Designing Robot Swarms

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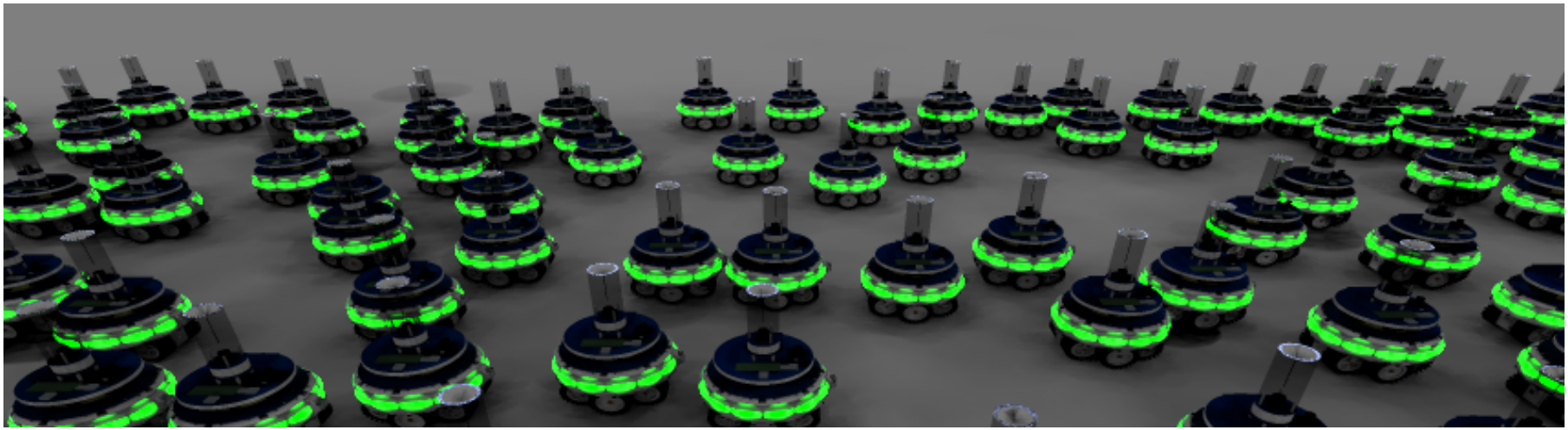

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What are they?

- **Delivery robots** in warehouses, hospitals
  - Centralised controllers (global knowledge)
  - Auction-based task allocation (cost bidding)

Amazon Kiva

Techi Medic

- **Biologically inspired**: more flexible and robust
  - Social insects: a lot of simple individuals without a grand plan or a boss complete **complex tasks**

  - Local interactions with environment: distributed solutions
  - Self-organisation programmed into genes: order arising from chaos

