Swarm Intelligence - Introduction

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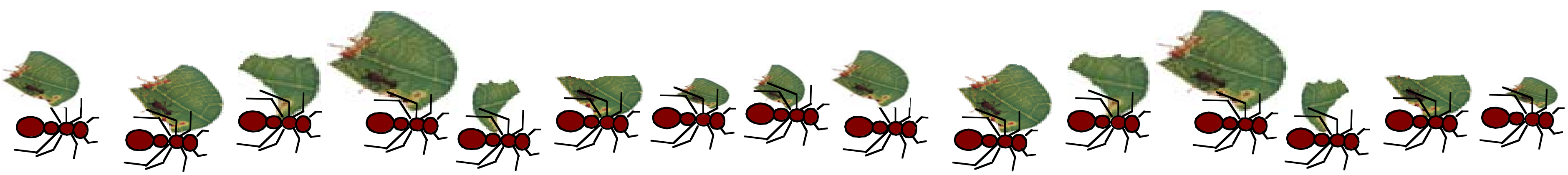


Why do we need new computing techniques?

The computer revolution changed human societies:

- communication
- transportation
- industrial production
- administration, writing, and bookkeeping
- technological advances / science
- entertainment

However, some problems cannot be tackled with traditional hardware and software!

Drawback of traditional techniques

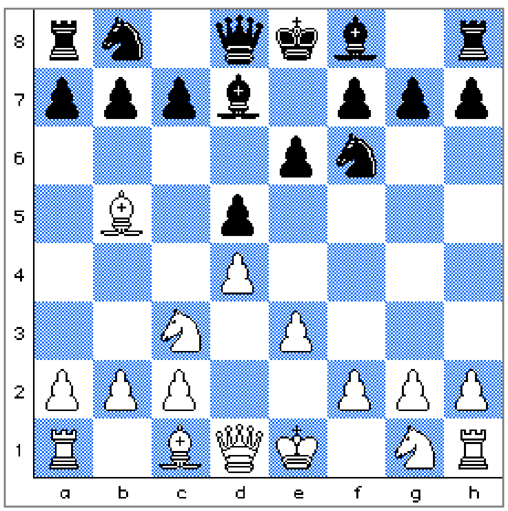
Computing tasks have to be

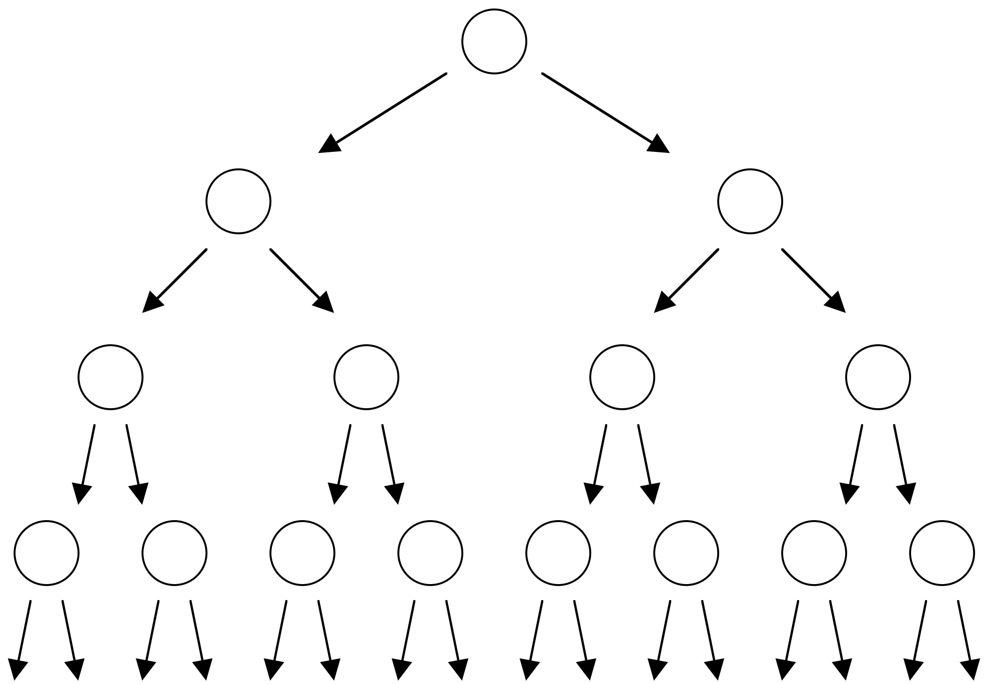
- well-defined
- fairly predictable
- computable in reasonable time with serial computers

Hard problems

Well-defined, but computational hard problems

- NP hard problems (Travelling Salesman Problem)
- Action-response planning (Chess playing)



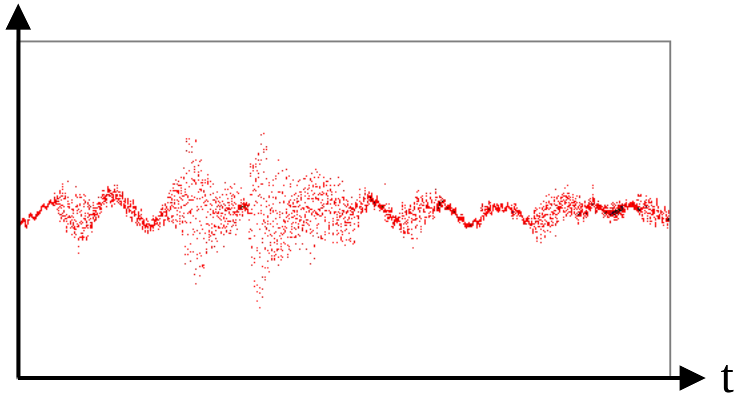


Hard problems

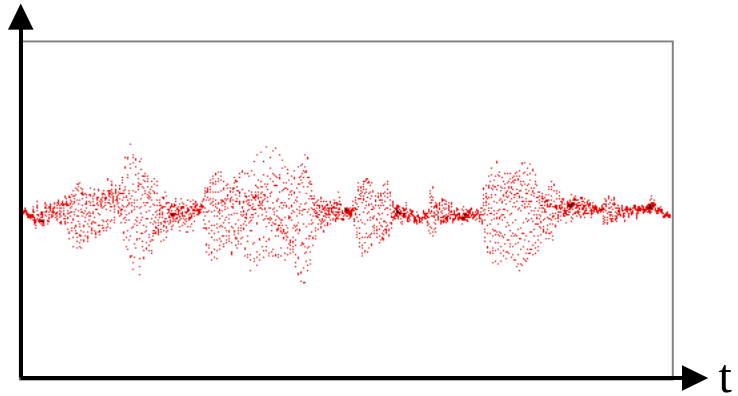
Fuzzy problems

- intelligent human-machine interaction
- natural language understanding

Example: Fuzziness in sound processing



“E-vo-lu-tio-na-ry Com-pu-ta-tion”

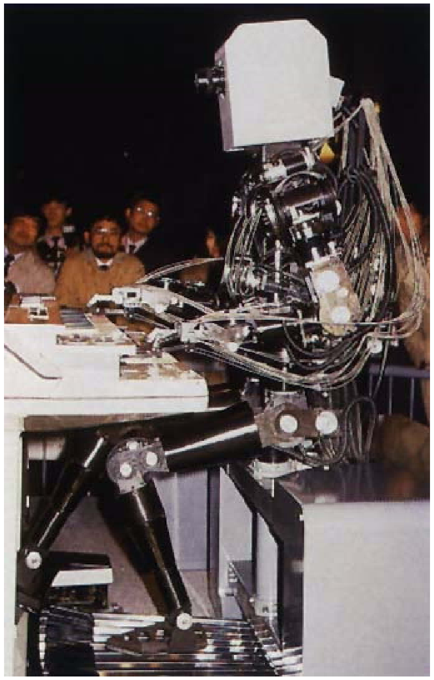


“E-vo-lu-tio-na-ry Com-pu-ta-tion”

Hard problems

Hardly predictable and dynamic problems

- real-world autonomous robots
- management and business planning



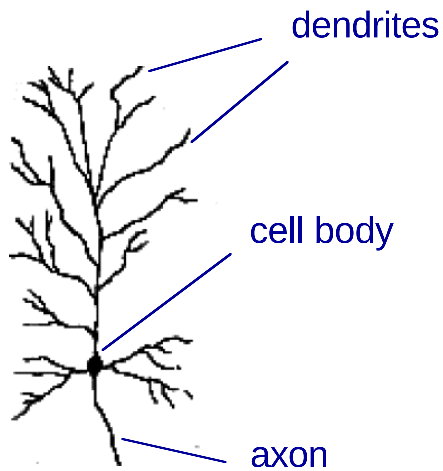
Japanese piano robot

Trade at the stock exchange

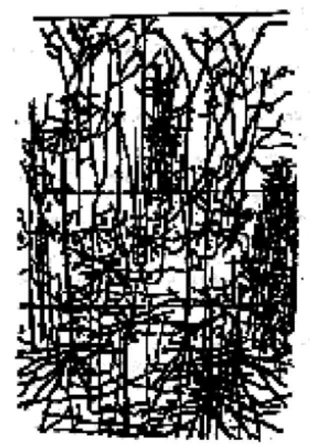
What are the alternatives?

