Swarm Intelligence

Eric Bonabeau

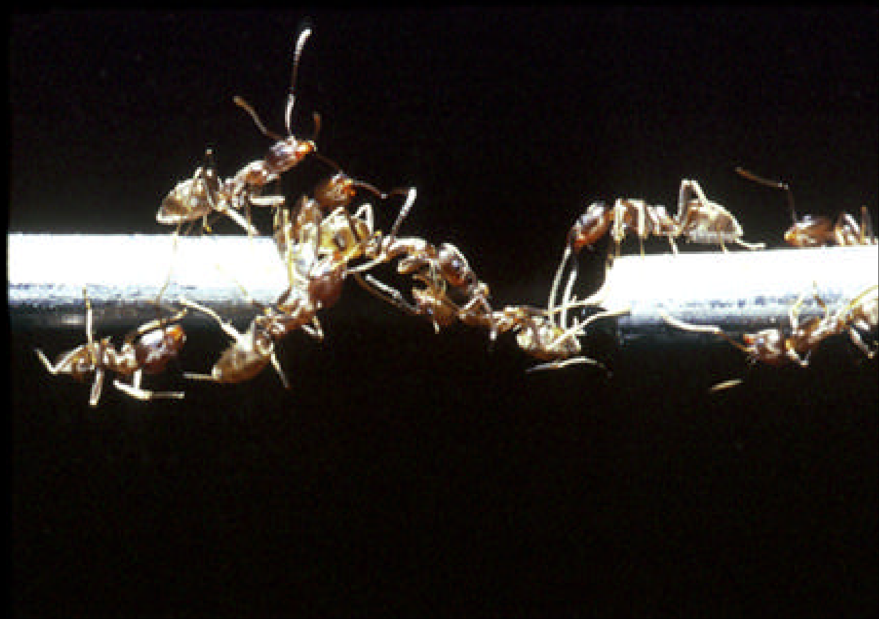
icosystem

Dumb parts, properly connected into a swarm, yield smart results.

Kevin Kelly

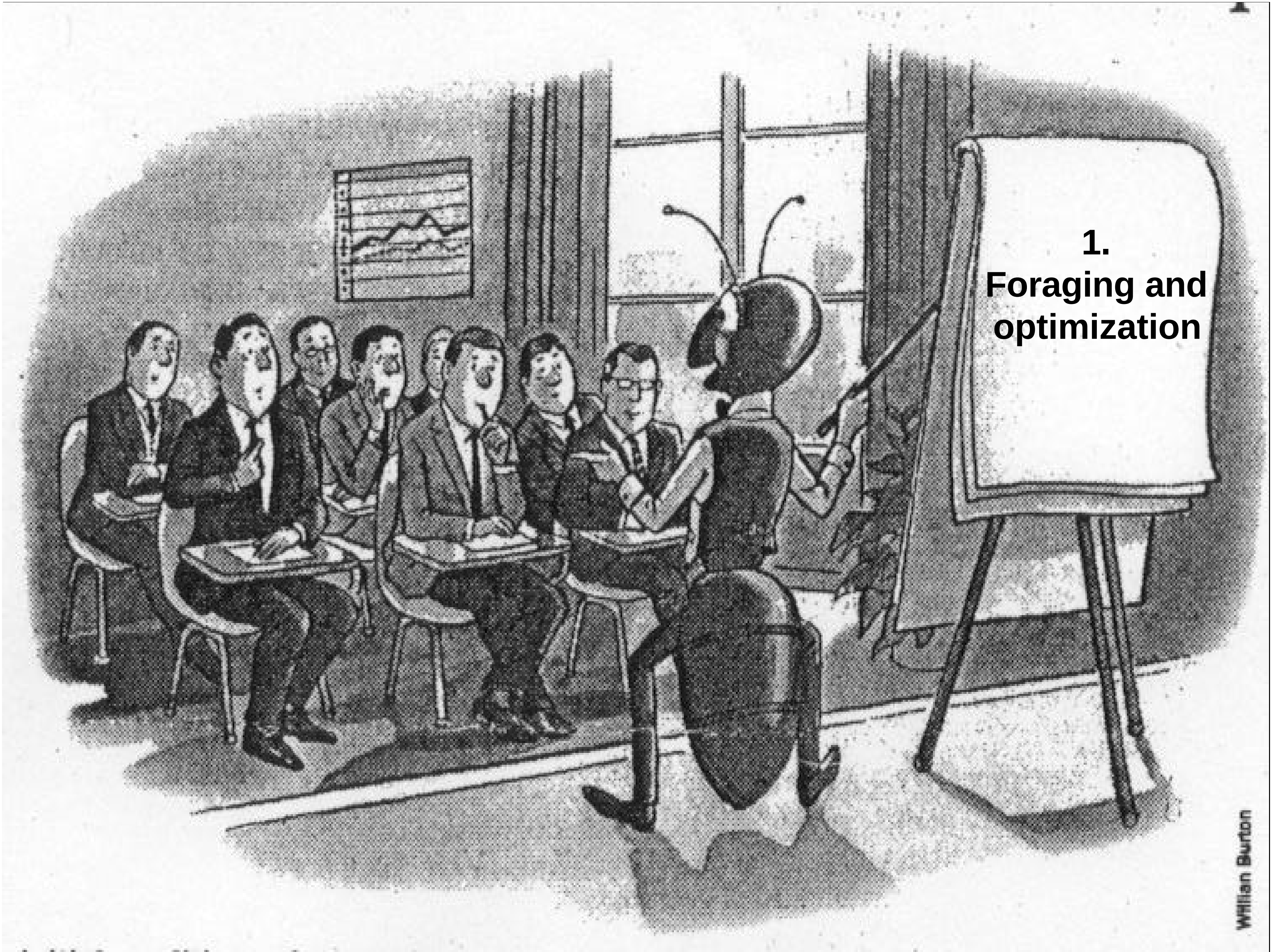
Great, but how do you properly connect the parts??