Emergence

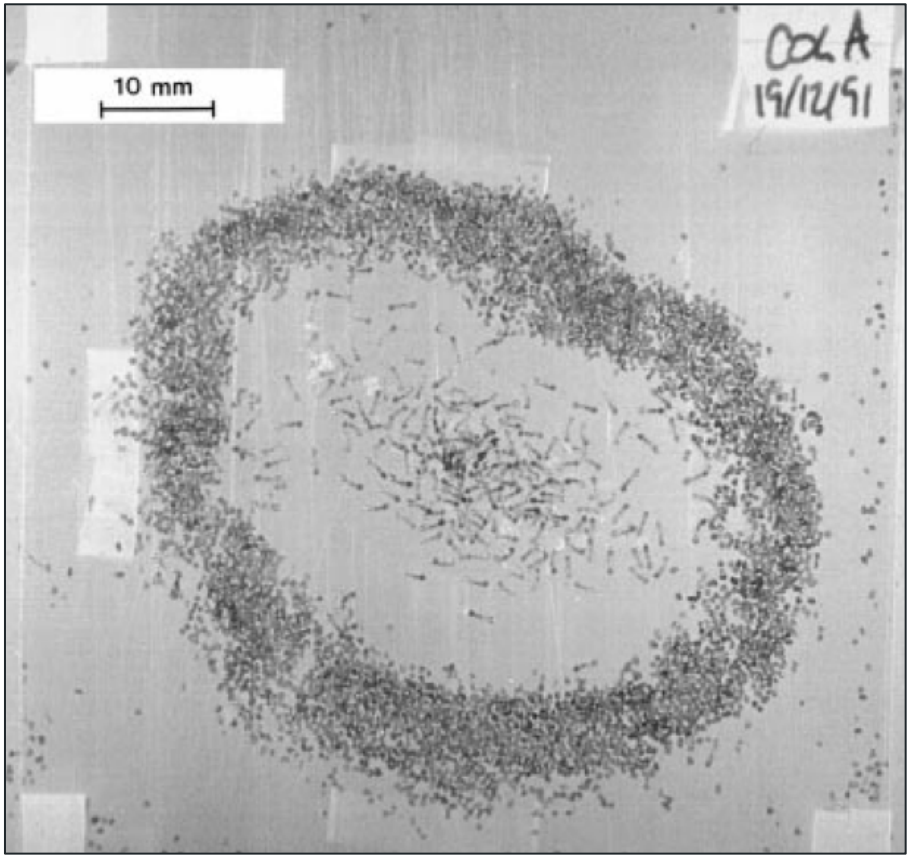
- System-level behaviour is greater than sum of its parts
- Growth of complexity in a **'bottom-up'** fashion
- Work + Extra "stuff": **information, interactions** that affect work
- Interesting for robotics: lower cost, easier maintenance

Collective construction

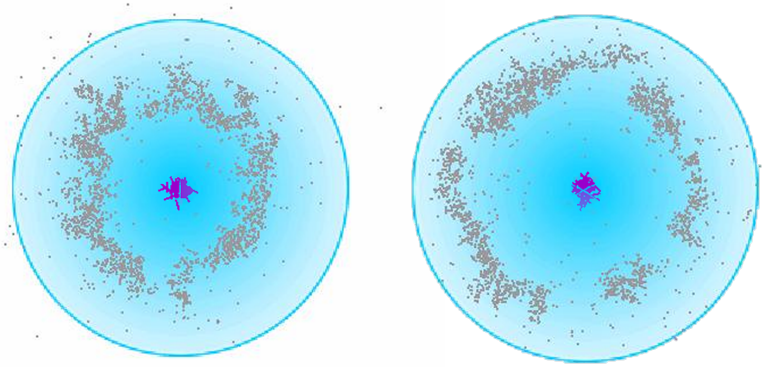
- Termite inspired: pheromone trails and deposits
- Ant and wasp inspired: using built structure

Stigmergy

“Controlling ant-based construction”