- DNA based computing (chemical computation)
- Quantum computing (quantum-physical computation)
- Bio-computing (simulation of biological mechanisms)

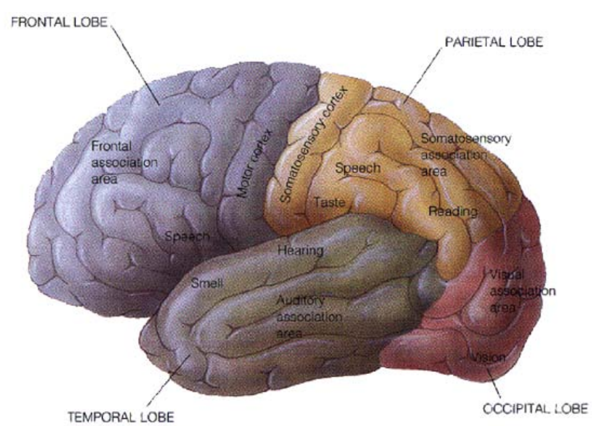
Brains and Artificial Neural Networks



The basic unit - the neurone



Vertical cut through the neocortex of a cat



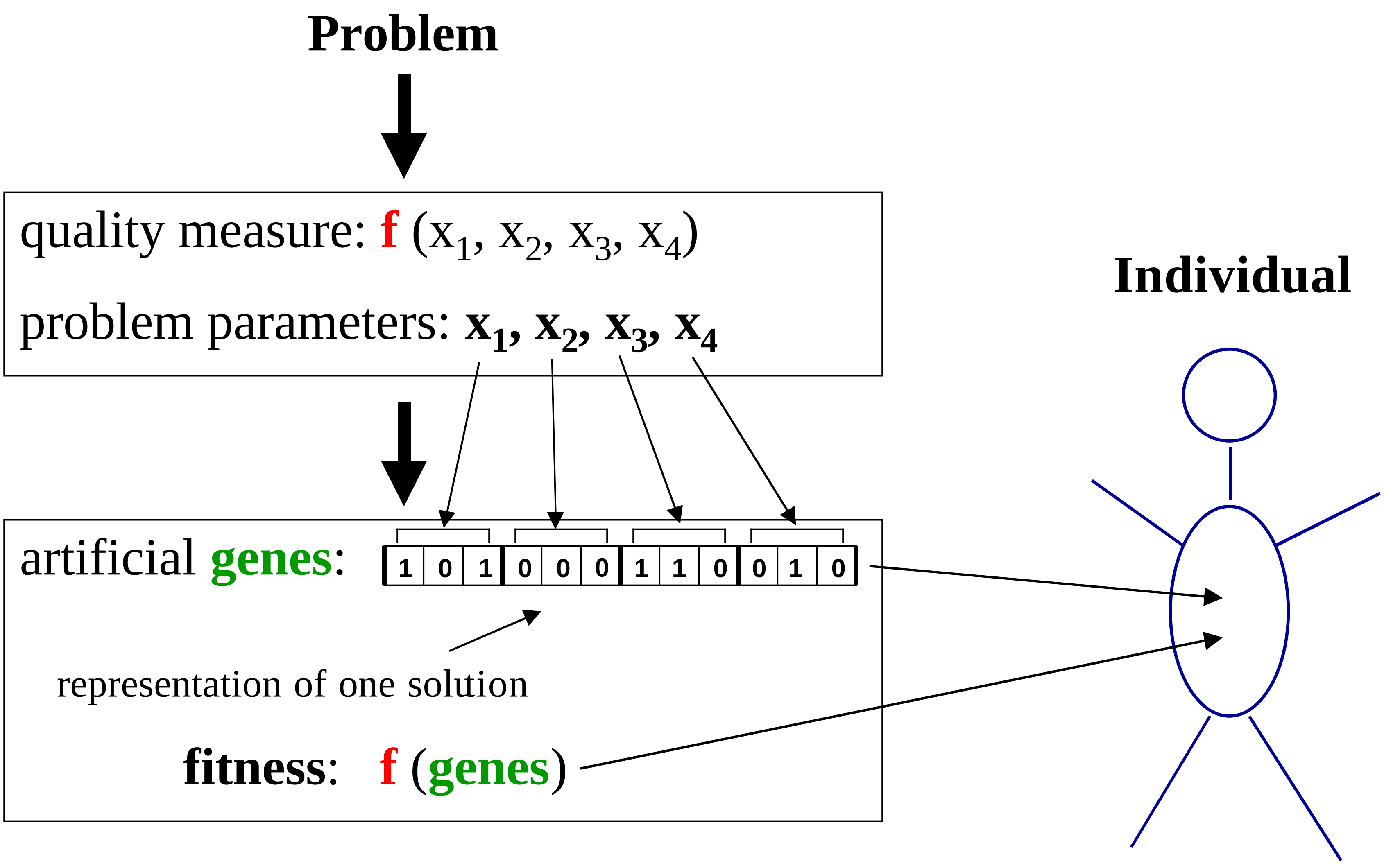
Functional areas of the cerebrum's left hemisphere

Functional units of the human brain

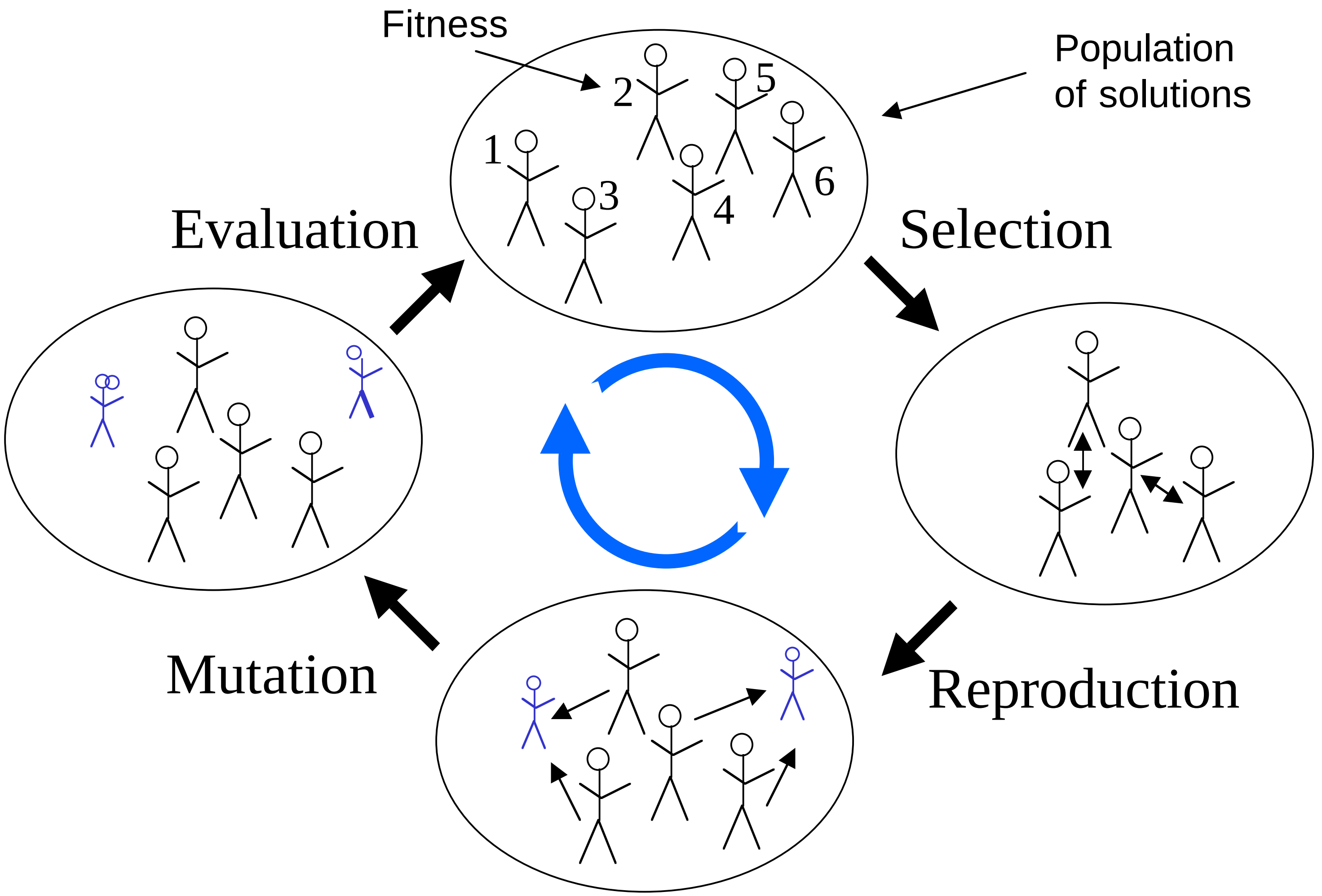
Properties of the brain

- holistic
- parallel
- associative
- learning
- redundancy
- self-organisation

Evolution and Evolutionary Algorithms



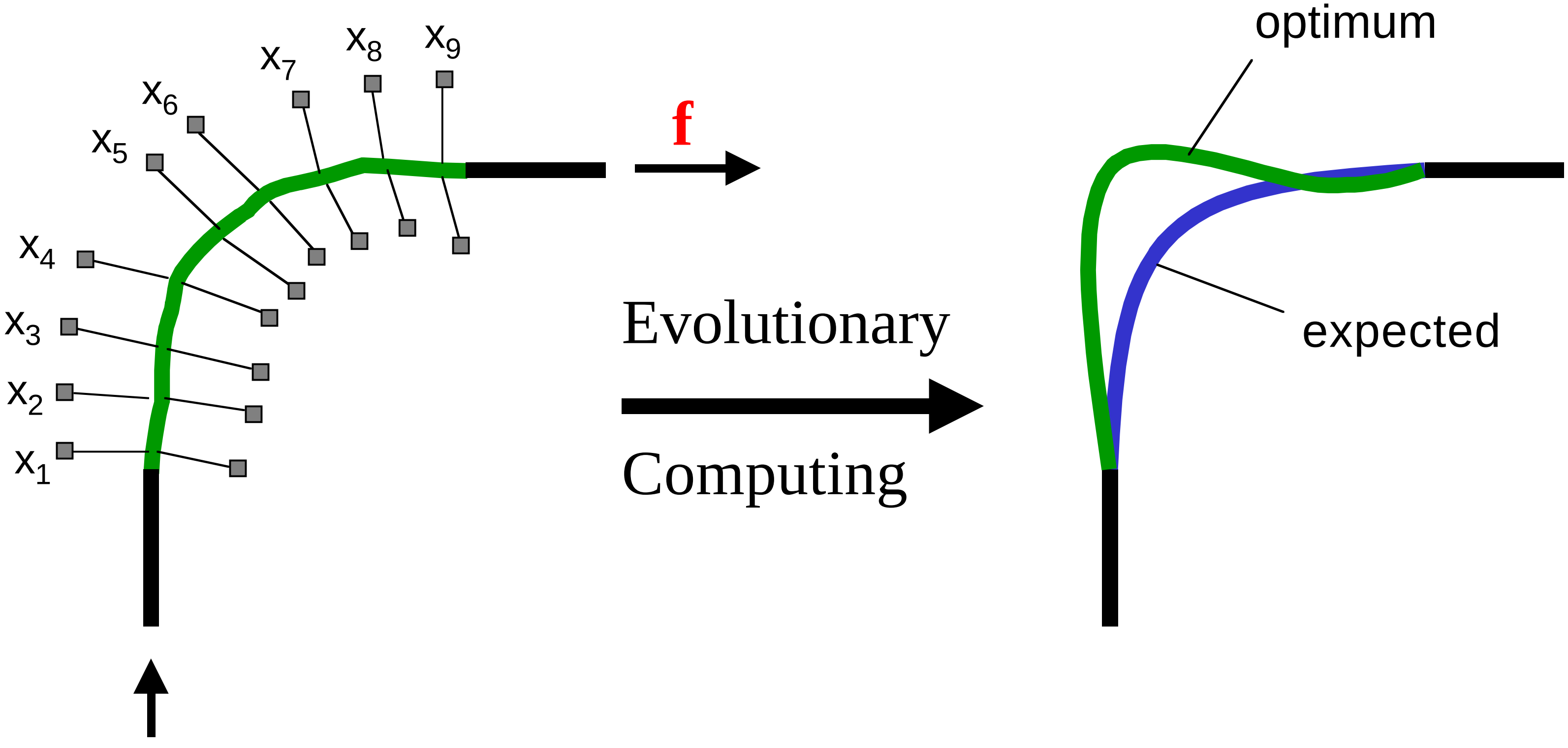
Evolution and Evolutionary Algorithms



EAs - Optimization without knowledge

The task: Design a bent tube with a maximum flow

Goal: water flow **f** $(x_1, x_2, \ldots, x_9) = f_{max}$



Foundations of Bio-Computing

	Inspiration	Identification	Application	Verification
Natural sciences	●	●		●
Complexity theory		●	●	
Adaptive algorithms			●	
Artificial Life	●		●	
Swarm Intelligence	●	●	●	