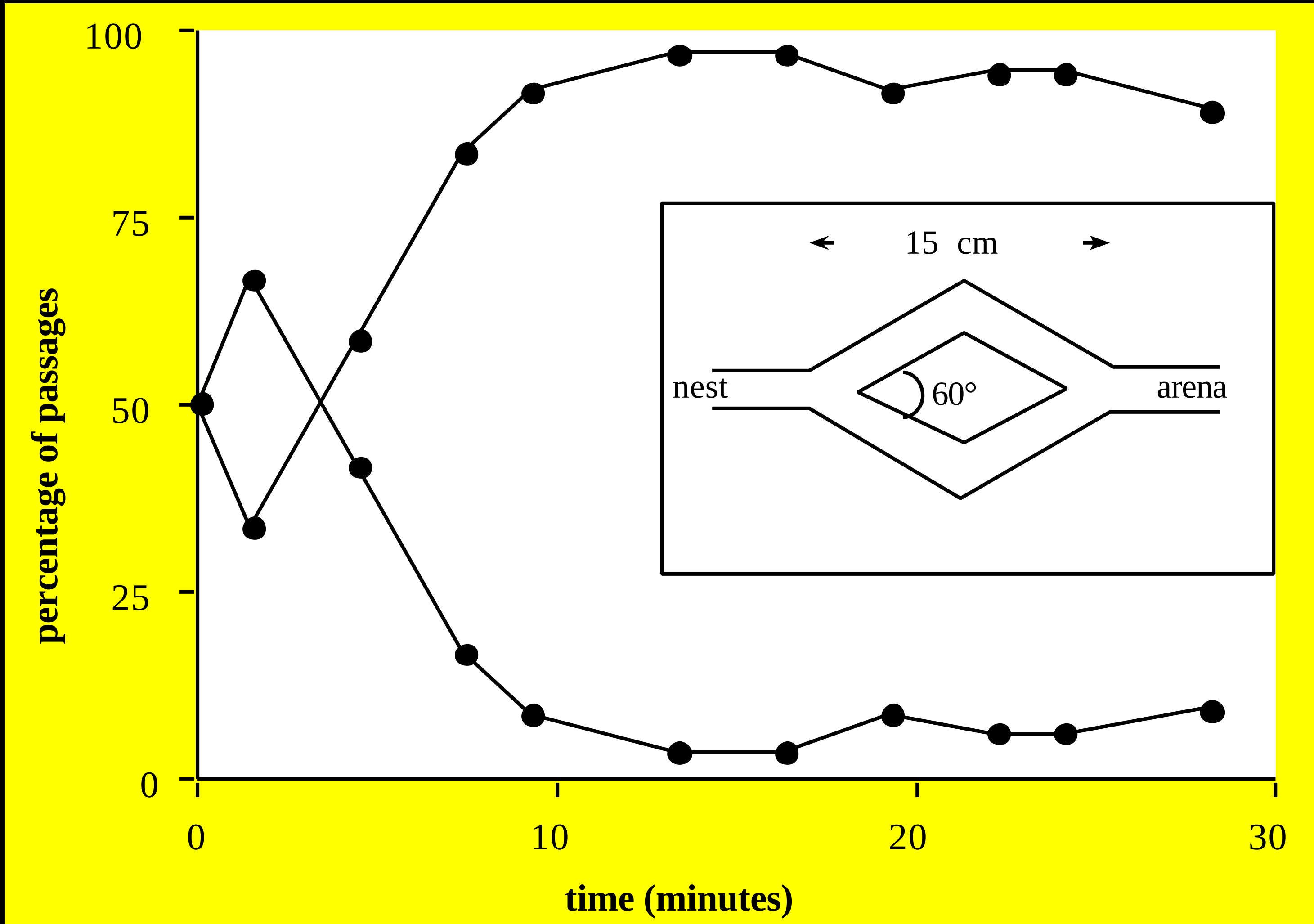
Social insects do it



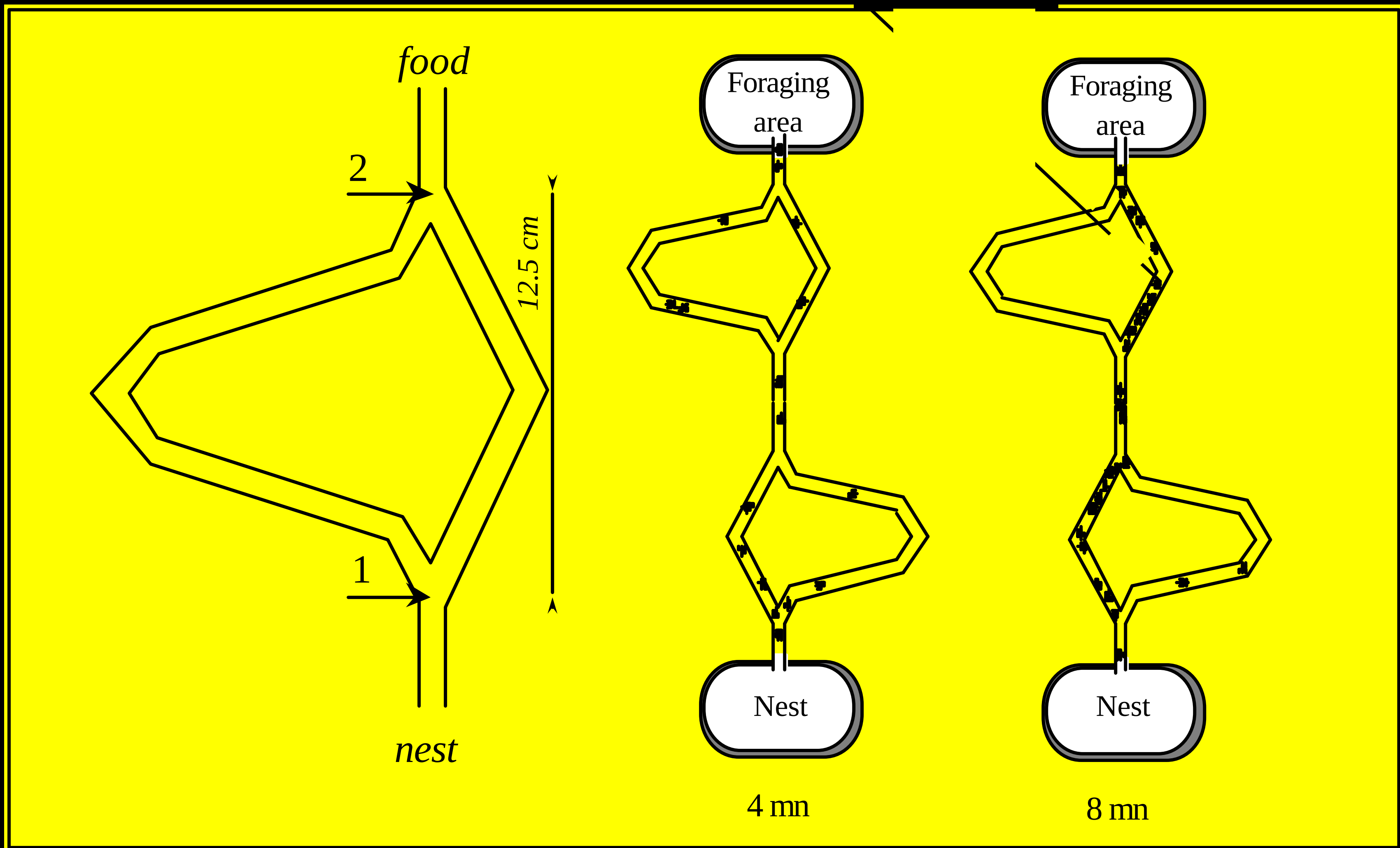
A social insect colony is...

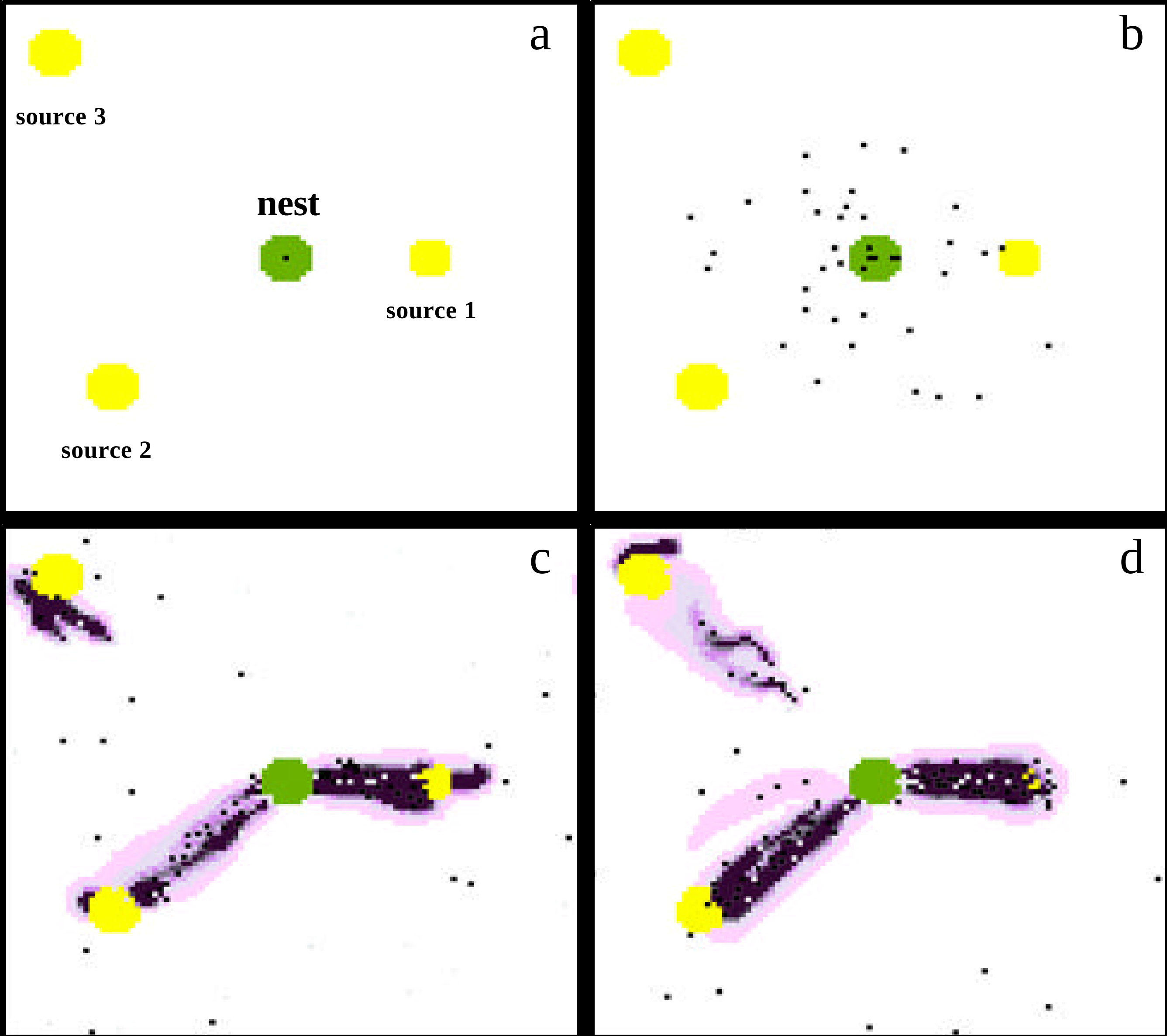
- ***Flexible***: the colony can respond to internal perturbations and external challenges
- ***Robust***: tasks are completed even if some individuals fail
- ***Decentralized***: there is no central control(ler) in the colony
- ***Self-organized***: paths to solutions are emergent rather than predefined


1.
Foraging and
optimization
Willian Burton



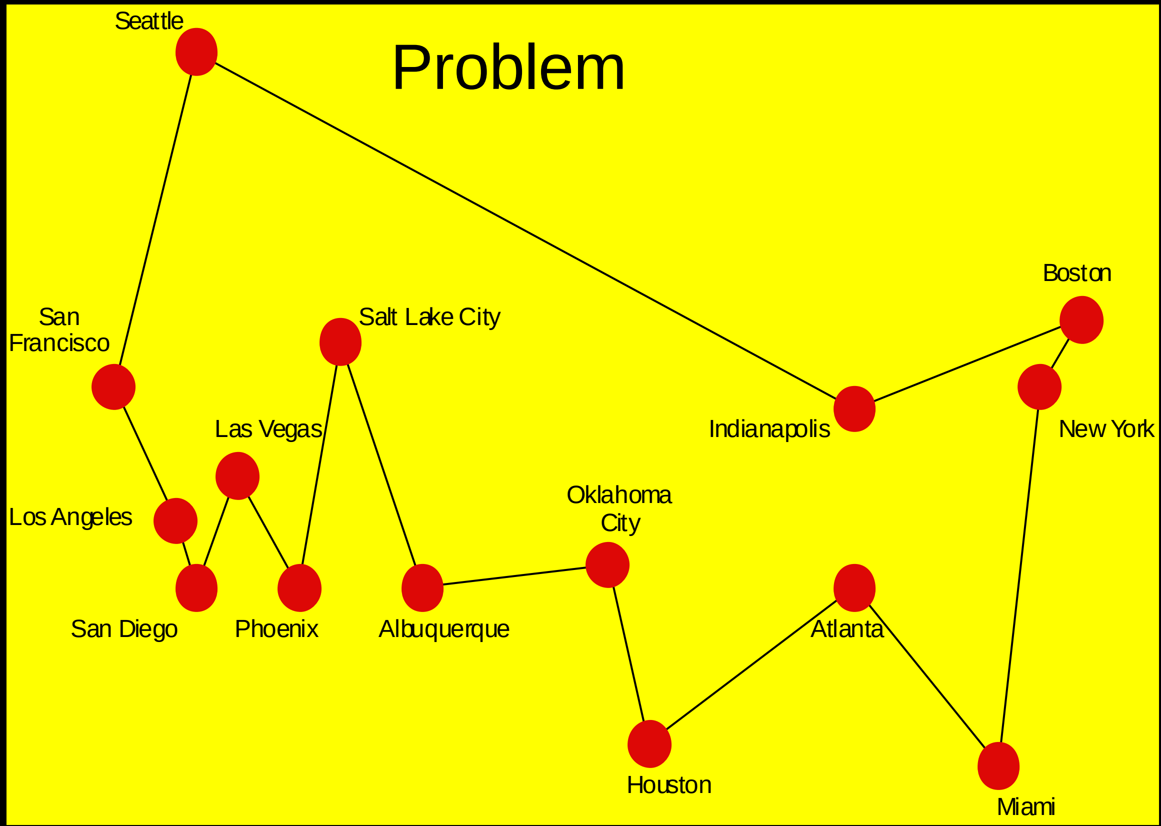
100
75
50
25
0
percentage of passages
0
10
20
30
time (minutes)
15 cm
nest
60°
arena


