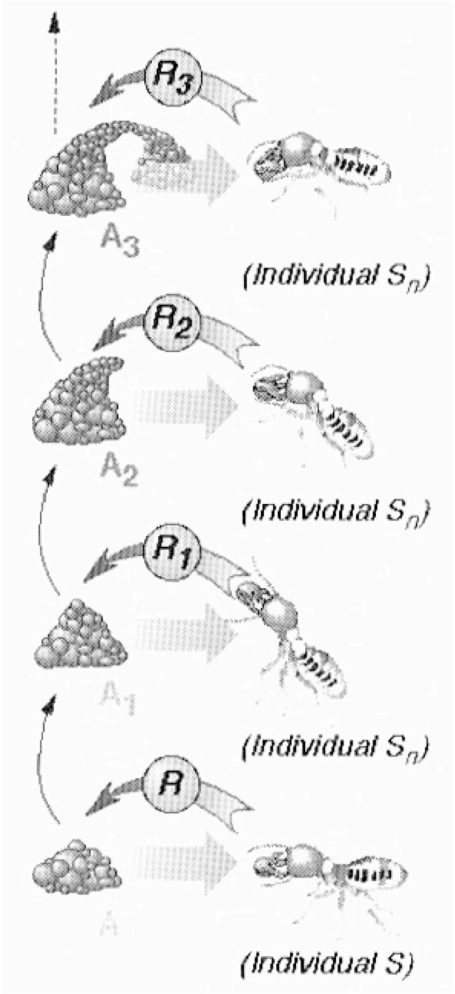



- Global pattern emergent from total system
- Individuals respond to local field

# Stigmergy

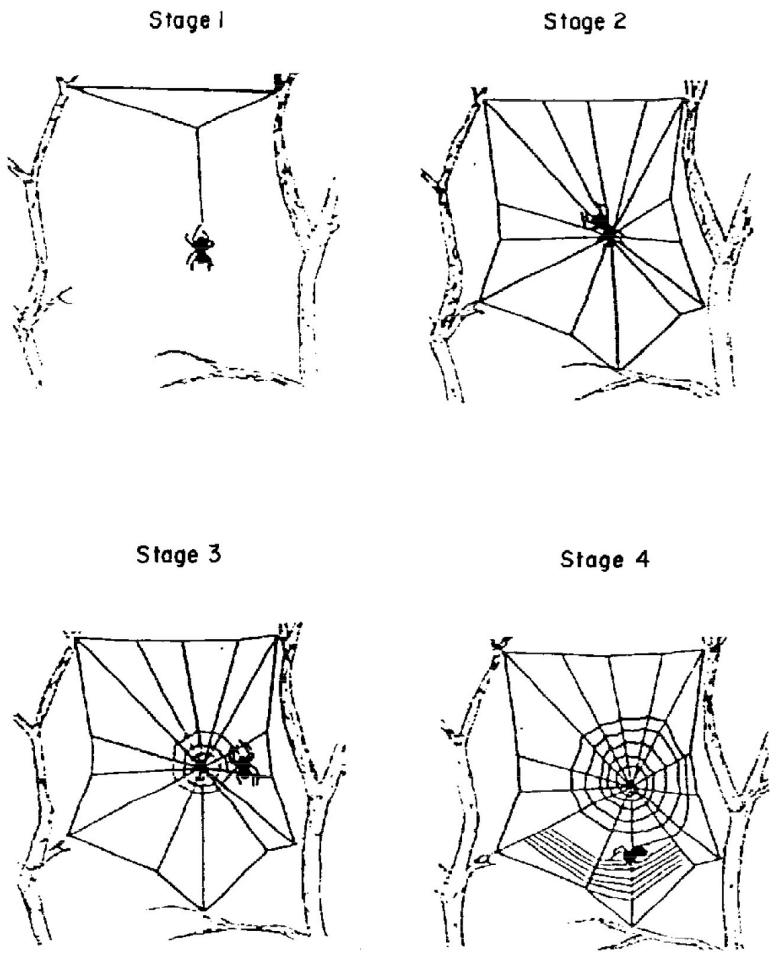
- From στιγμός = pricking + ἔργον = work
- The project (work) in the environment is an instigation
- Agent interactions may be:
  - direct
  - indirect (time-delayed through environment)
- Mediates individual and colony levels