Fields of application

- Robotics / Artificial Intelligence
- Process optimisation / Staff scheduling
- Telecommunication companies
- Entertainment

What are the limitations

- biology makes compromises between different goals
- biology sometimes fails
- some natural mechanisms are not well understood
- well-defined problems can be solved by better means

What is Swarm Intelligence (SI)?

“The emergent collective intelligence of groups of simple agents.”

(Bonabeau et al, 1999)

Examples

- group foraging of social insects
- cooperative transportation
- division of labour
- nest-building of social insects
- collective sorting and clustering

Why is Swarm Intelligence interesting for IT?

Analogies in IT and social insects

- distributed system of interacting autonomus agents
- goals: performance optimization and robustness
- self-organized control and cooperation (decentralized)
- division of labour and distributed task allocation
- indirect interactions

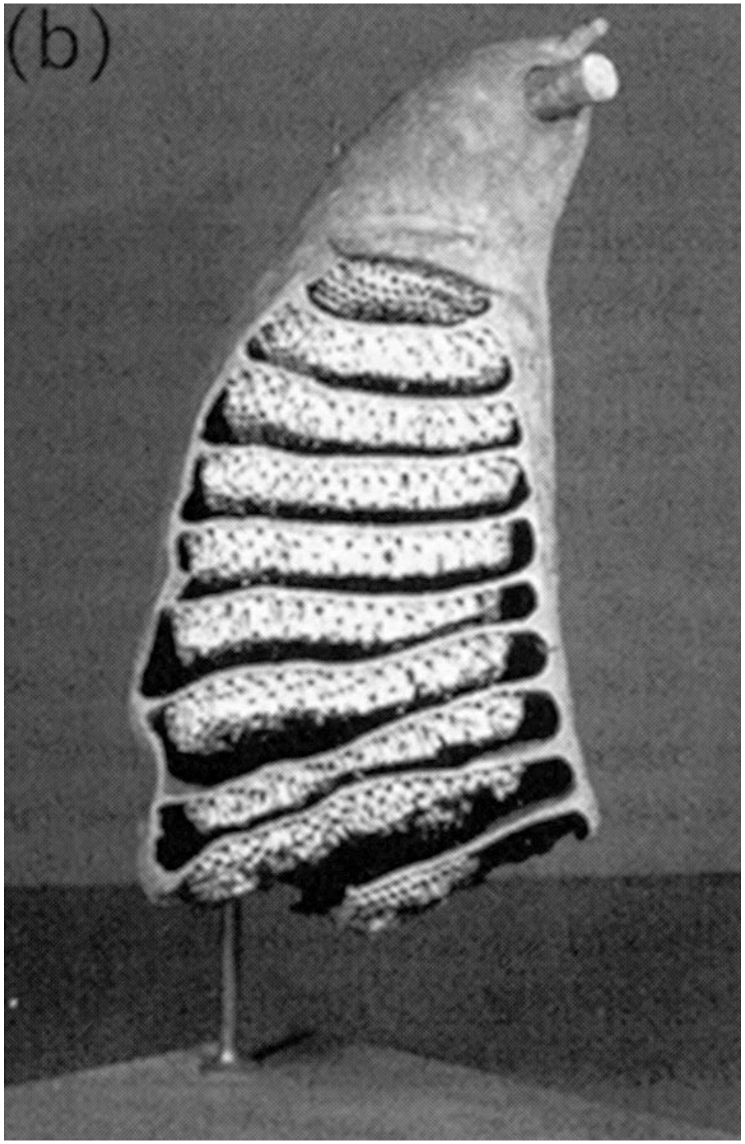
How can we design SI systems?

The 3 step process

- **identification of analogies**: in swarm biology and IT systems
- **understanding**: computer modelling of realistic swarm biology
- **engineering**: model simplification and tuning for IT applications

Some observations...

Nest-building in social wasps



Group defence in honey bees

Ants

Why are ants interesting?

- ants solve complex tasks by simple local means
- ant productivity is better than the sum of their single activities
- ants are ‘grand masters’ in search and exploitation

Which mechanisms are important?

- cooperation and division of labour
- adaptive task allocation
- work stimulation by cultivation
- pheromones

What are there principal mechanisms of natural organization?

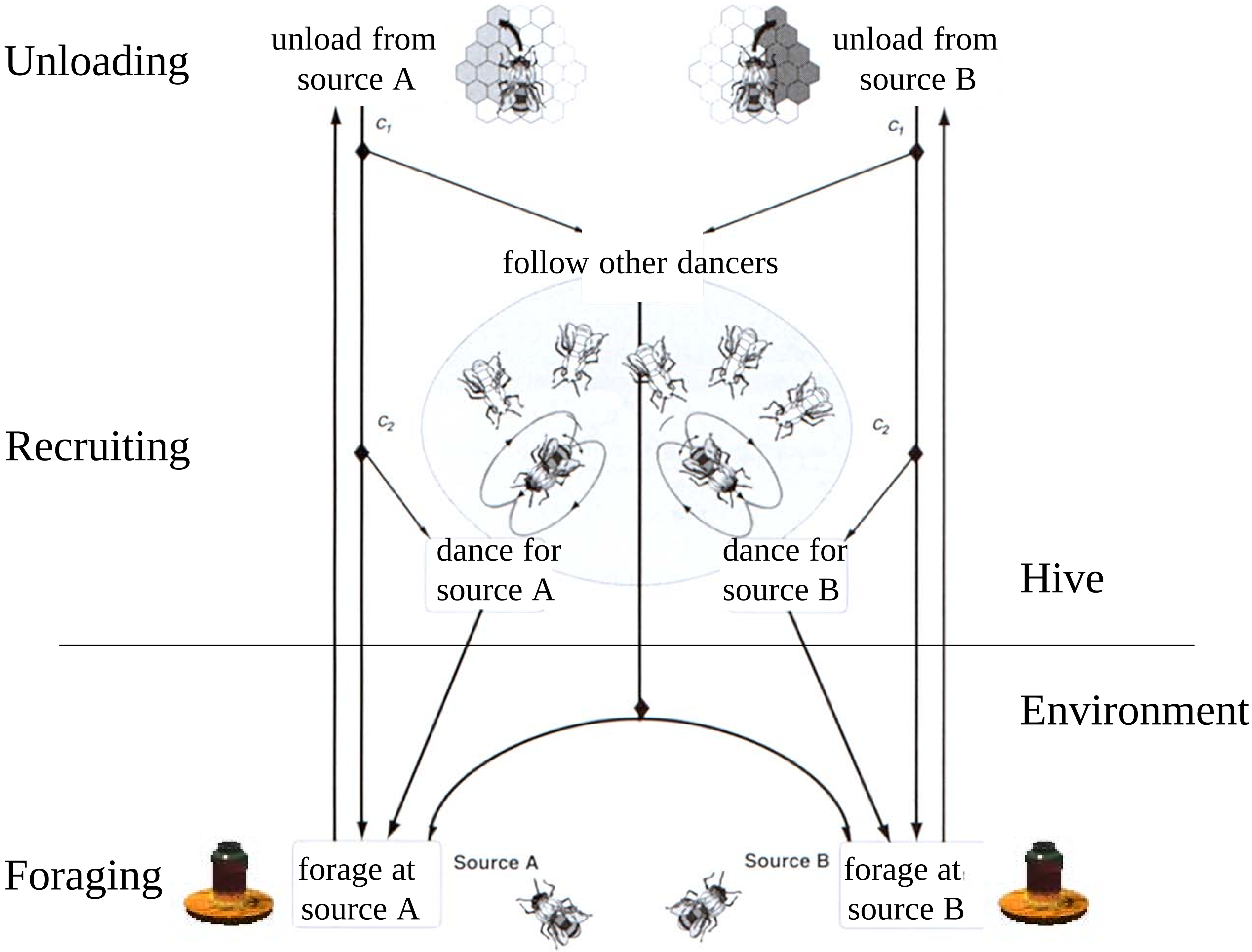
Self-organization

'Self-organization is a set of dynamical mechanisms whereby structures appear at the global level of a system from interactions of its lower-level components.'