food
2
1
nest
12.5 cm
Foraging area
Nest
4 mn
Foraging area
Nest
8 mn

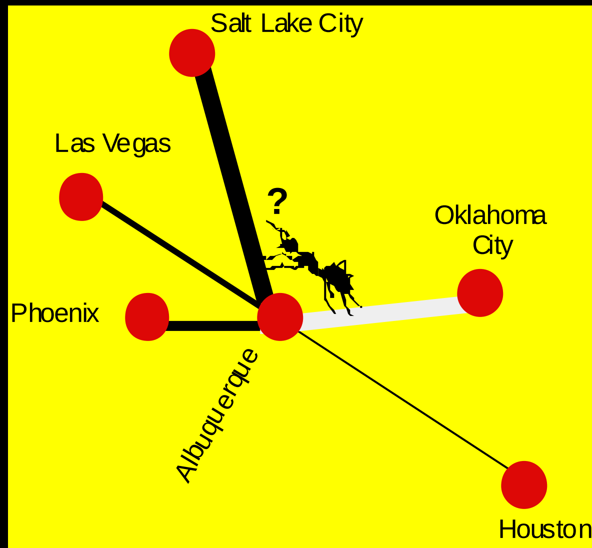

a
source 3
nest
source 1
source 2
b
c
d

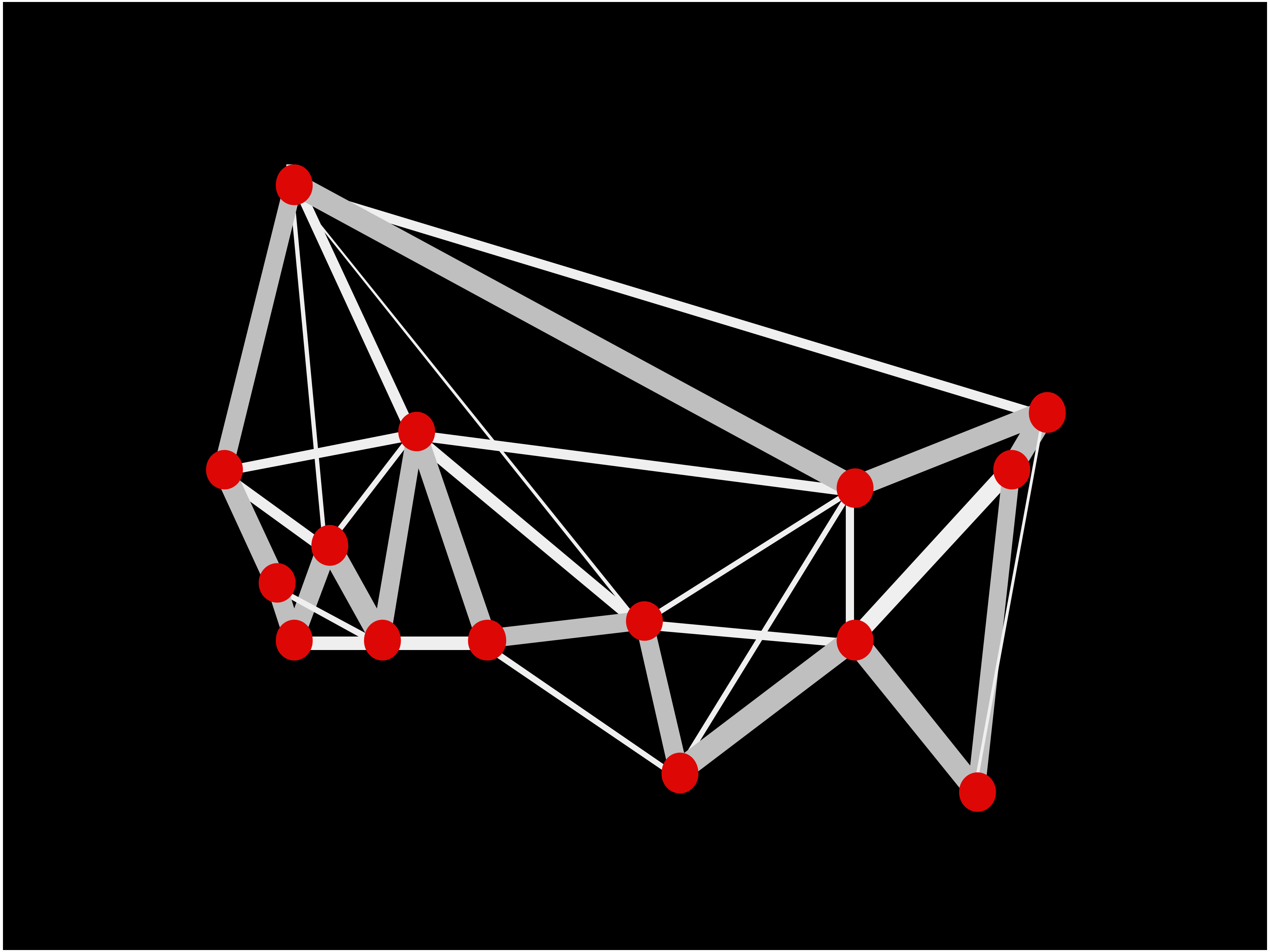
Traveling sales-ants

- d_{ij}= distance between i and city j
- τ_{ij}= virtual pheromone on link (i,j)
- m agents, each building a tour
- At each step of a tour, the probability to go from city i to city j is proportional to $(\tau_{ij})^{a}(d_{ij})^{-b}$
- After building a tour of length L, each agent reinforces the edges is has used by an amount proportional to 1/L
- The virtual pheromone evaporates: $\tau \longrightarrow (1-\rho)\,\tau$



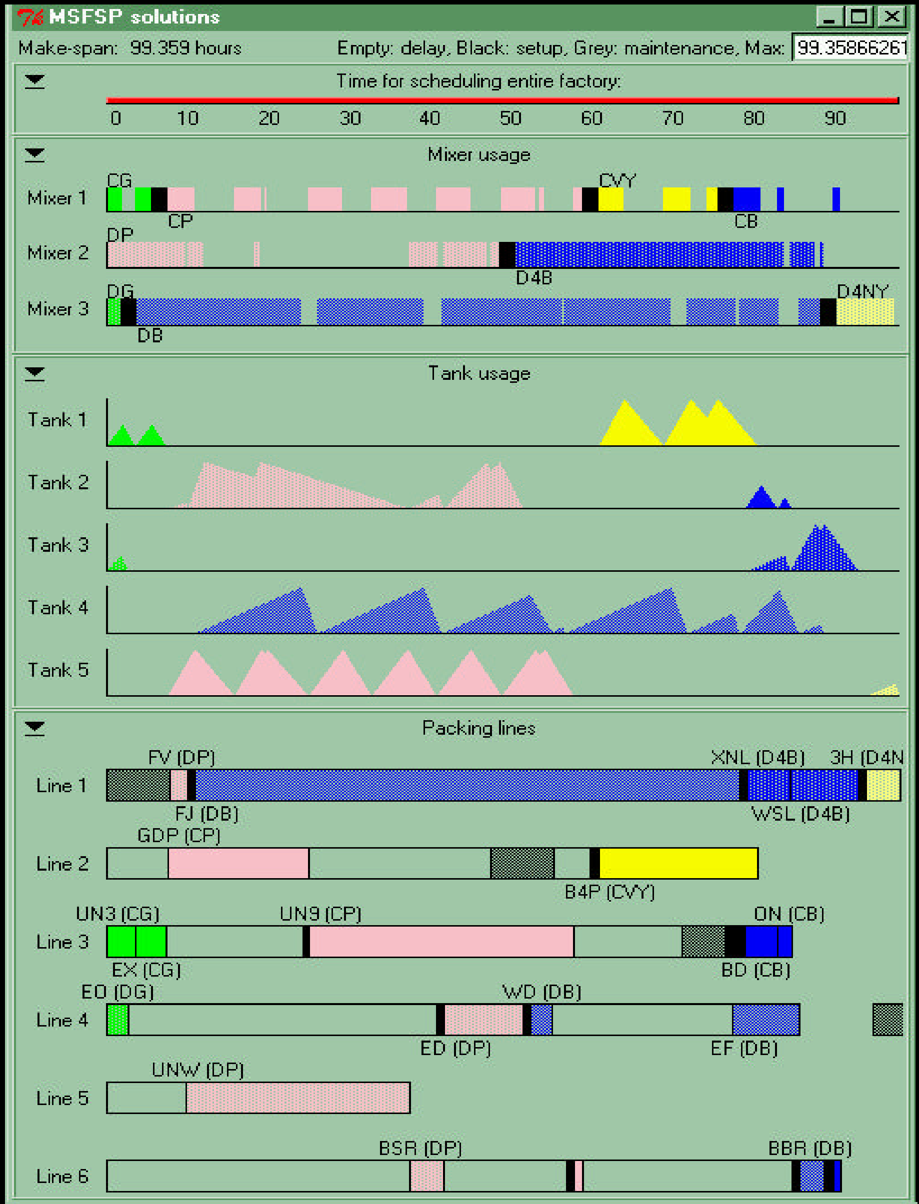
The ant algorithm





The same method applies to all assignment-type problems

- Traveling salesman problem
- Quadratic assignment problem
- Job-shop scheduling
- Graph coloring
- Vehicle scheduling



Problem

- Production scheduling
- Dynamic problem with tough constraints

Results

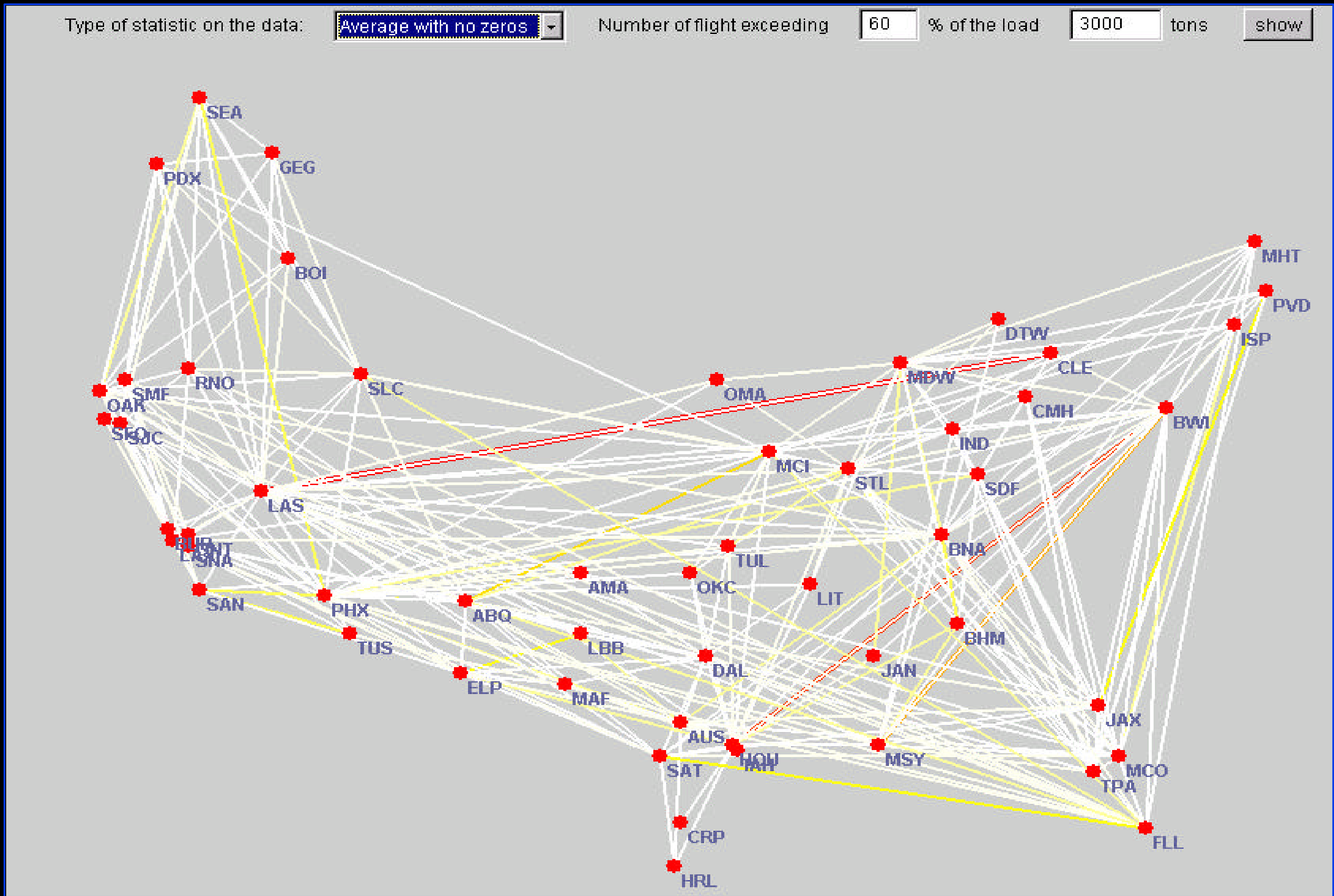
- Always finds a solution
- Better than best solution on market
- Order of magnitude faster!
- Copes with glitches and perturbations