# Stigmergy in termite nest building




Fig, from EVALife

# Stigmergy in spider webs

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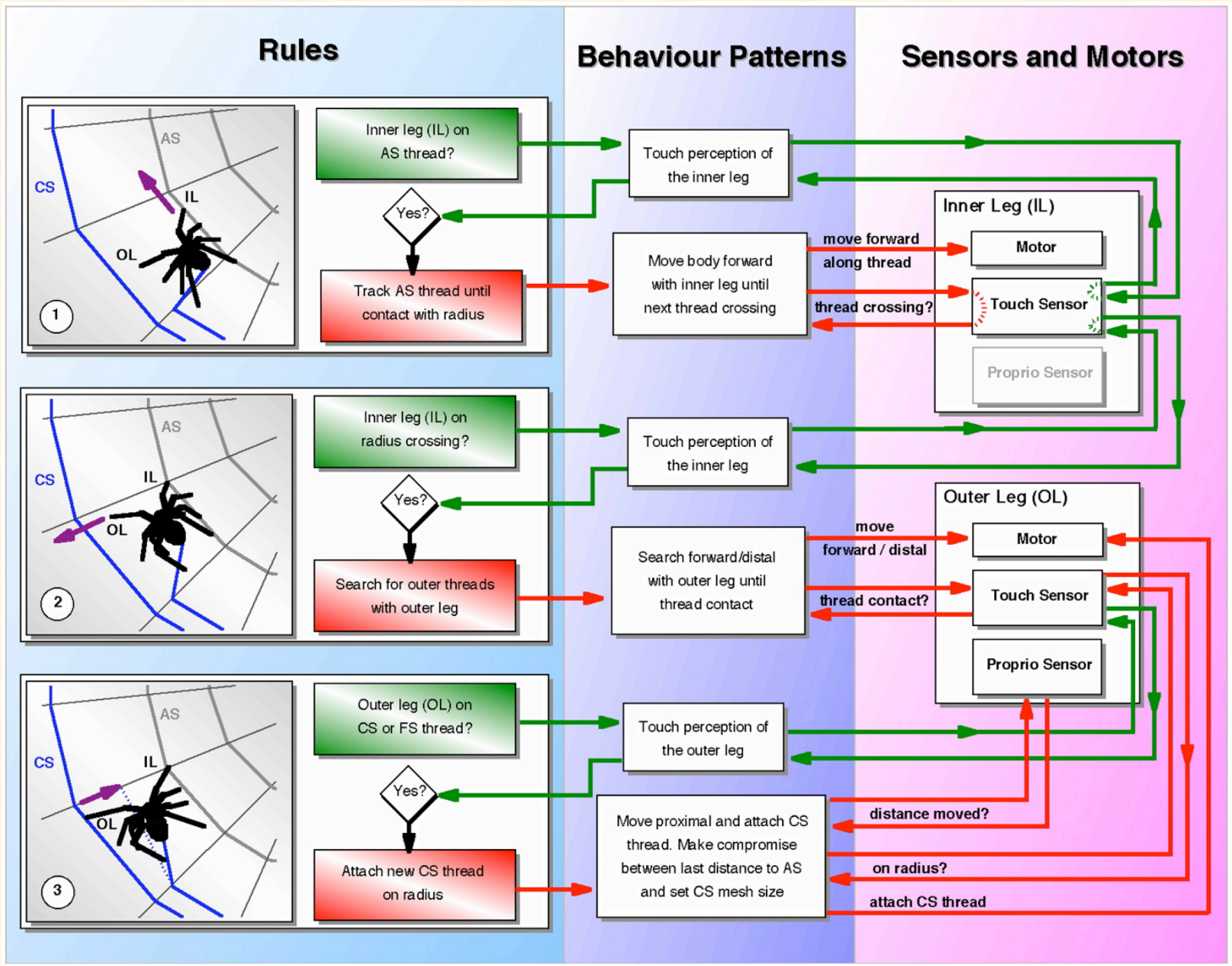
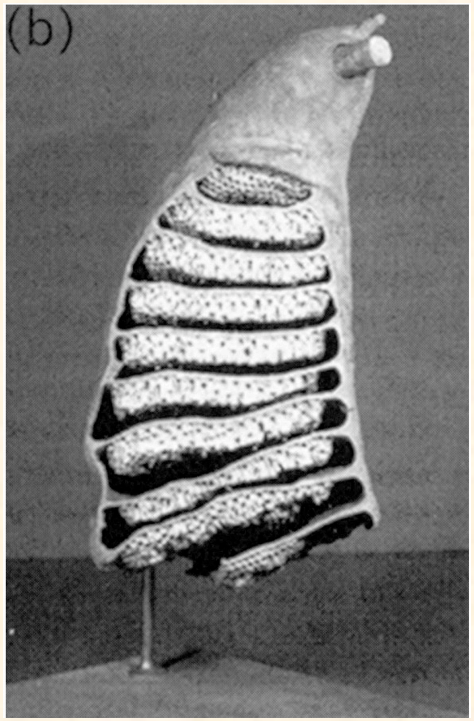