(Bonabeau et al, in Swarm Intelligence, 1999)

The four bases of self-organization

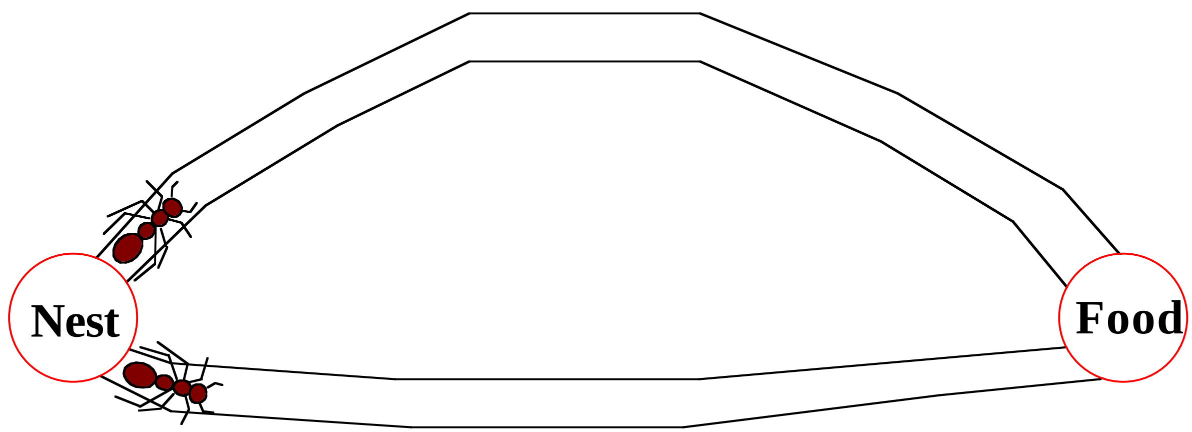
- positive feedback (amplification)
- negative feedback (for counter-balance and stabilization)
- amplification of fluctuations (randomness, errors, random walks)
- multiple interactions



Unloading
unload from source A
unload from source B
c_1
c_1
follow other dancers
Recruiting
c_2
c_2
dance for source A
dance for source B
Hive
Environment
Foraging
forage at source A
Source A
Source B
forage at source B

