Lecture 2

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Ants

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Investigation of Self-Organization and Complex Systems

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

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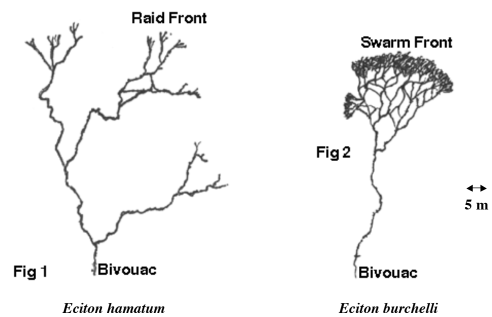
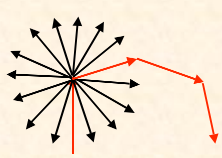
Army Ant Raiding Patterns



8/23/04 from Solé & Goodwin, *Signs of Life* 6

Coordination in Army Ant Colonies

- Timing:
  - nomadic phase (15 days)
  - stationary phase (20 days)
- Navigation in stationary phase
  - 14 raids
  - 123° apart



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Collective Navigation

- Ant may use polarized sunlight to determine direction
- But army ants have single-facet eyes
  - most insects have multiple facet eyes
- Theory: the two facets of individual ants in group function collectively as a multiple facet eye

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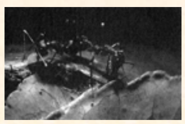
Weaver Ants

- 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



Workers Bridging Gap

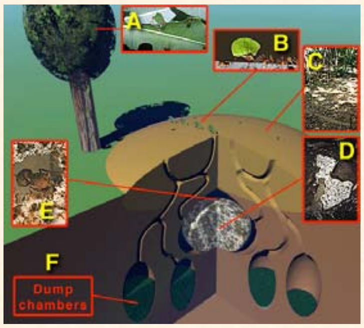
Adults Using Larvae as "Glue Guns"

(fig. from *Self-Org. Biol.Sys.*)

Fungus Cultivator Ants

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

Fungus Cultivator Nest



(fig. from AntColony.org)

Leaf Cutting

- Leaves being cut by workers

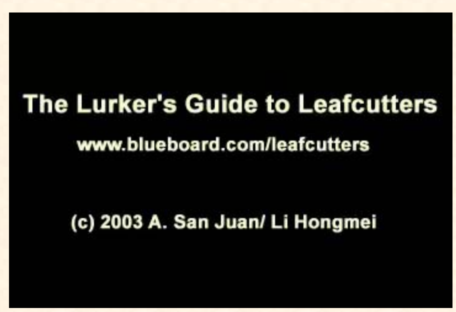
(fig. from AntColony.org)

Transport of Cut Leaves

- Cut leaves are transported from source to nest along trails
- Some temporarily held in caches near the tree

(fig. from AntColony.org)

Transporting Cut Leaves to Nest



(vid. from www.blueboard.com/leafcutters)

Protection by Minims

- Small workers (minims) ride piggy-back
- Protect large workers from parasitic fly trying to lay eggs on head

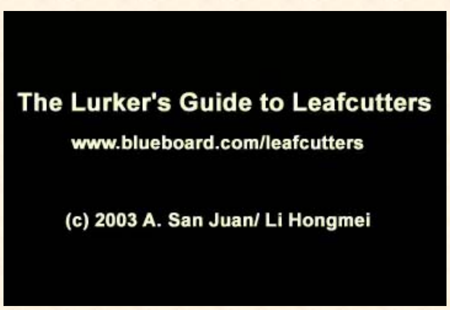
8/23/04 (fig. from AntColony.org) 17

A Large Nest

- Two mounds, 50 cm in diameter
- Part of a single nest
- Foraging trail visible

8/23/04 (fig. from AntColony.org) 18

Nest Construction



- Several tons of earth may be removed by large colony

8/23/04 (vid. from www.blueboard.com/leafcutters) 19

Leaf Brought to Fungus Garden

- Leaf being brought to fungus garden in nest
- Leaf mulch is fed to fungus

8/23/04 (fig. from AntColony.org) 20

The Fungus Garden

- Fungus grows special nutritional structures
- Ant larvae and adults can eat these

8/23/04 (fig. from AntColony.org) 21

Queen in Fungus Garden

- Queen stays in fungus garden
- Lays eggs
- Hatched larvae eat fungus
- Larvae cared for by nurse workers

8/23/04 (fig. from AntColony.org) 22

Dump Chambers

- Dump chamber in lab
- In nature, may be 2m underground
- Contain:
  - waste leaf material
  - dead fungus
  - dead ants

8/23/04 (fig. from AntColony.org) 23

Maeterlinck on Ants

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

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Emergent Aspects

- Colony size ~ 8×10^6
  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!

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How Do They Do It?

- Communication in Red Harvester Ants
- Good source: Deborah Gordon: *Ants at Work* (1999)

8/23/04 (video from *Stanford Report*, April 2003) 26

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

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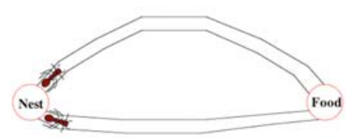
Ant foraging

Cooperative search by pheromone trails



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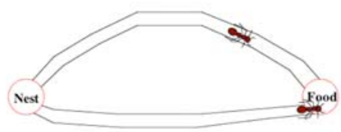
Ant foraging

Cooperative search by pheromone trails



Ant foraging

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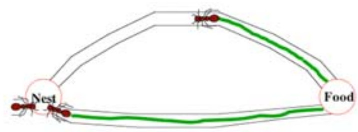