Rules
Behaviour Patterns
Sensors and Motors
AS
CS
IL
OL
1
Inner leg (IL) on AS thread?
Yes?
Track AS thread until contact with radius
Touch perception of the inner leg
Move body forward with inner leg until next thread crossing
move forward along thread
thread crossing?
Inner Leg (IL)
Motor
Touch Sensor
Proprio Sensor
2
Inner leg (IL) on radius crossing?
Yes?
Search for outer threads with outer leg
Touch perception of the inner leg
Search forward/distal with outer leg until thread contact
move forward / distal
thread contact?
Outer Leg (OL)
Motor
Touch Sensor
Proprio Sensor
3
Outer leg (OL) on CS or FS thread?
Yes?
Attach new CS thread on radius
Touch perception of the outer leg
Move proximal and attach CS thread. Make compromise between last distance to AS and set CS mesh size
distance moved?
on radius?
attach CS thread

# Advantages of Stigmergy

- Permits simpler agents
- Decreases direct communication between agents
- Incremental improvement
- Flexible, since when environment changes, agents respond appropriately



# Some Principles Underlying Emergent Systems

- "More is different"
- "Ignorance is useful"
- "Encourage random encounters"
- "Look for patterns in signals"
- "Pay attention to your neighbor"
  ("Local information leads to global wisdom")

— Johnson, *Emergence*, pp. 77-9.

# Similar Principles of SO

- Ant colonies
- Development of embryo
- Molecular interactions within cell
- Neural networks

# Comparison of Ant Colonies and Neural Networks

| | *Ant Colonies* | *Neural Nets* |
|---|---|---|
| No. of units | high | high |
| Robustness | high | high |
| Connectivity | local | local |
| Memory | short-term | short/long term |
| Connect. stability | weak | high |
| Global patterns | trails | brain waves |
| Complex dynamics | observed | common |

# Self-Organization

- Concept originated in physics and chemistry
  - emergence of macroscopic patterns
  - out of microscopic processes & interactions
- "Self-organization is a set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lower-level components." — Bonabeau, Dorigo & Theraulaz, p. 9

# Four Ingredients of Self-Organization

- Activity amplification by positive feedback
- Activity balancing by negative feedback
- Amplification of random fluctuations
- Multiple Interactions

— Bonabeau, Dorigo & Theraulaz, pp. 9-11

# Characteristics of Self-Organized System

- Creation of spatiotemporal structures in initially homogeneous medium
- Multistability
- Bifurcations when parameters are varied