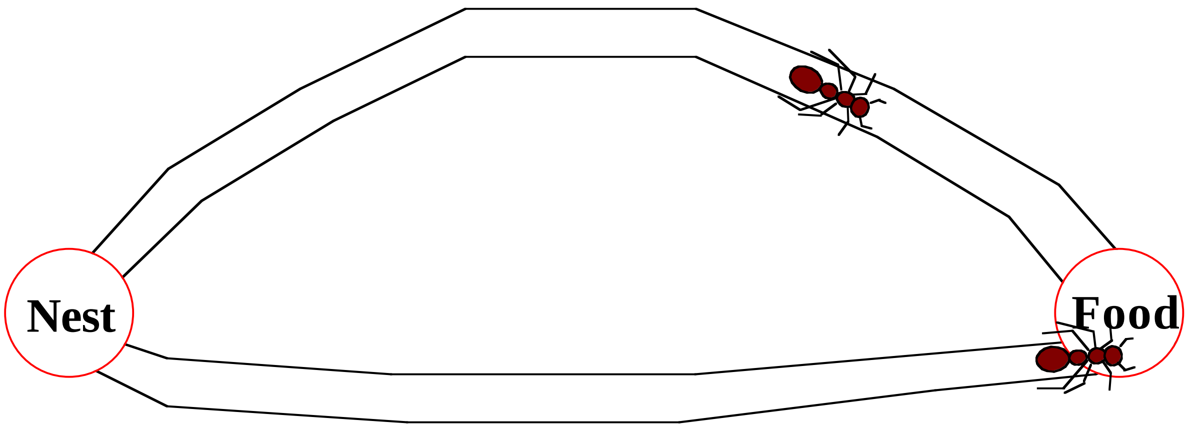
Ant foraging

Cooperative search by pheromone trails



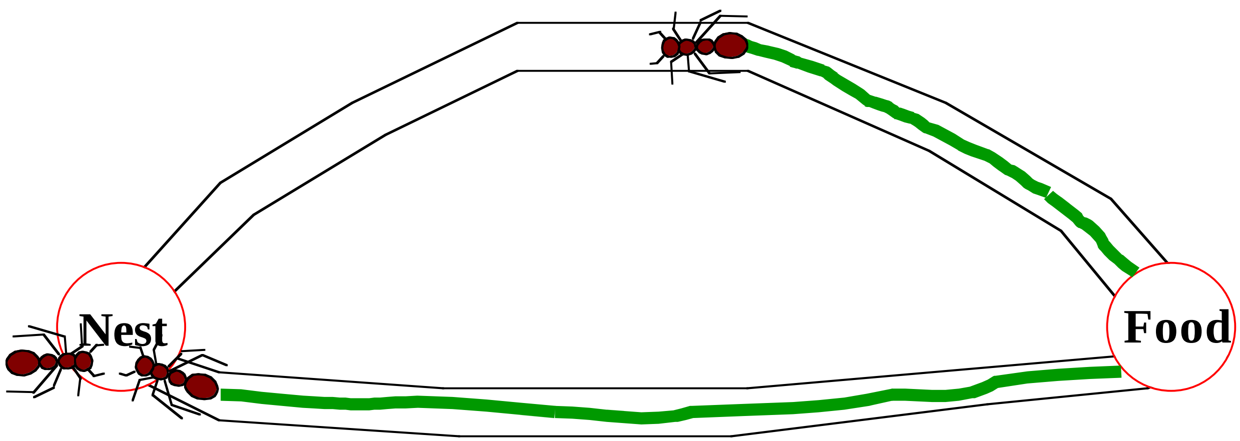
Ant foraging

Cooperative search by pheromone trails



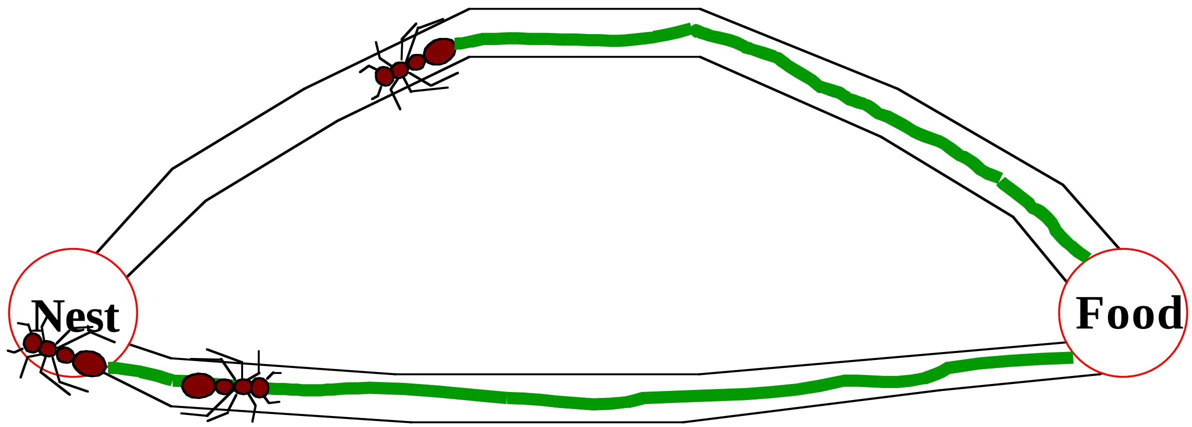
Ant foraging

Cooperative search by pheromone trails



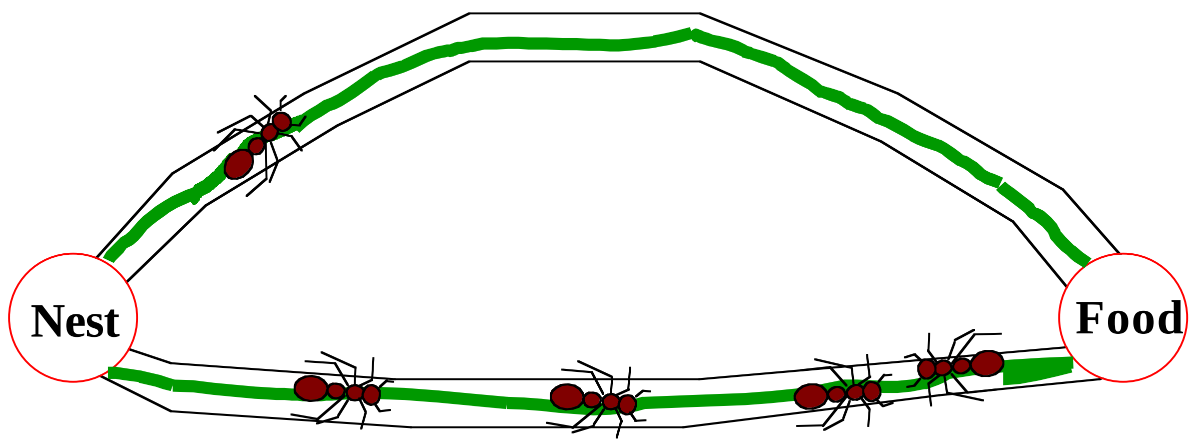
Ant foraging

Cooperative search by pheromone trails



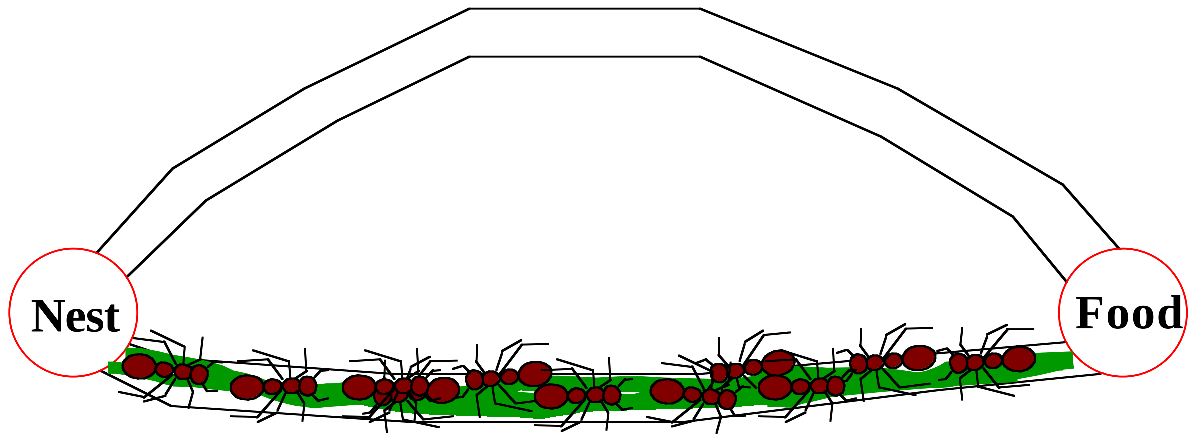
Ant foraging

Cooperative search by pheromone trails



Ant foraging

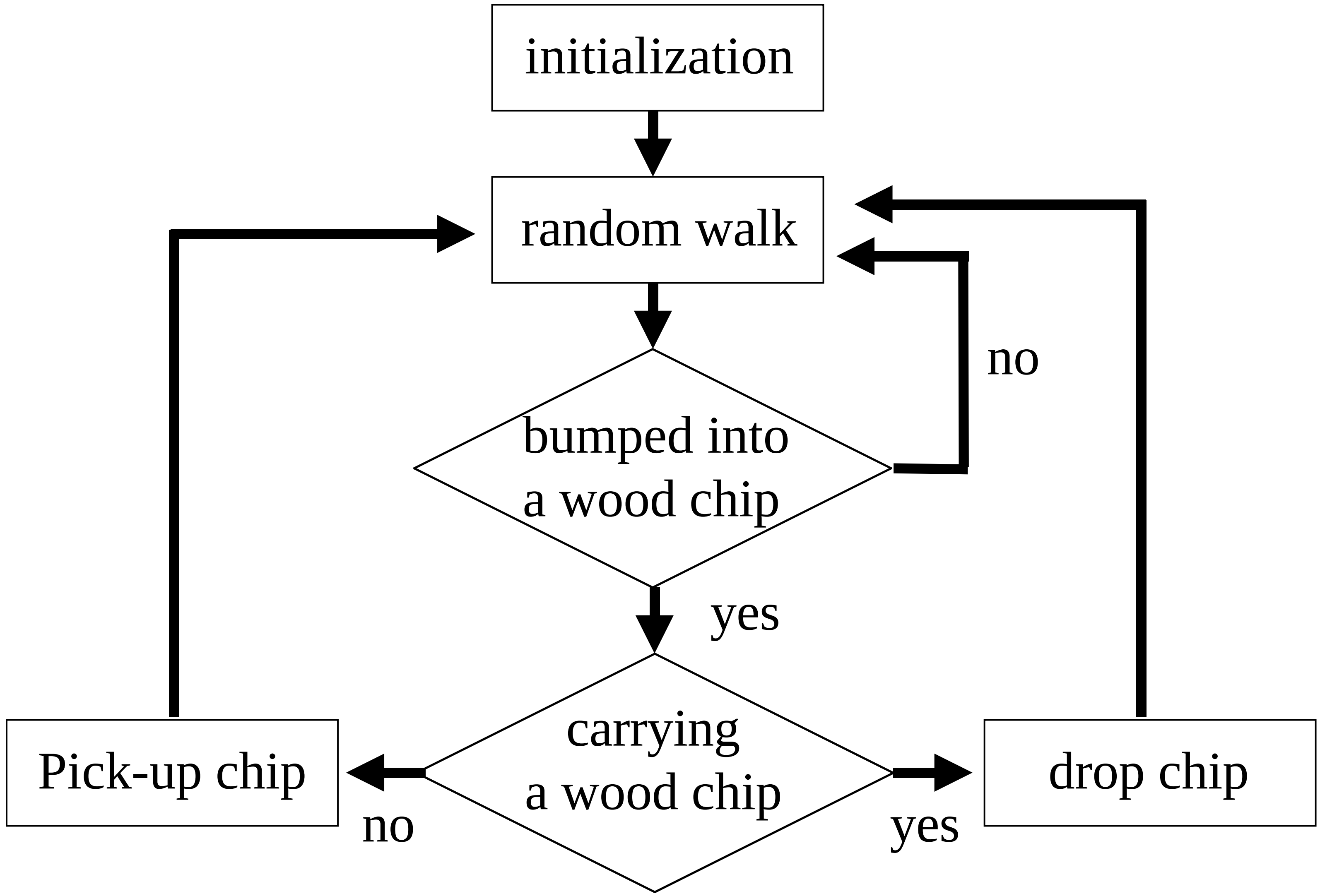
Cooperative search by pheromone trails



Characteristics of self-organized systems

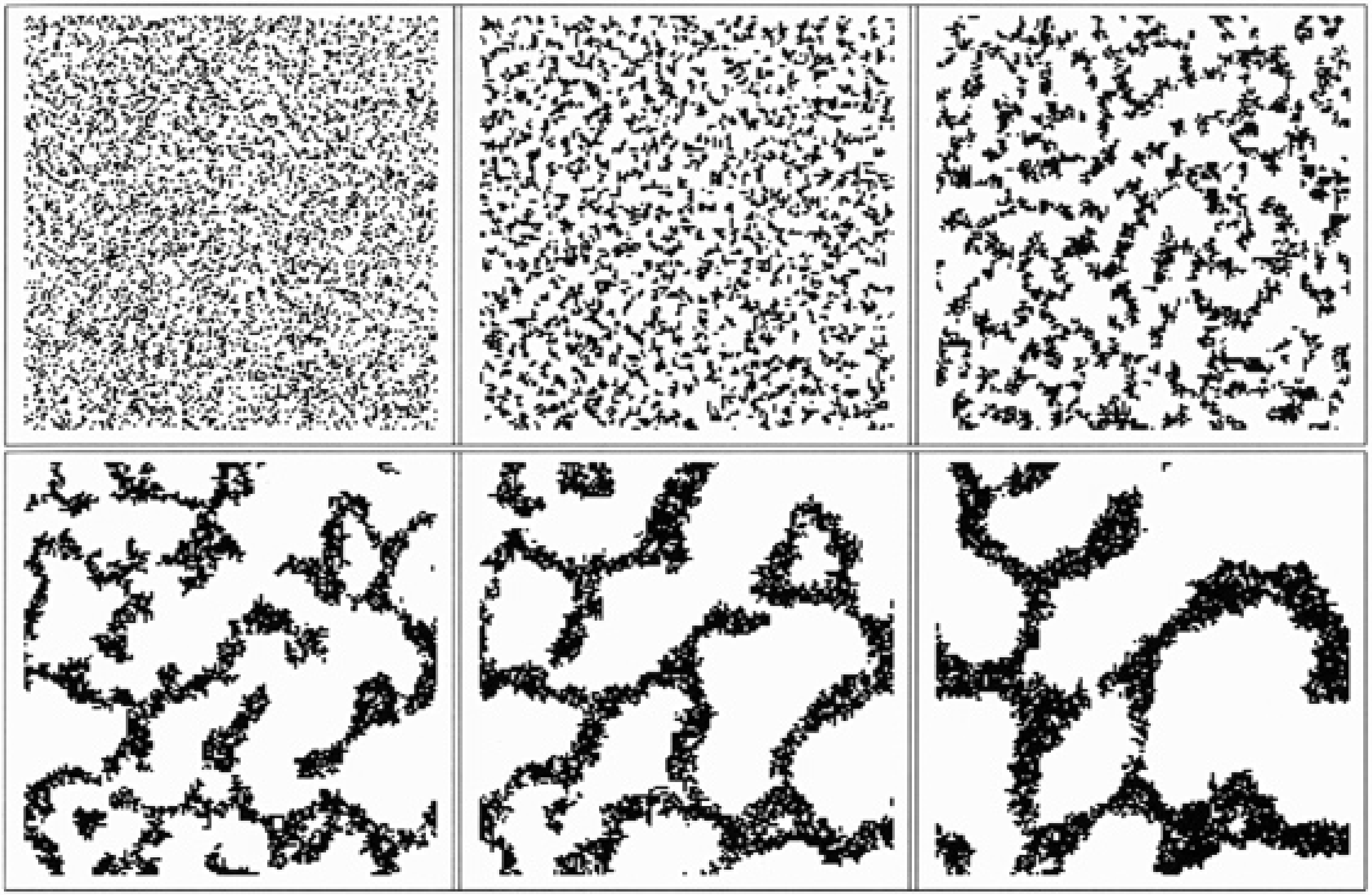
- structure emerging from a homogeneous startup state
- multistability - coexistence of many stable states
- state transitions with a dramatical change of the system behaviour

Self-organization in a termite simulation



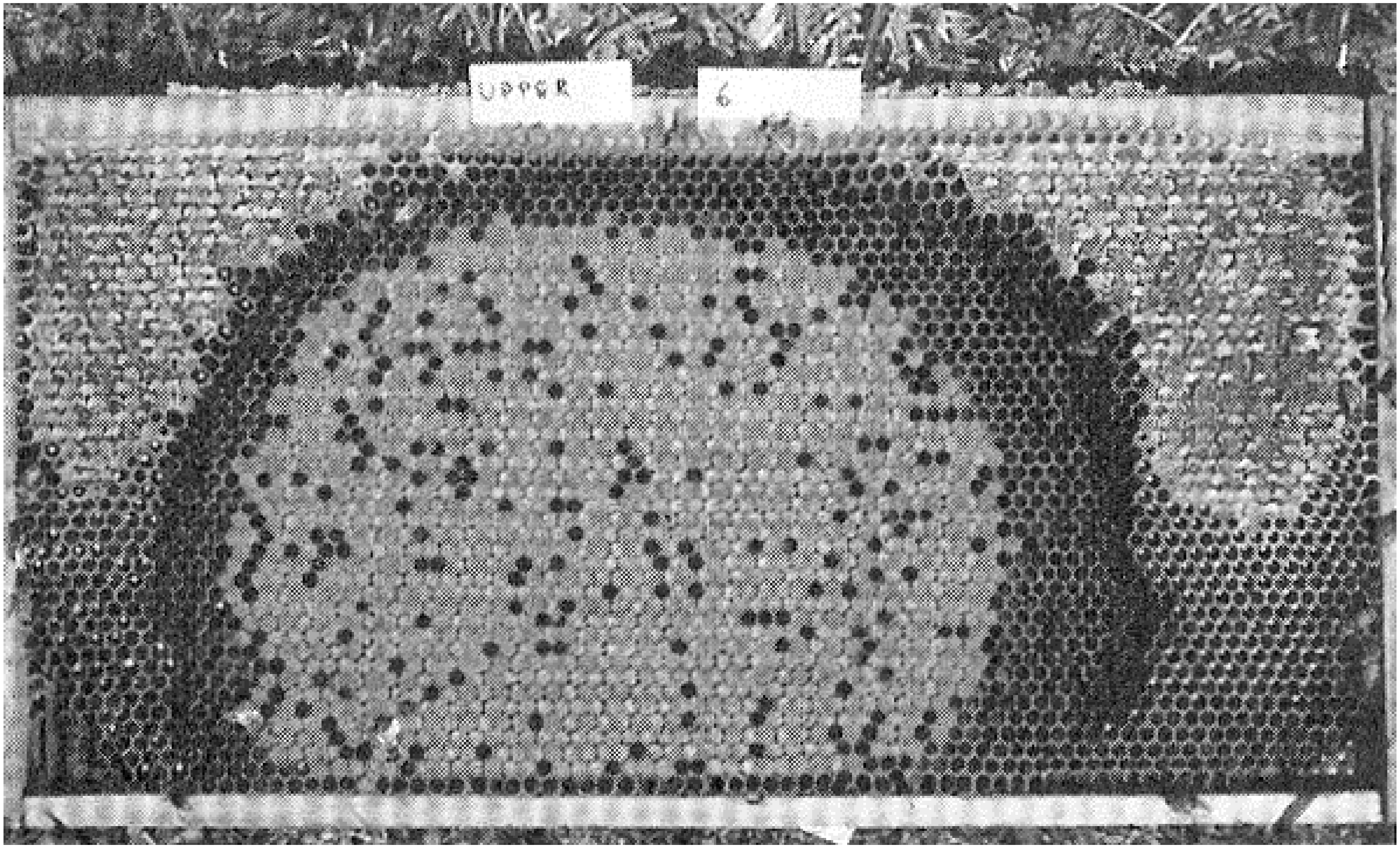
(Mitchel Resnick, 1994)