Problem

- Optimize routing
- Simple rules

Results

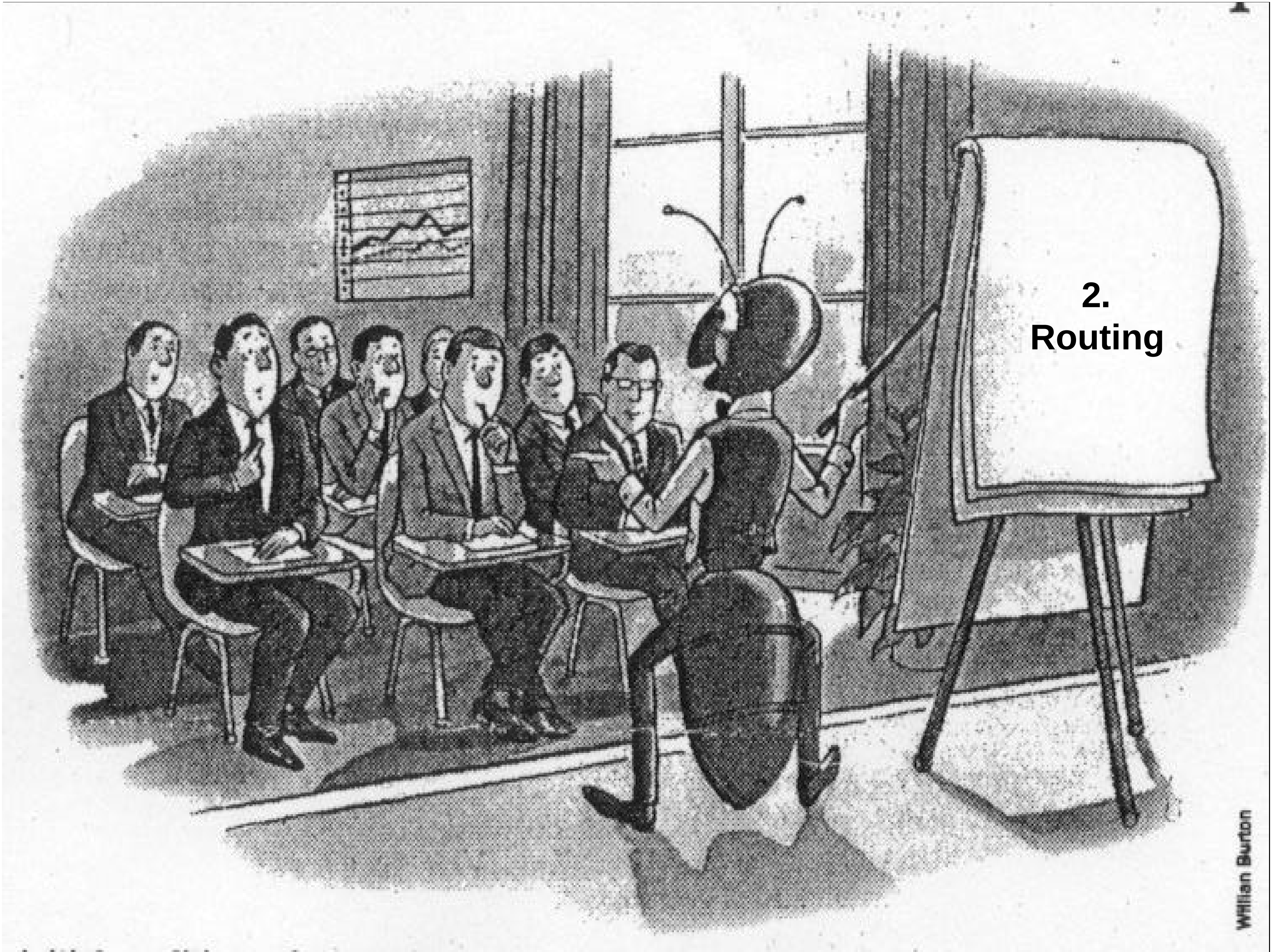
- 71% improvement
- At least $10m/yr



Why does it work so well???

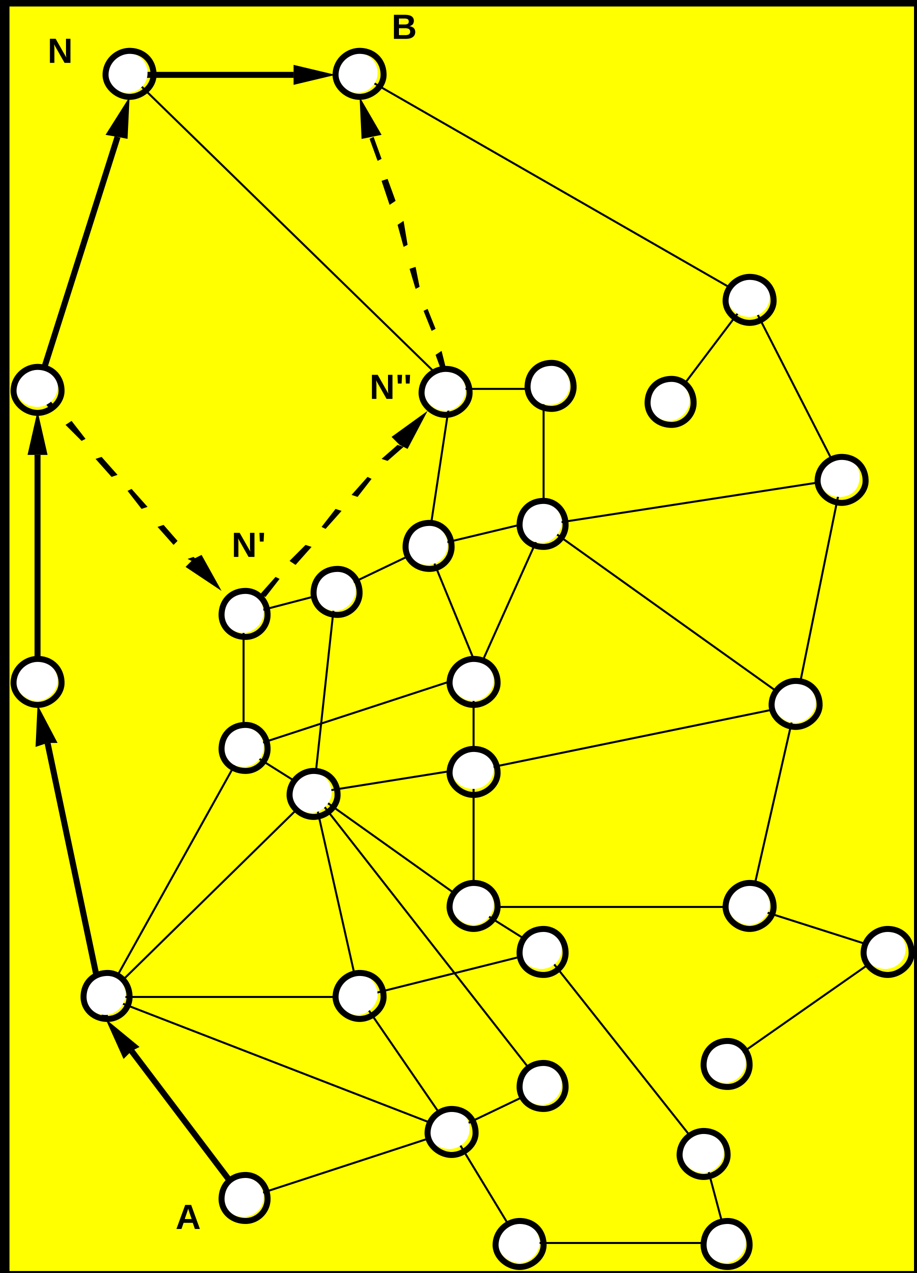
- Local reinforcement of portions of solutions and global dissipation. Requires a certain problem structure (e.g., ant-based optimization is very good at solving structured [real-world] QAP instances).

- Keeping a distributed memory of exploration. Not only does this increase the efficiency of the optimization, it also facilitates its response to changing conditions because it can make use of previous knowledge about solution space.


2.
Routing
Willian Burton

Routing in communications networks

- Routing: mechanism that handles messages at switching stations.
- Messages must reach their destinations.
- It should take as little time as possible to go from source to destination.
- Traffic is constantly changing: routing must adapt.


N
B
N''
N'
A

Routing

Switching stations or nodes have routing tables that tell messages where they should go next given their destination.

- Simple agents are launched in the network. Each agent goes from a source to a destination node.