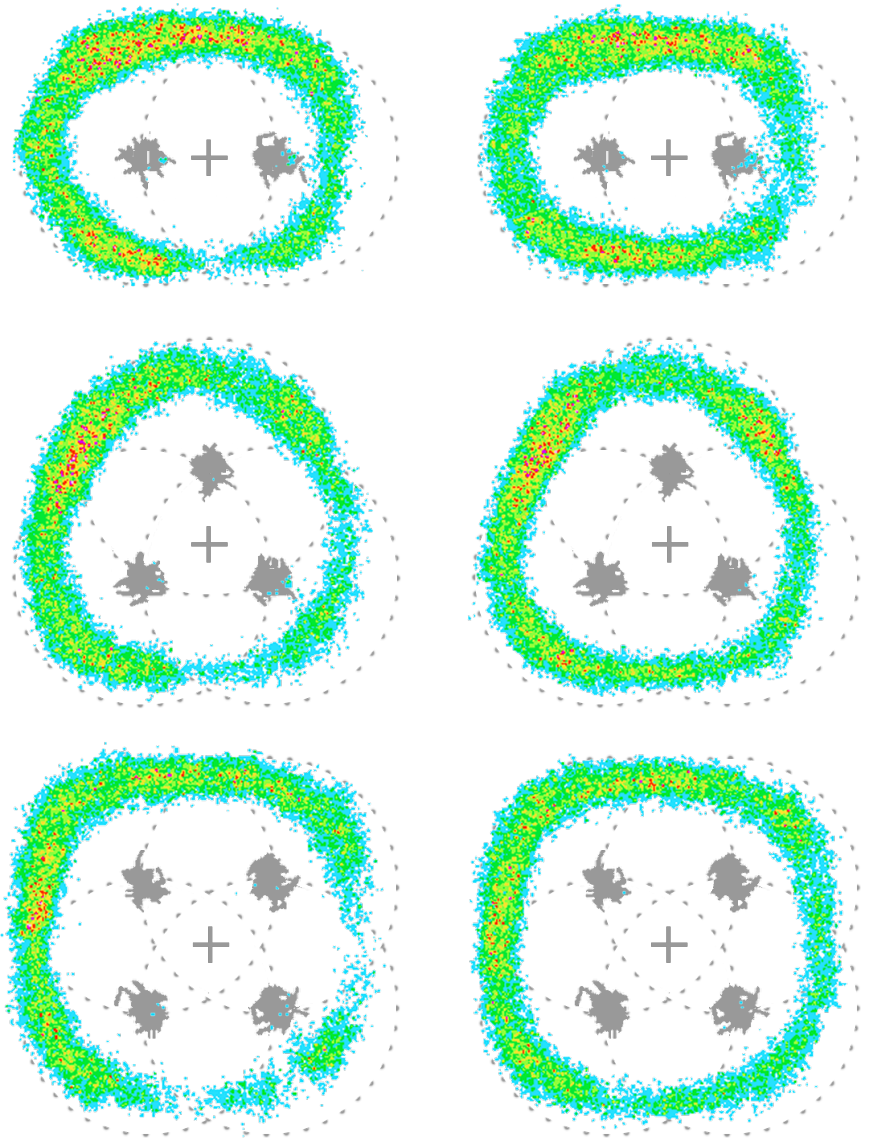
- “Internal” and “external” ants
- Brood pheromone cloud