Self-organization in a termite simulation



(Mitchel Resnick, 1994)

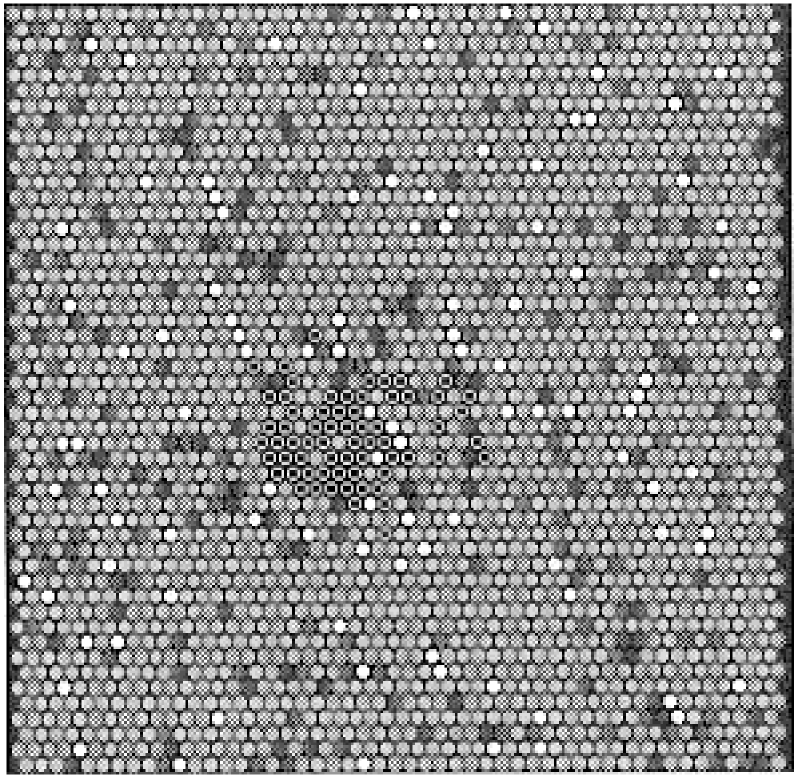
Self-organization in honey bee nest building

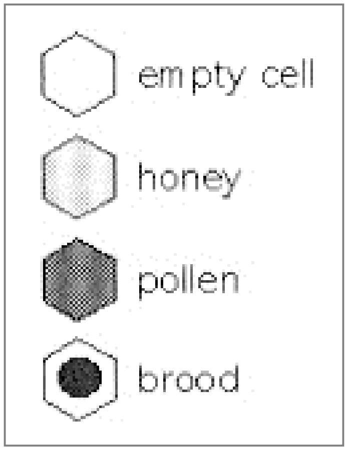


Self-organization in honey bee nest building

- the queen moves randomly over the combs
- eggs are more likely to be layed in the neighbourhood of brood
- honey and pollen are deposited randomly in empty cells
- four times more honey is brought to the hive than pollen
- removal ratios for honey: 0.95; pollen: 0.6
- removal of honey and pollen is proportional to the number of surrounding cells containing brood

Simulation of honey bee nest building





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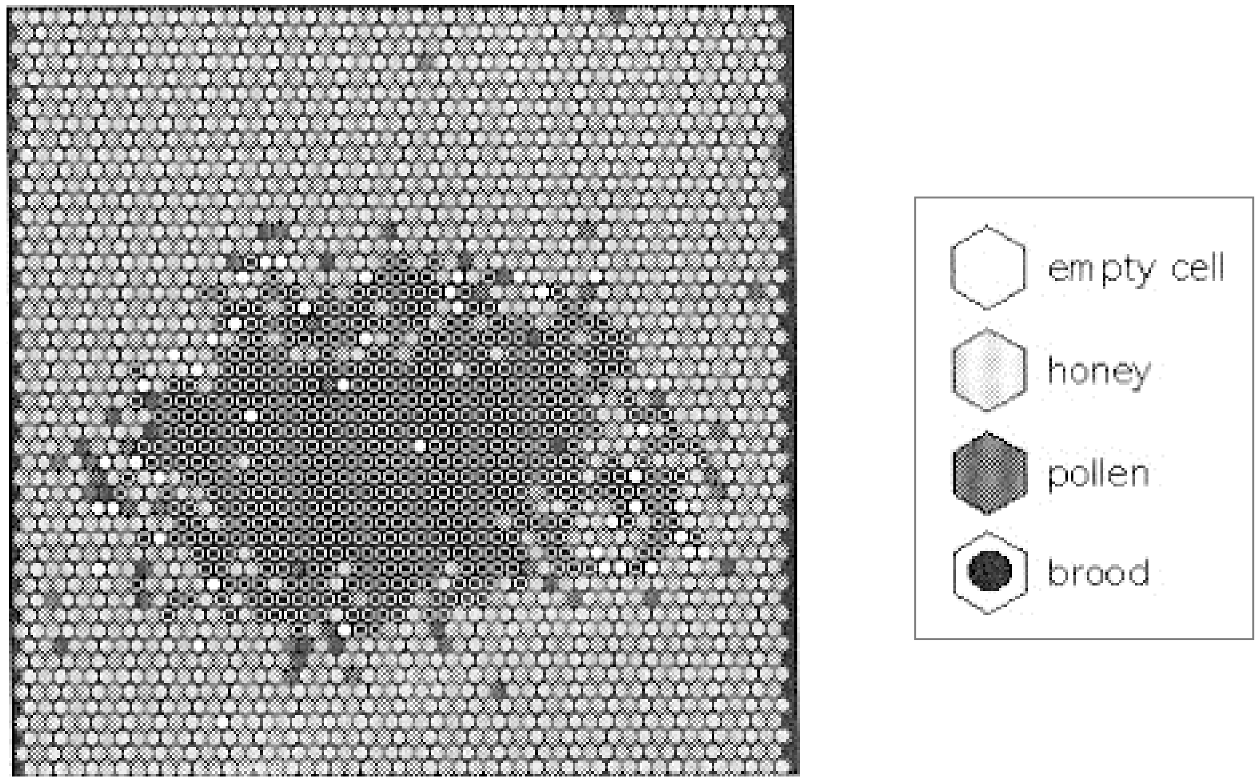

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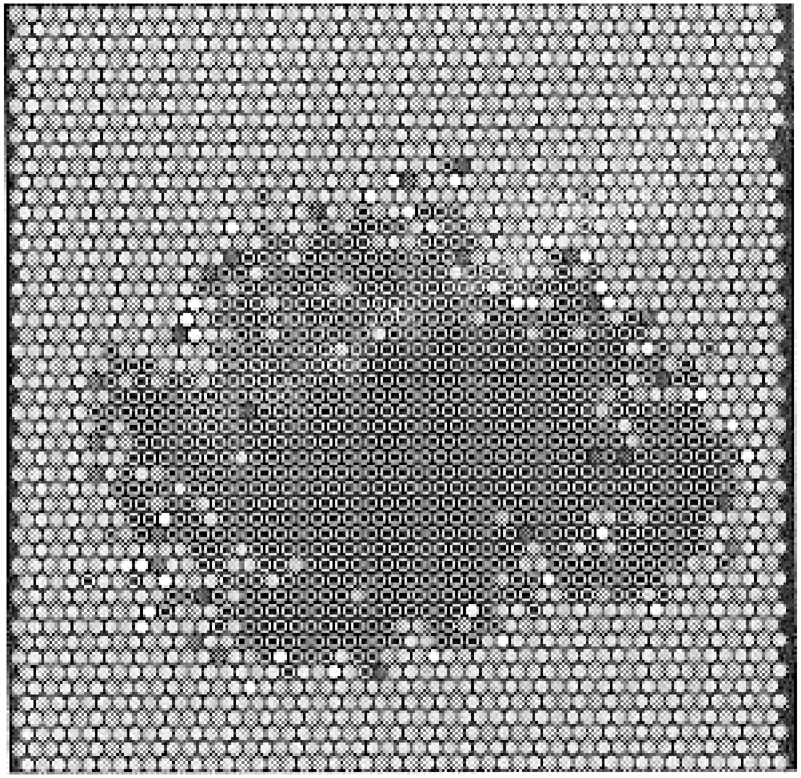