Ant foraging

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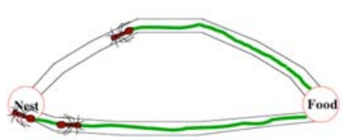
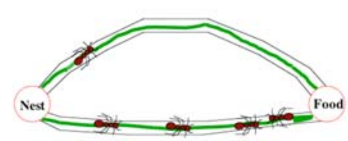


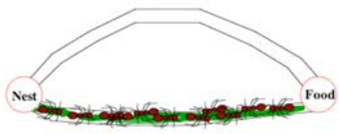
Ant foraging

Cooperative search by pheromone trails



Ant foraging

Cooperative search by pheromone trails



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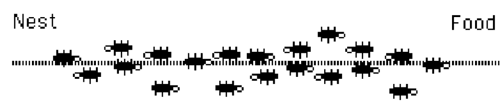
Adaptive Path Optimization



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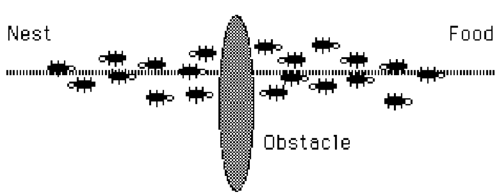
Adaptive Path Optimization



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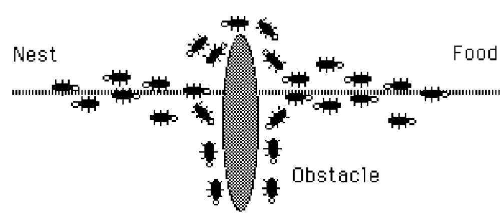
Adaptive Path Optimization



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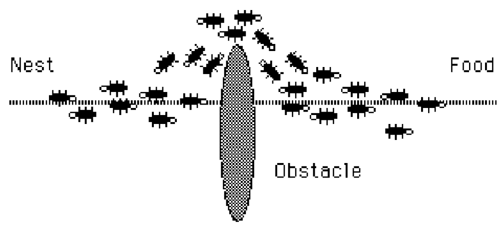
Adaptive Path Optimization



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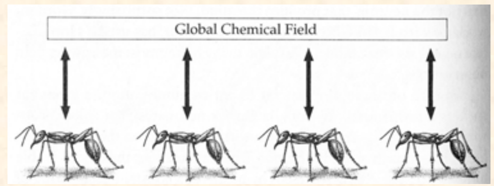
Circular Causality



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

8/23/04 fig. from Solé & Goodwin 38

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

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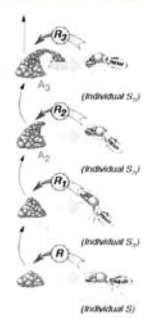
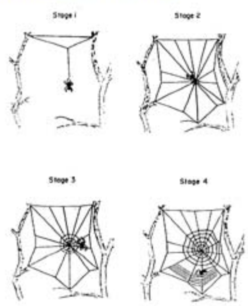
Stigmergy in termite nest building



8/23/04 Fig. from EVALife 40

Stigmergy in spider webs



Fig, from EVALife

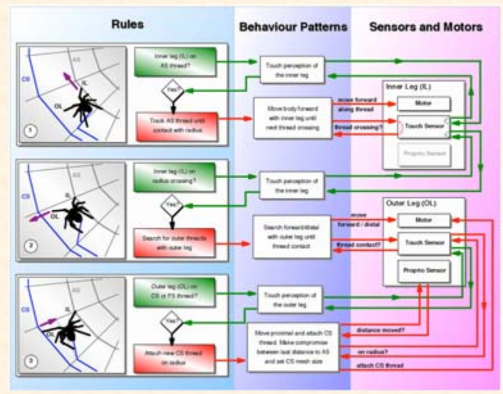


Fig. from EVALife

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

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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

8/23/04 from Solé & Goodwin: *Signs of Life*, p. 149 46

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

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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

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Characteristics of Self-Organized System

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

8/23/04 — Bonabeau, Dorigo & Theraulaz, *Swarm Intelligence*, pp. 12-14 49

Two Approaches to the Properties of Complex Systems

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Focal Issue: Emergence

- Deals with: elements & interactions
- Based on: relation between parts & whole
- Emergent simplicity
- Emergent complexity
- Importance of scale (level)

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Focal Issue: Complexity

- Deals with: information & description
- Based on: relation of system to its descriptions
- Information theory & computation theory are relevant
- Must be sensitive to level of description

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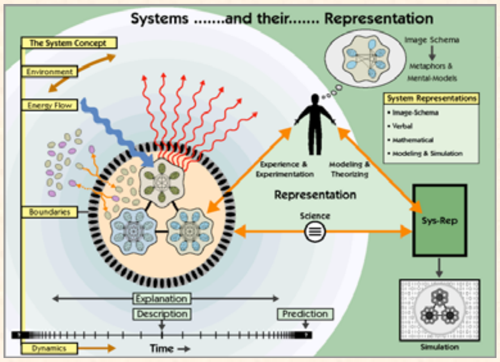

Fig. from NECSI

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Additional Bibliography

1. Solé, Ricard, & Goodwin, Brian. *Signs of Life: How Complexity Pervades Biology*. Basic Books, 2000.
2. Bonabeau, Eric, Dorigo, Marco, & Theraulaz, Guy. *Swarm Intelligence: From Natural to Artificial Systems*. Oxford, 1999.
3. Gordon, Deborah. *Ants at Work: How an Insect Society Is Organized*. Free Press, 1999.
4. Johnson, Steven. *Emergence: The Connected Lives of Ants, Brains, Cities, and Software*. Scribner, 2001. A popular book, but with many good insights.

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