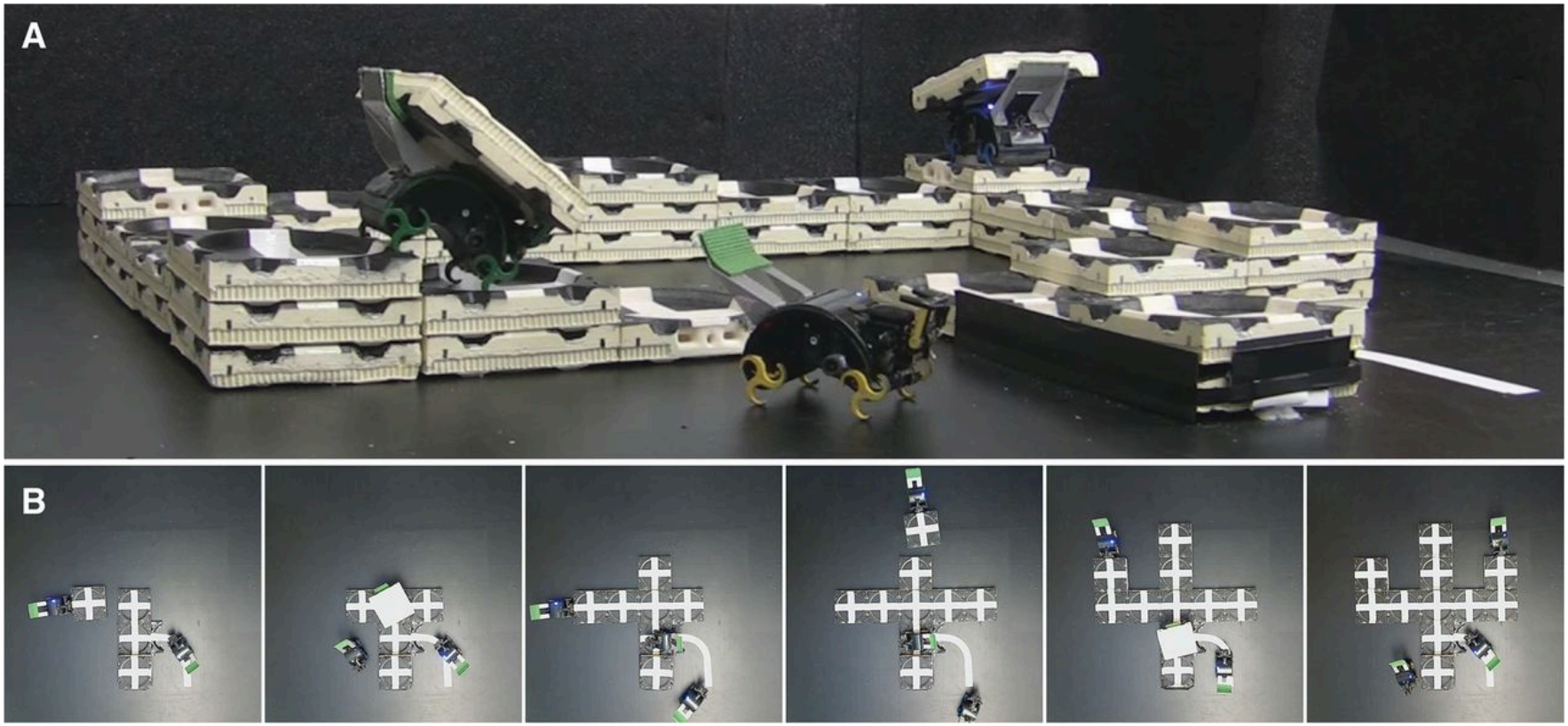
10 internal ants

50 internal ants

- **Can we get different shapes, unseen in nature?**
- Yes! By using multiple brood clusters