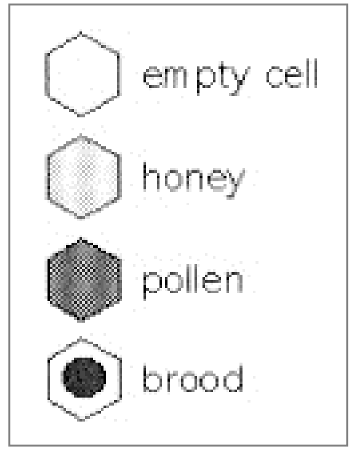

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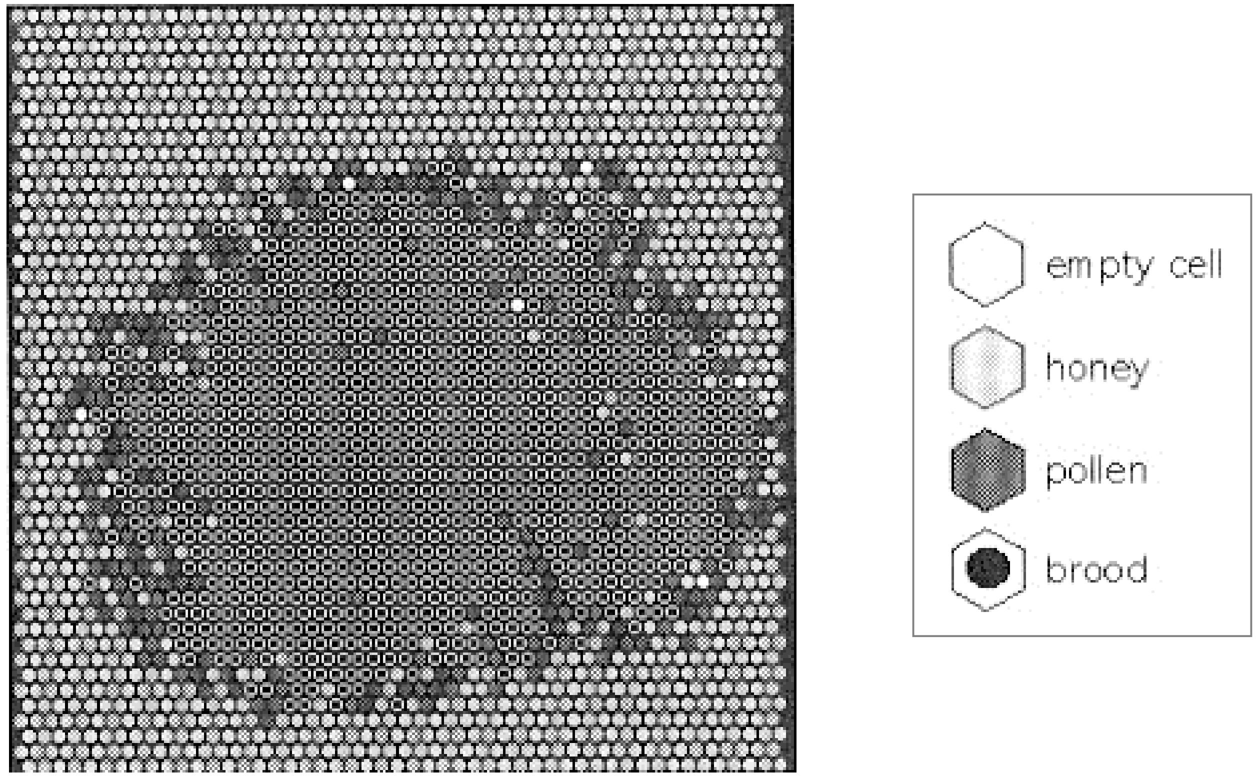

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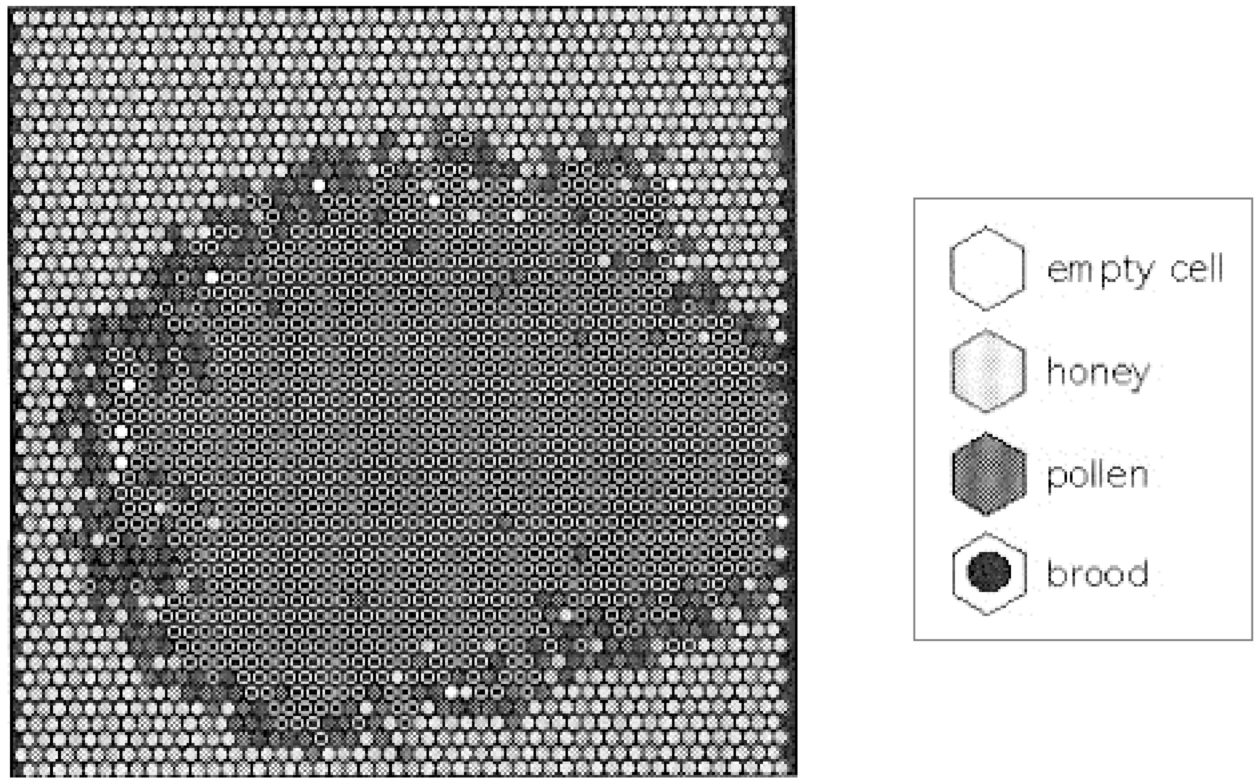

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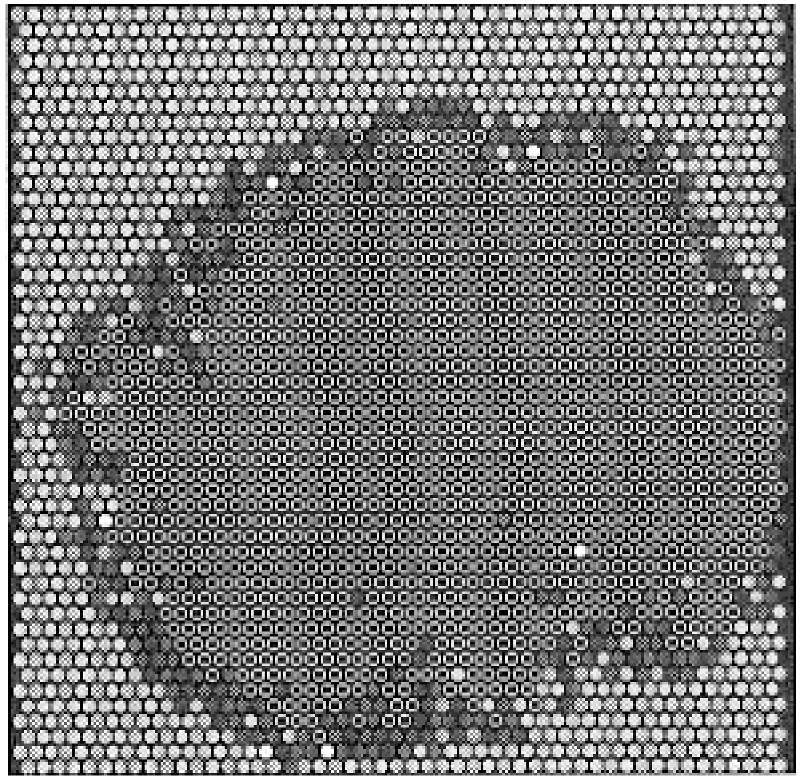
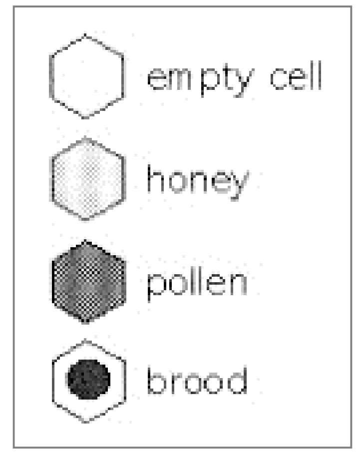




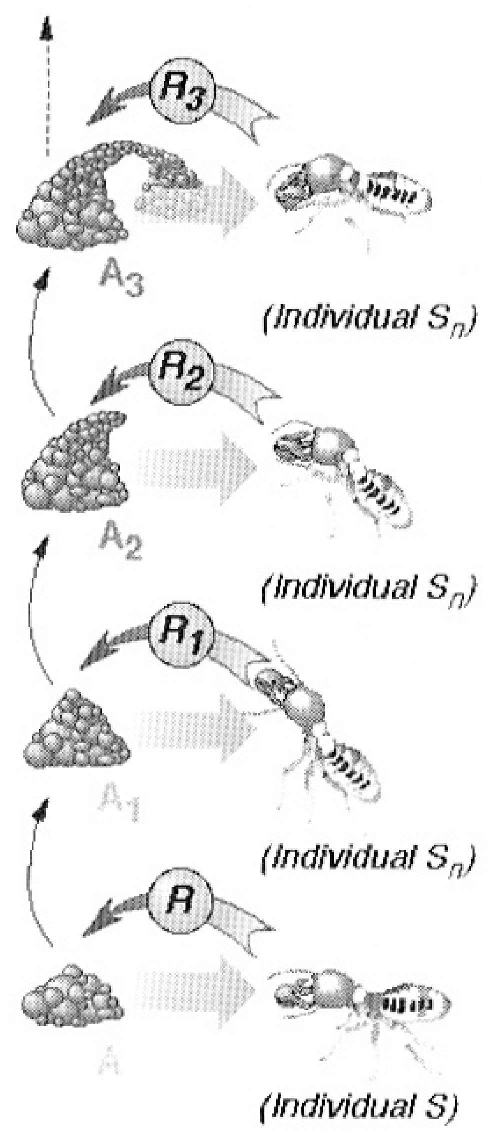
Stigmergy

Stigmergy: *stigma* (sting) + *ergon* (work)
= ‘stimulation by work’