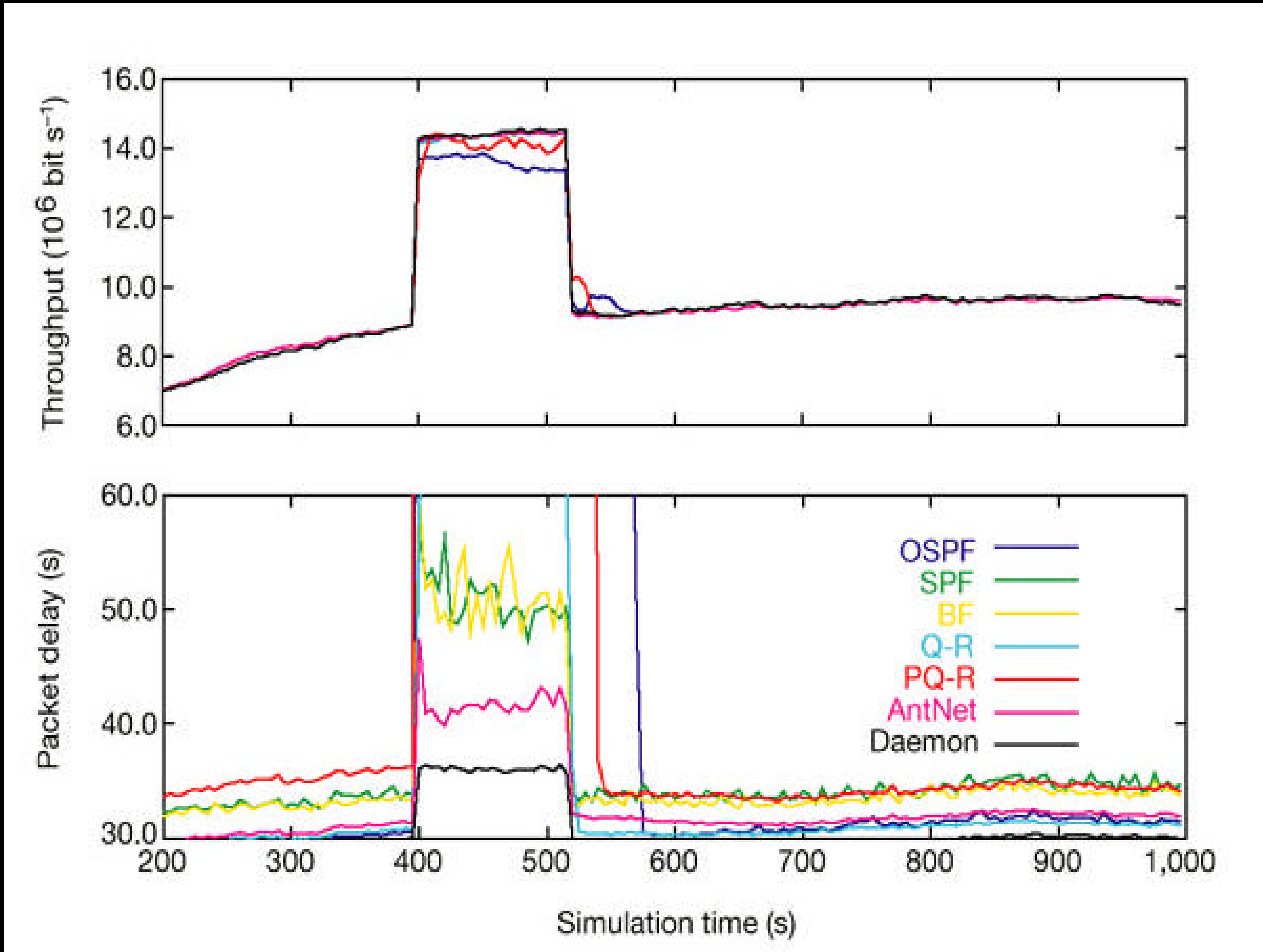
- An agent updates routing tables on its way to its destination, *viewing its source as a destination*.

  "If you are going toward my source node,
  then hop to the node I am just coming from.
  Or don't."

- The influence of an agent decreases with its age.

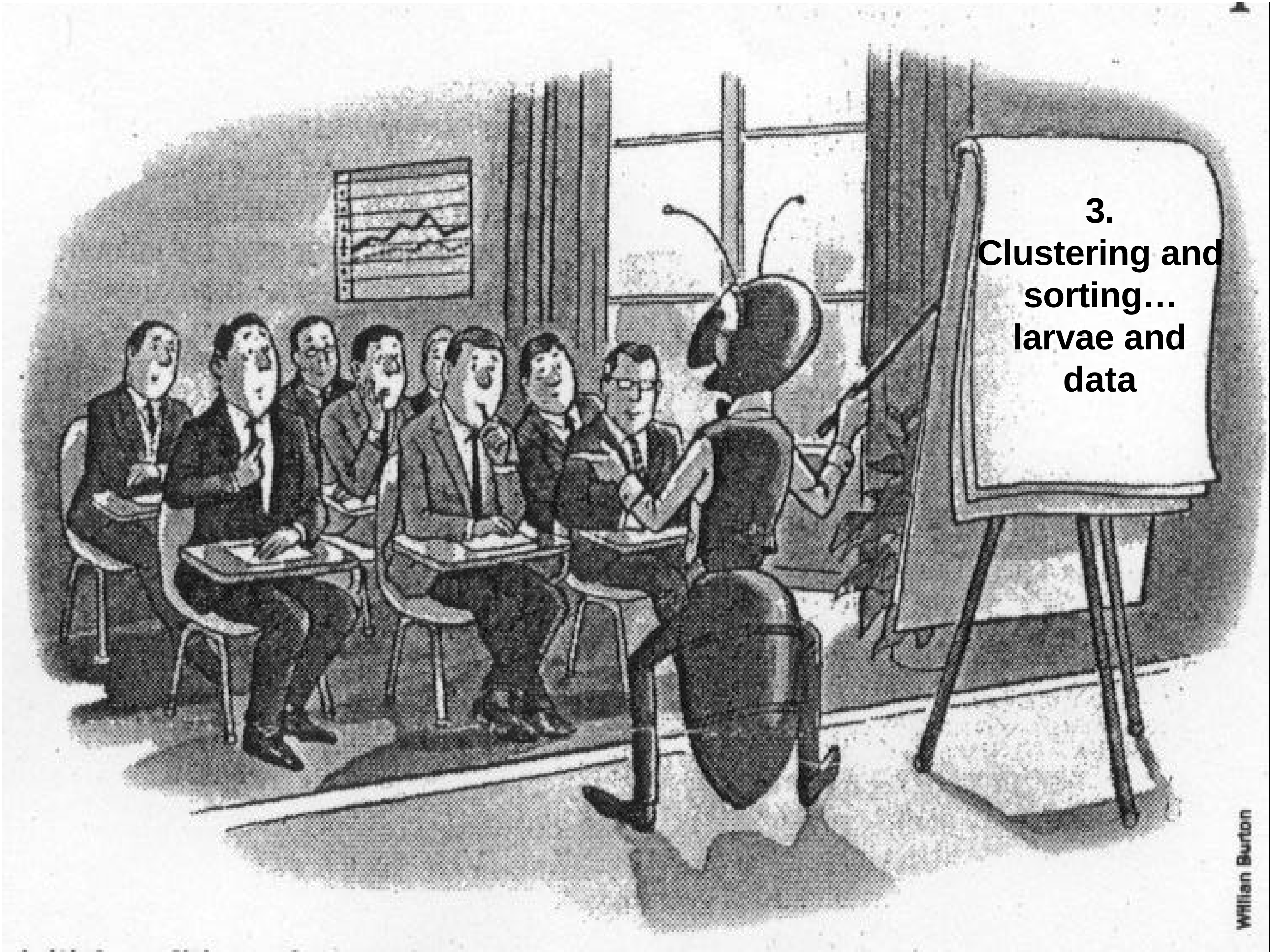
- Agents are artificially delayed at congested nodes.

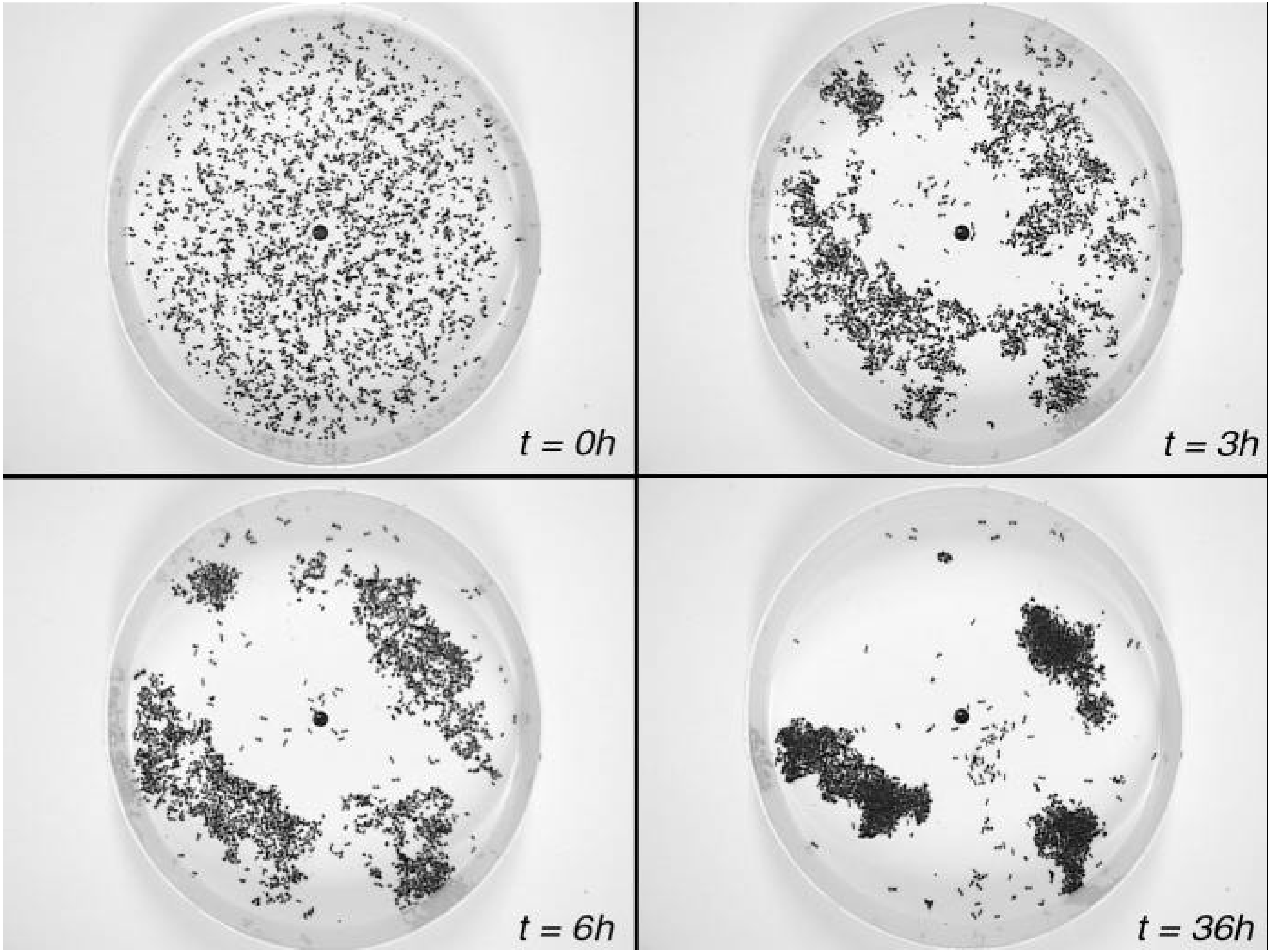
Results (with AntNet)



Hot spot superimposed to Poisson traffic.