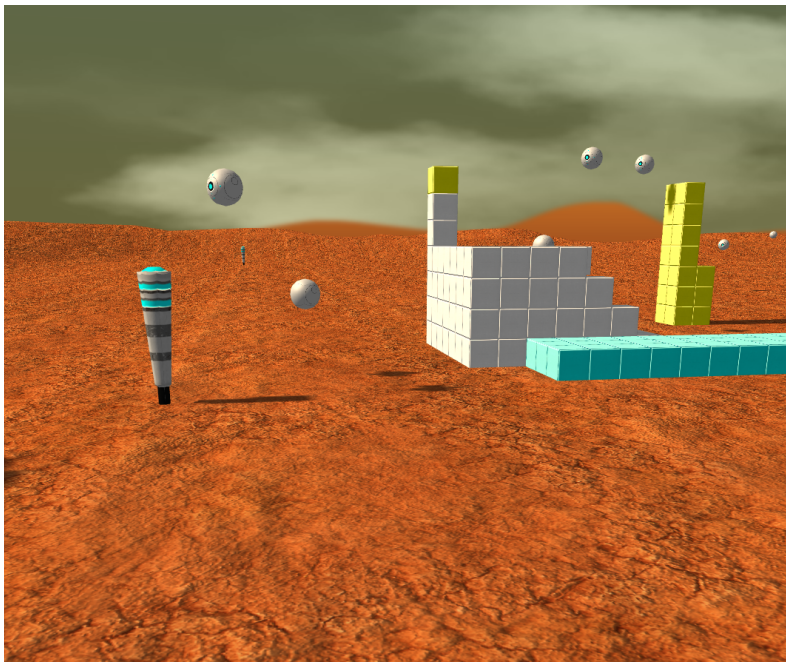


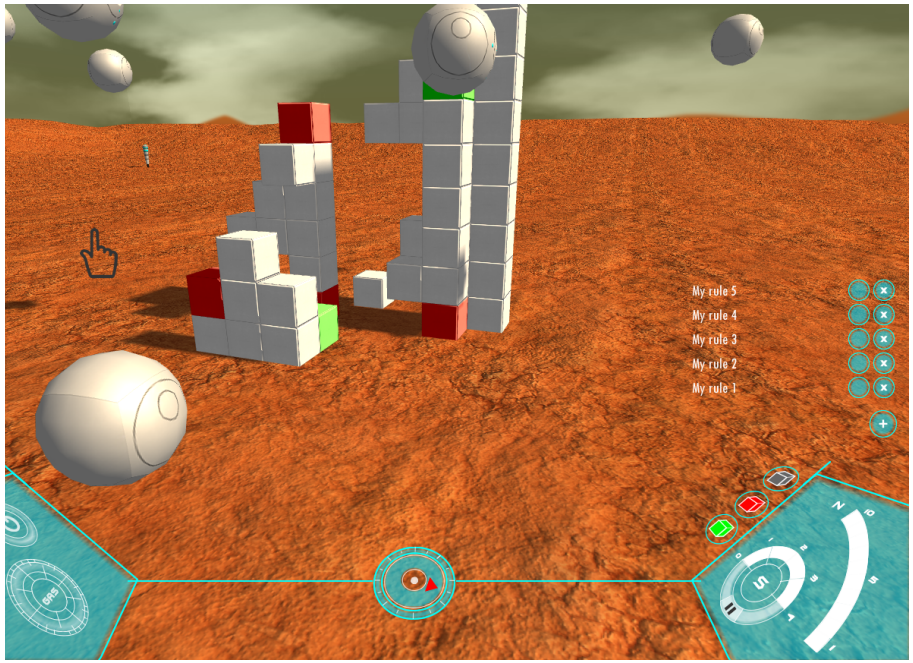
- TERMES: 3D construction with robots



The Hive Mind

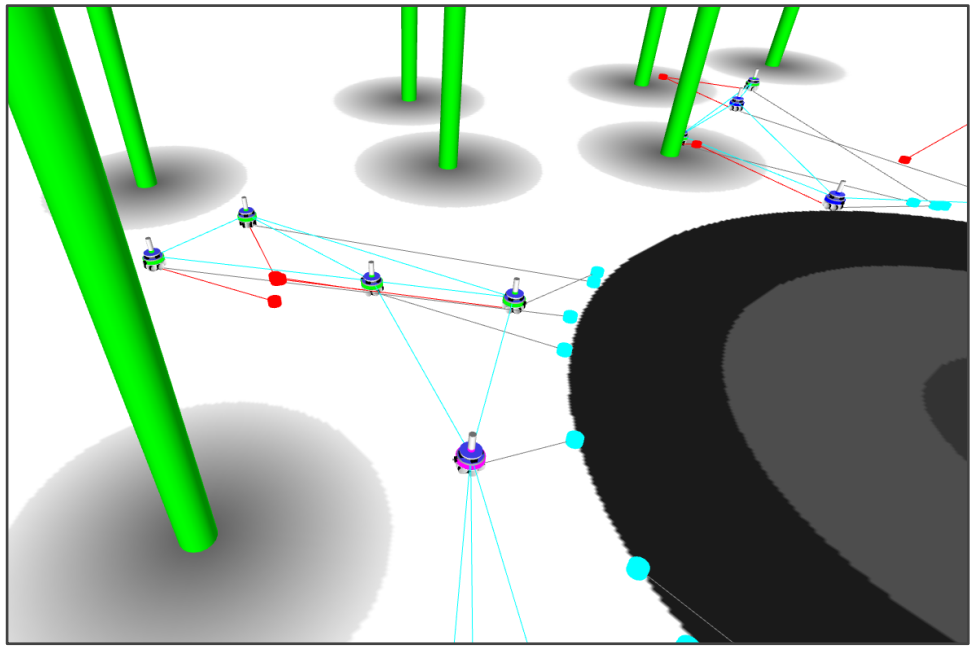
- http://thehivemindgame.net
- Program robots to build things on an alien planet