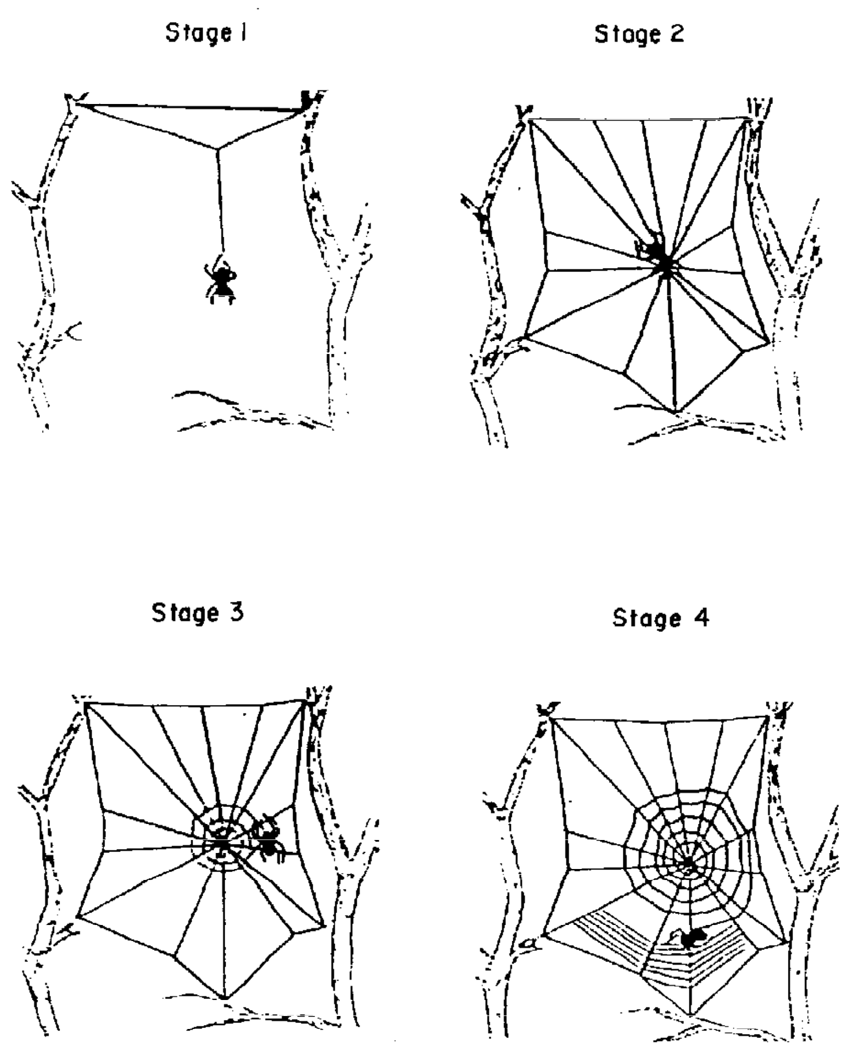
Characteristics of stigmergy

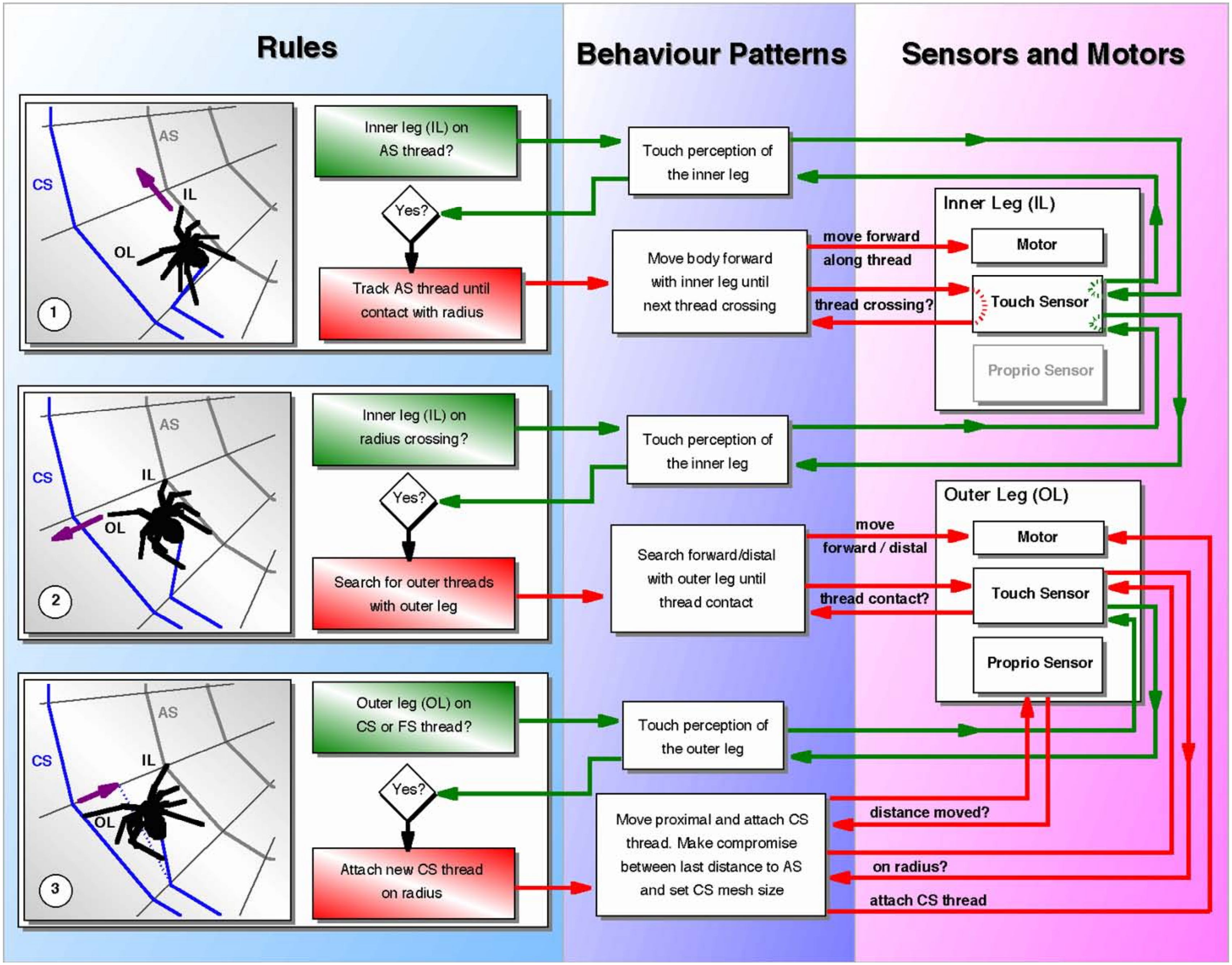
- indirect agent interaction modification of the environment
- environmental modification serves as external memory
- work can be continued by any individual
- the same, simple, behavioural rules can create different designs according to the environmental state

Stigmergy in termite nest building



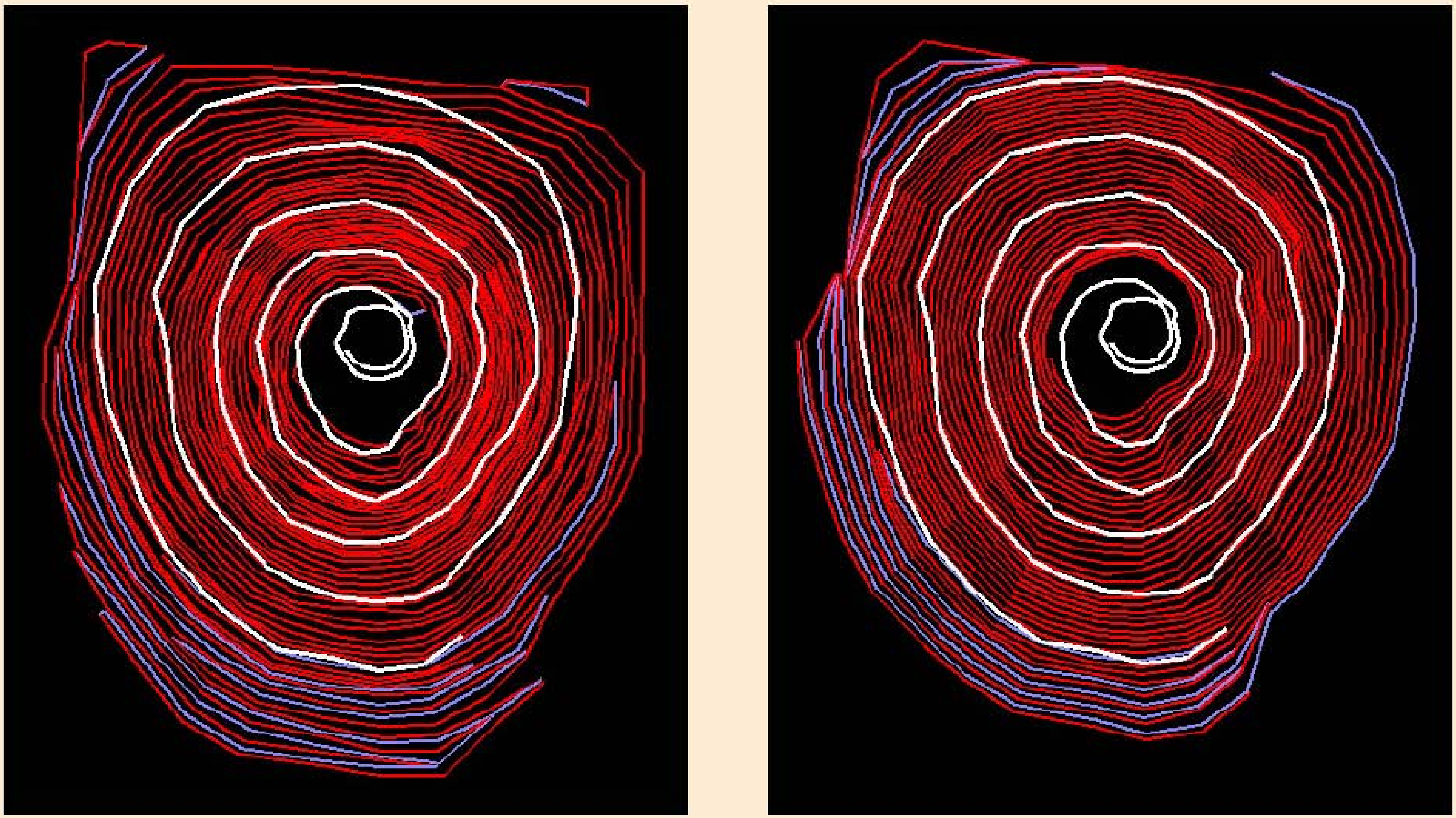
Stigmergy in spider webs




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

Stigmergy in spider webs

Spiral analysis - Real spider vs simulation



A. diadematus Virtual spider

Summary

Motivation and methods in biologically inspired IT

- there are analogies in distributed computing and social insects
- biology has found solution to hard computational problems
- biologically inspired computing requires:
  - identification of analogies
  - computer modelling of biological mechanisms
  - adaptation of biological mechanisms for IT applications

Summary

Two principles in swarm intelligence

- self-organization is based on:
  - activity amplification by positive feedback
  - activity balancing by negative feedback
  - amplification of random fluctuations
  - multiple interactions
- stigmergy - stimulation by work - is based on:
  - work as behavioural response to the environmental state
  - an environment that serves as a work state memory
  - work that does not depend on specific agents