Moving average over 10s.


3.
Clustering and sorting…
larvae and data
Willian Burton


t = 0h
t = 3h
t = 6h
t = 36h

Clustering model

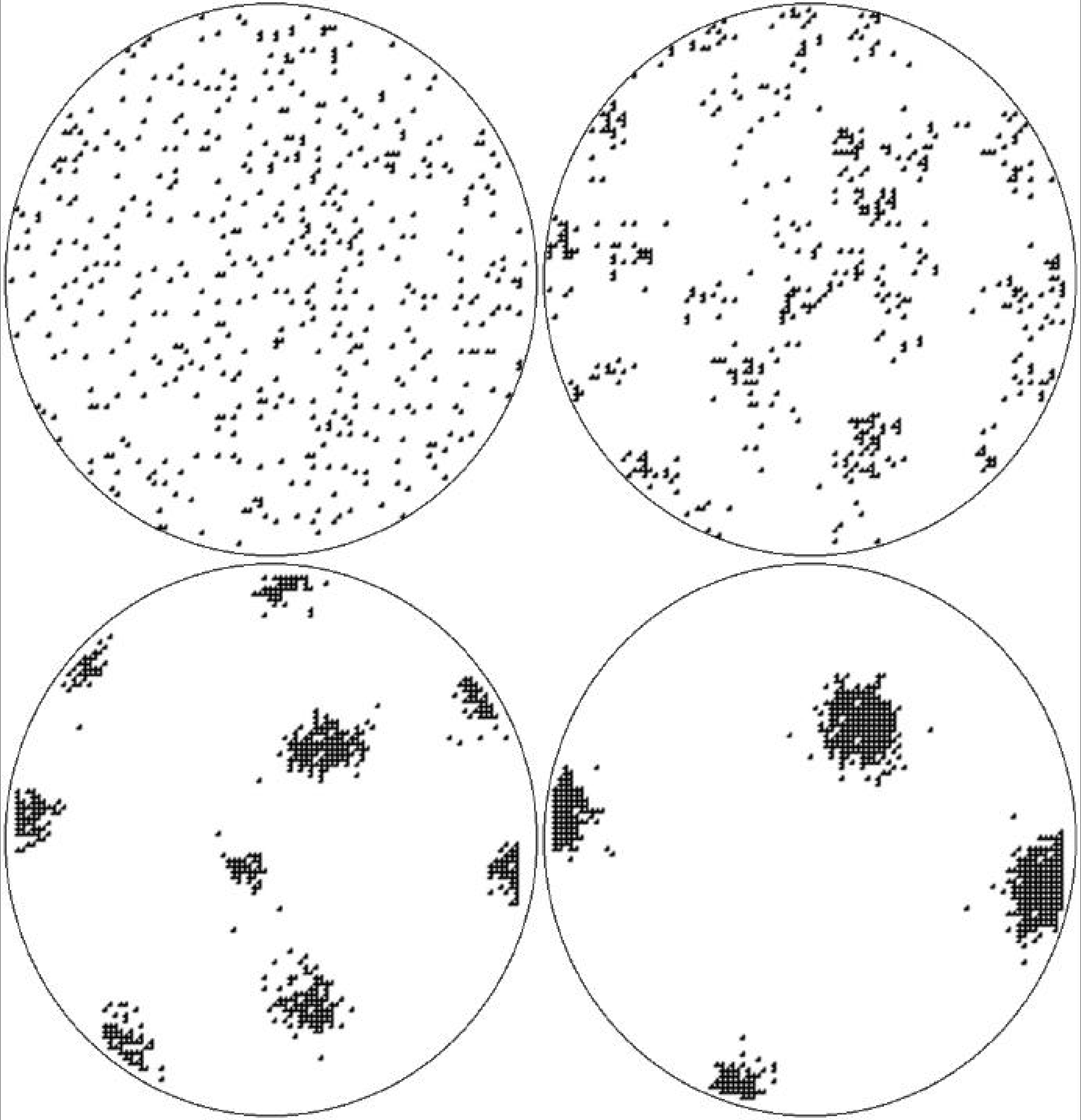
- An isolated item is more likely to be picked up by an unladen agent:

$$P_p=[k_1/(k_1+f)]^2$$

where f=density of items in neighborhood

- A laden agent is more likely to drop an item next to other items:

$$P_d=[f/(k_2+f)]^2$$



From clustering to sorting

- The same principle can be applied to sort items of several types (i=1,...,n).

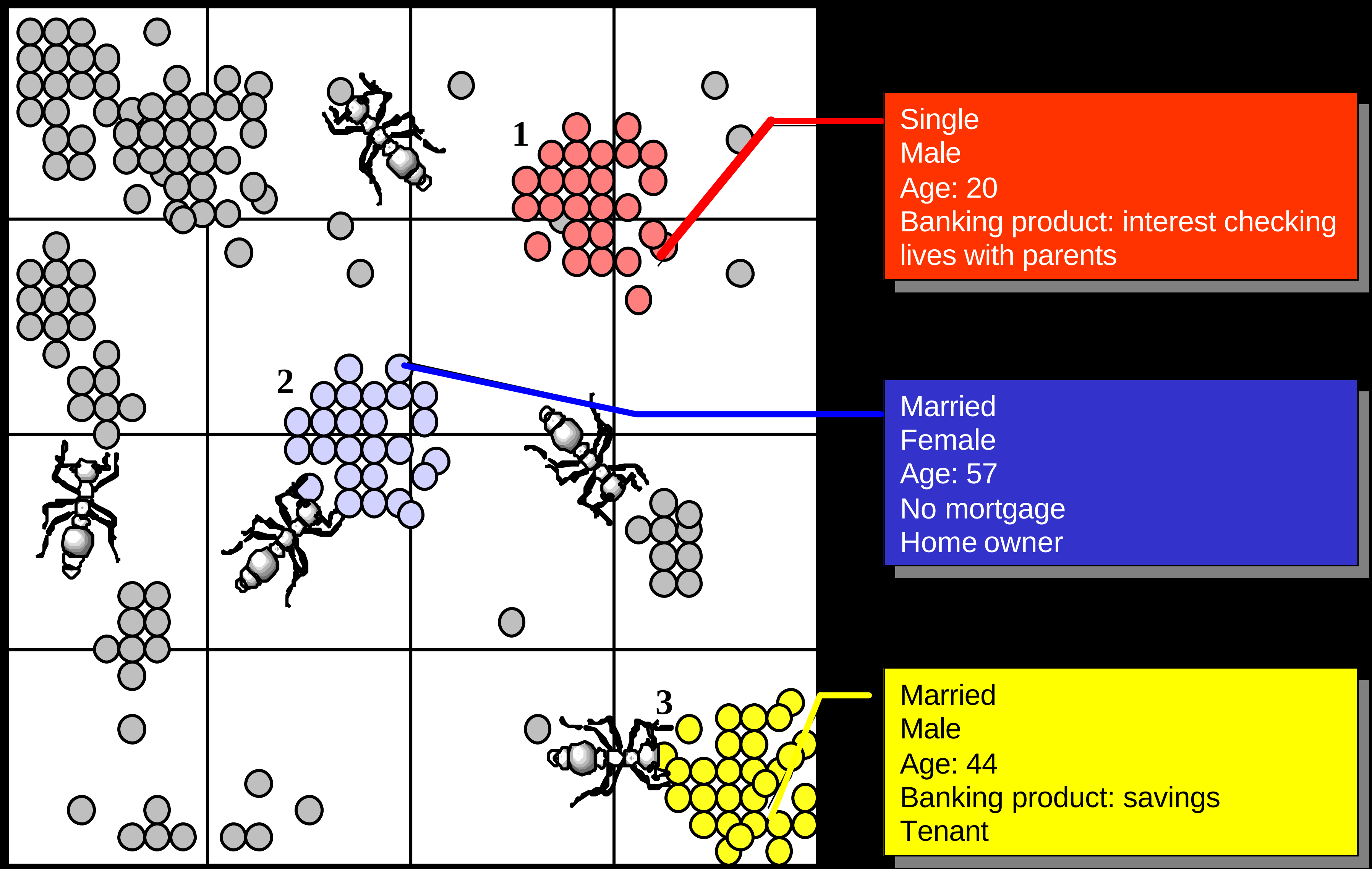
- f is replaced by f_i, the fraction of type i items in the agent's neighborhood:

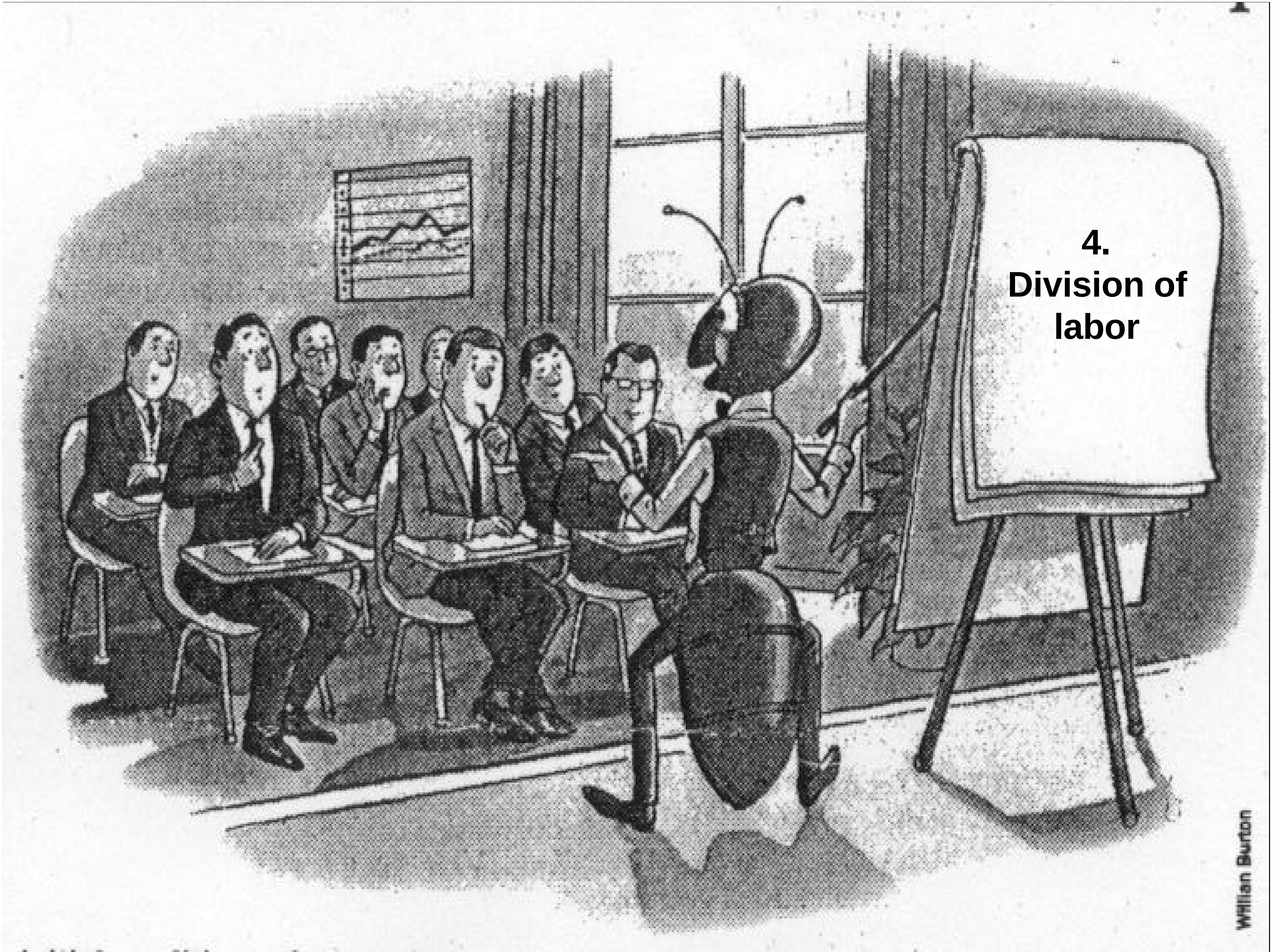
$$P_p(i)=[k_1/(k_1+f_i)]^2$$

$$P_d(i)=[f/(k_2+f_i)]^2$$

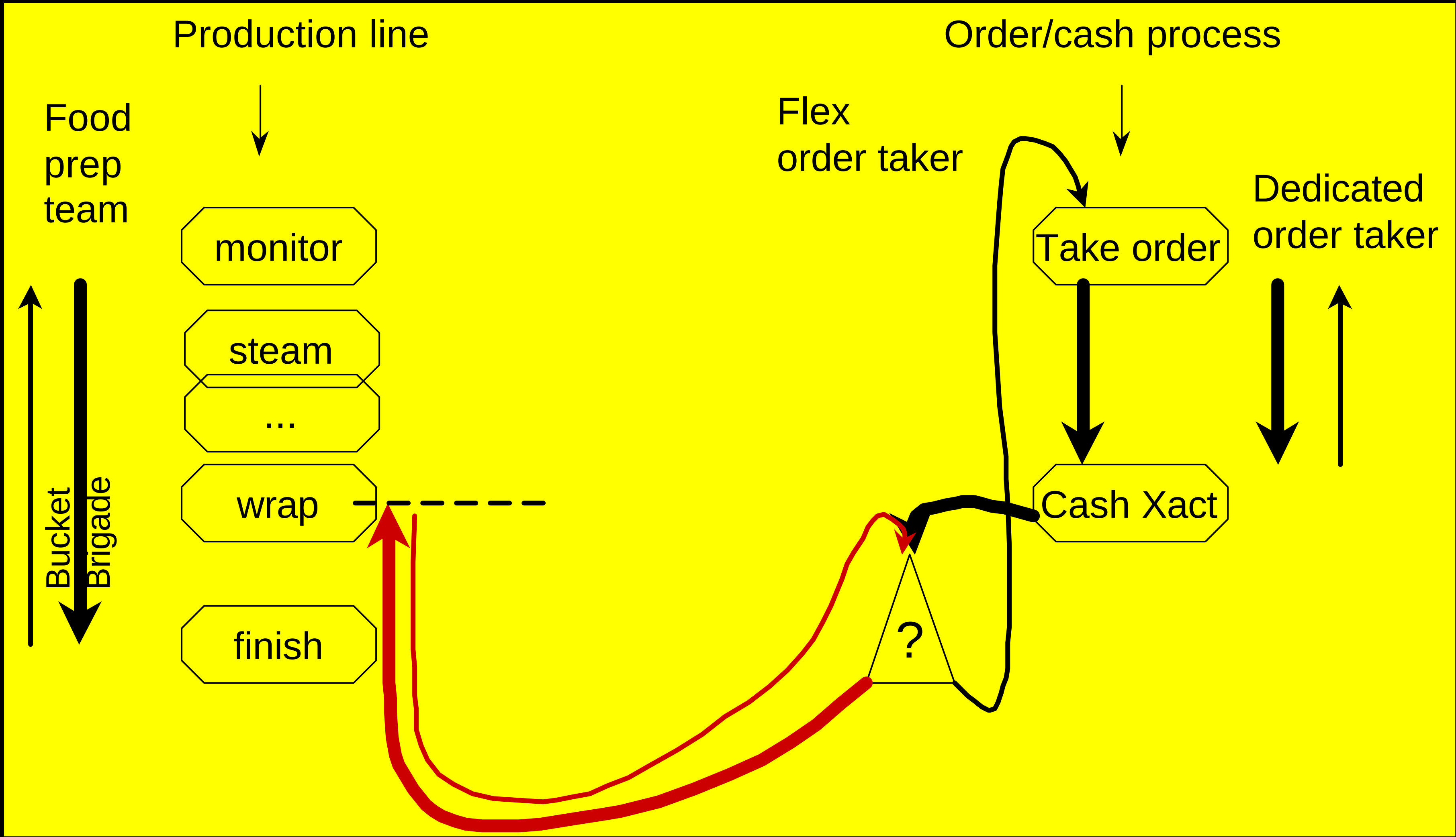
If items are described by real-valued attributes (points in R^n), the same principle can still be applied: f is now replaced by a normalized distance between the item carried by the agent and items in the agent's neighborhood.

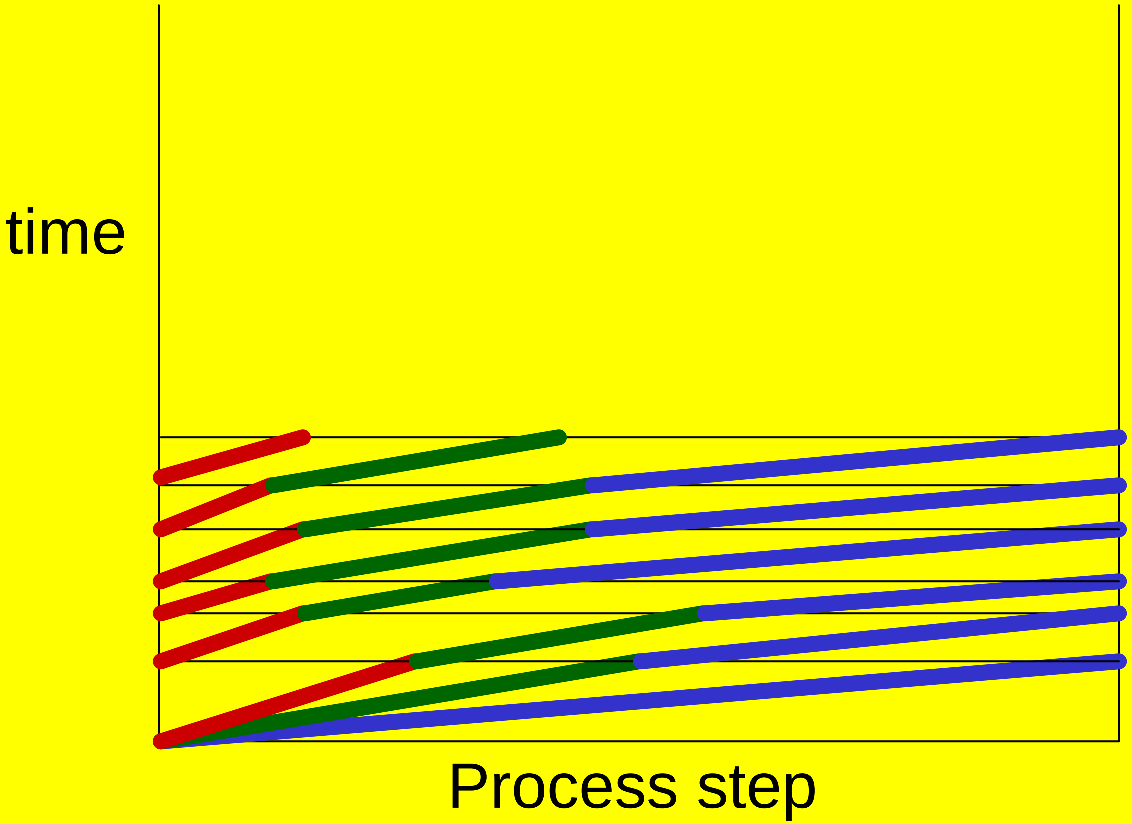
→ Items will end up being next to items with close attributes.

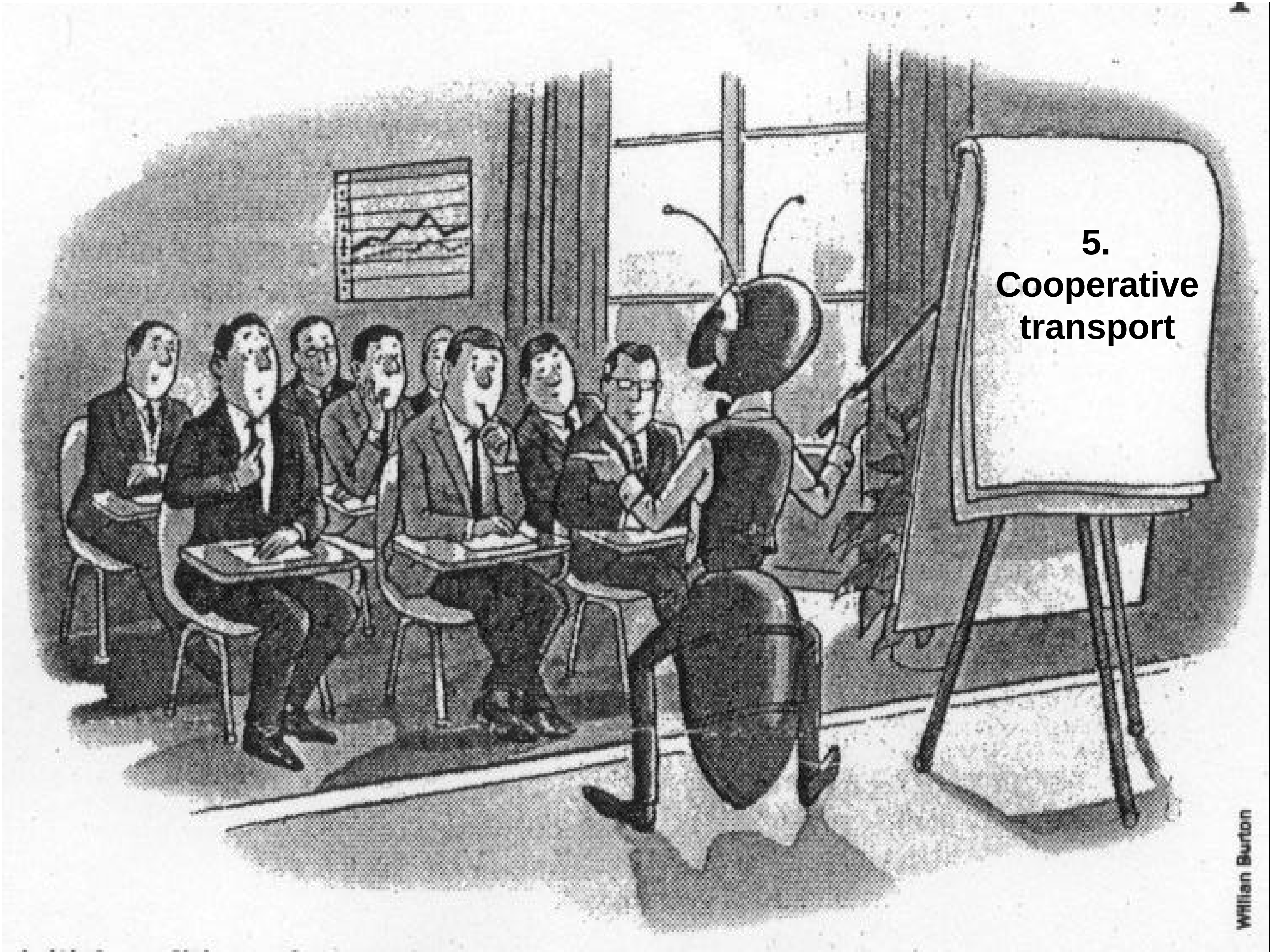

1
2
3
Single
Male
Age: 20
Banking product: interest checking
lives with parents
Married
Female
Age: 57
No mortgage
Home owner
Married
Male
Age: 44
Banking product: savings
Tenant

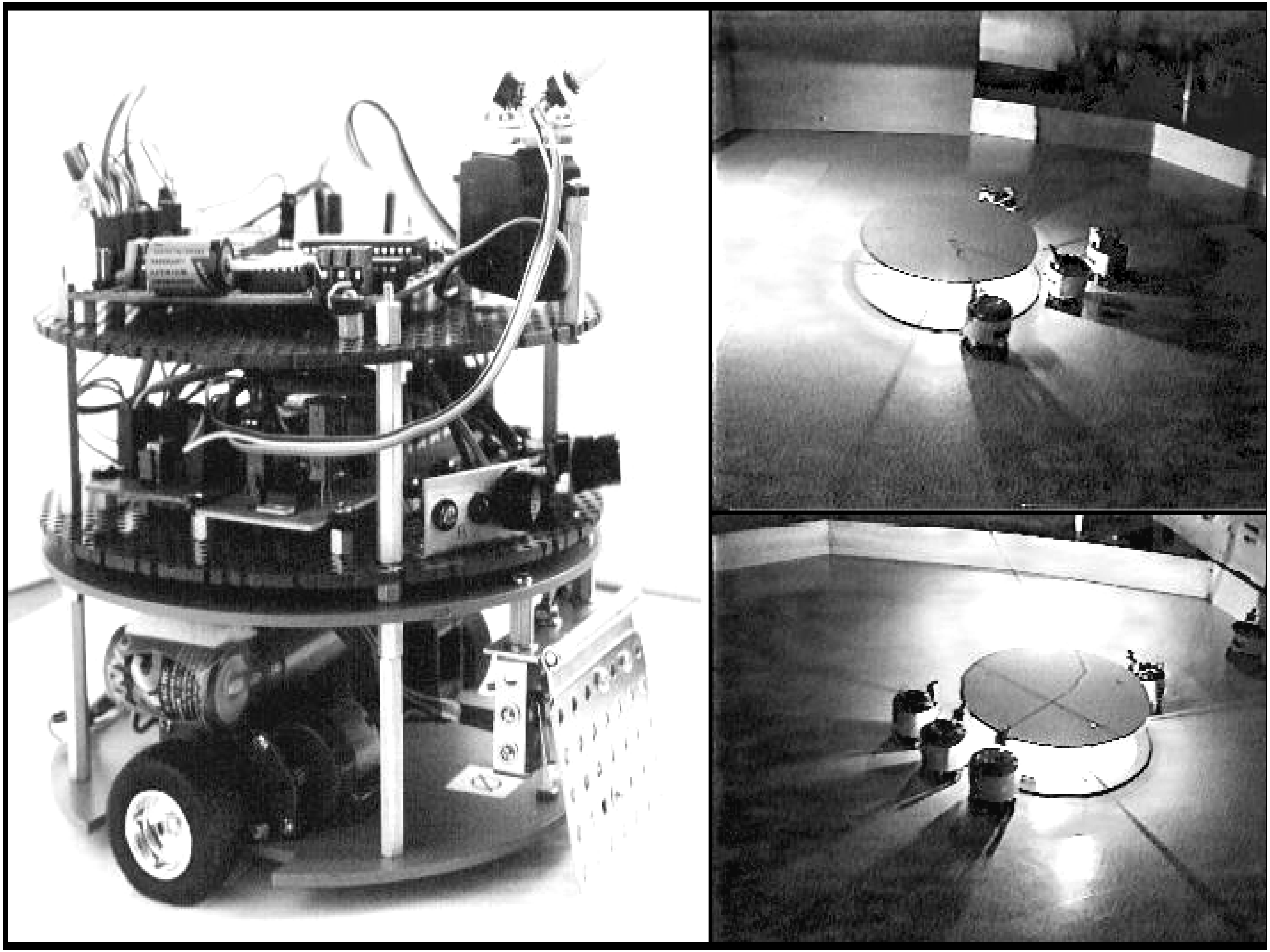

4.
Division of
labor
Willian Burton

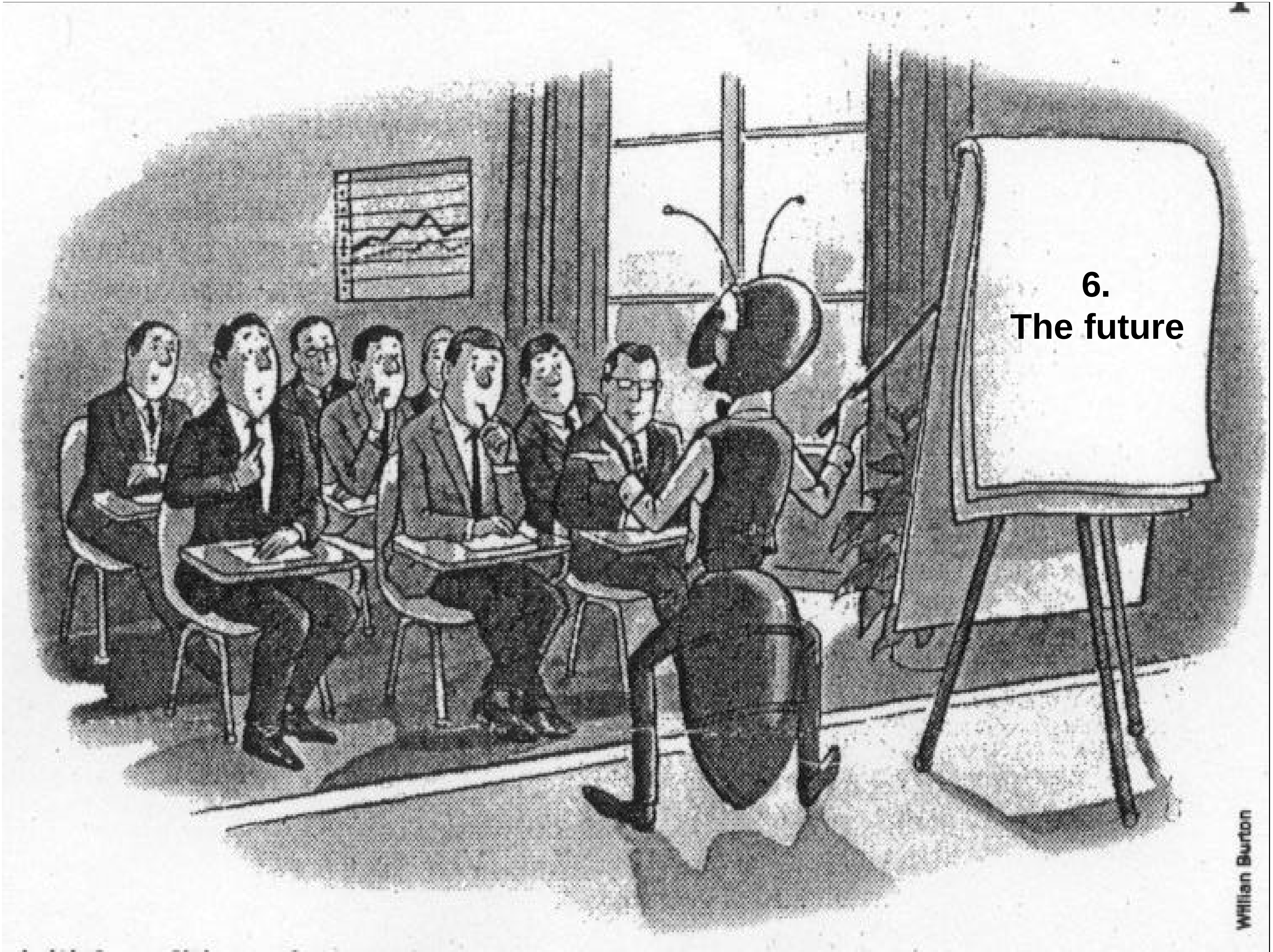
Bucket brigades at Taco Bell




time
Process step


5.
Cooperative
transport
Willian Burton




6.
The future
Willian Burton

Miniaturization

Satellite Maintenance

Pipe Inspection

Cleaning Ship Hulls

Engine Maintenance

Telecommunications

Self-Assembling Robots

Medical

Job Scheduling

Combinatorial Optimization

Data Clustering

Interacting Chips in Mundane Objects

Pest Eradication

Vehicle Routing

Optimal Resource Allocation

Distributed Mail Systems