Collective foraging

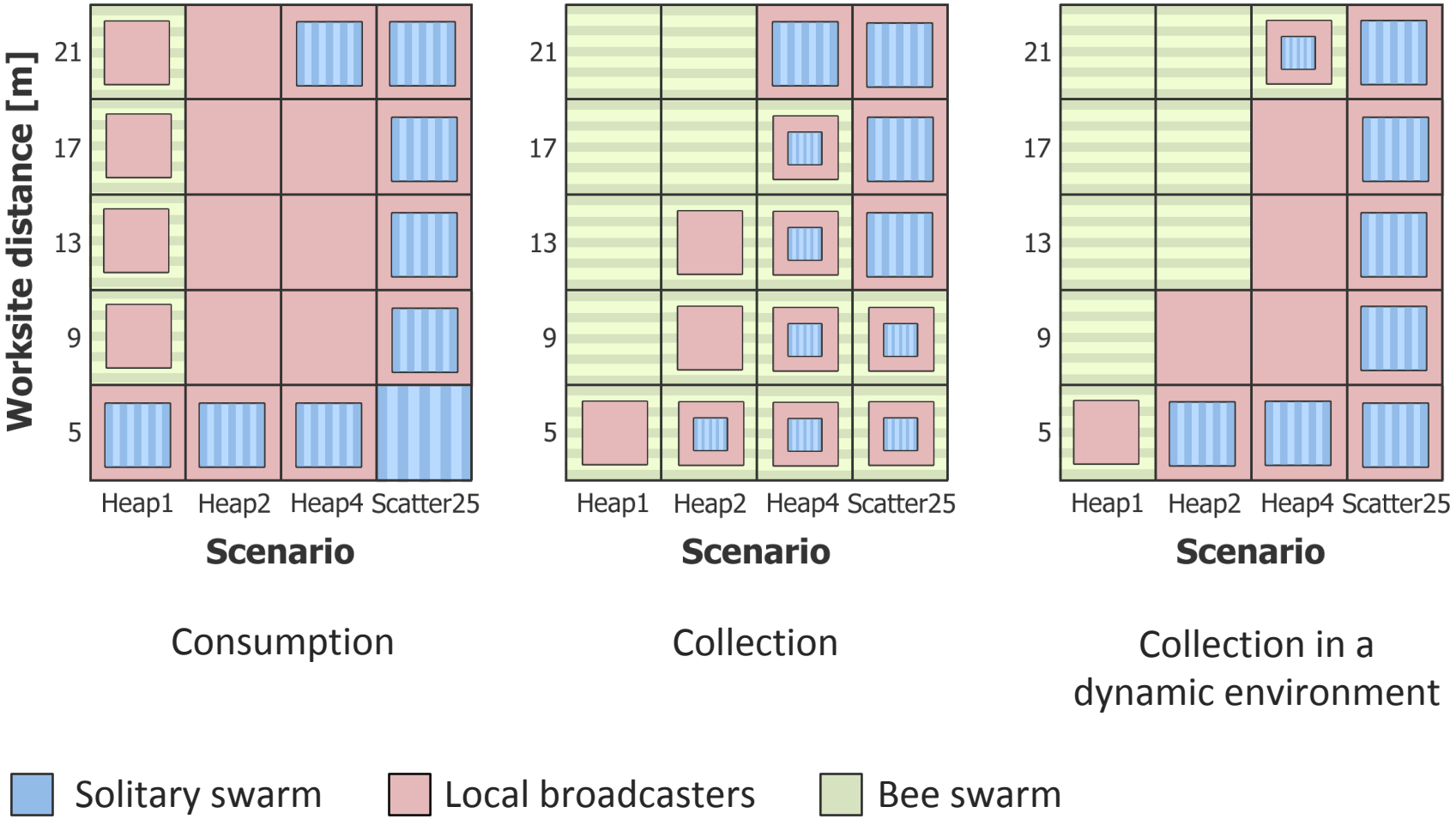
- **Searching** for “food” in an unknown environment
- “Food” is either **consumed** or **brought back** to “nest”
- Paradigm for
  - Resource collection
  - Warehouse / customer servicing
  - Search and rescue
  - Toxic waste cleanup
  - …



- **What type of robot controller is suitable in a given environment?**

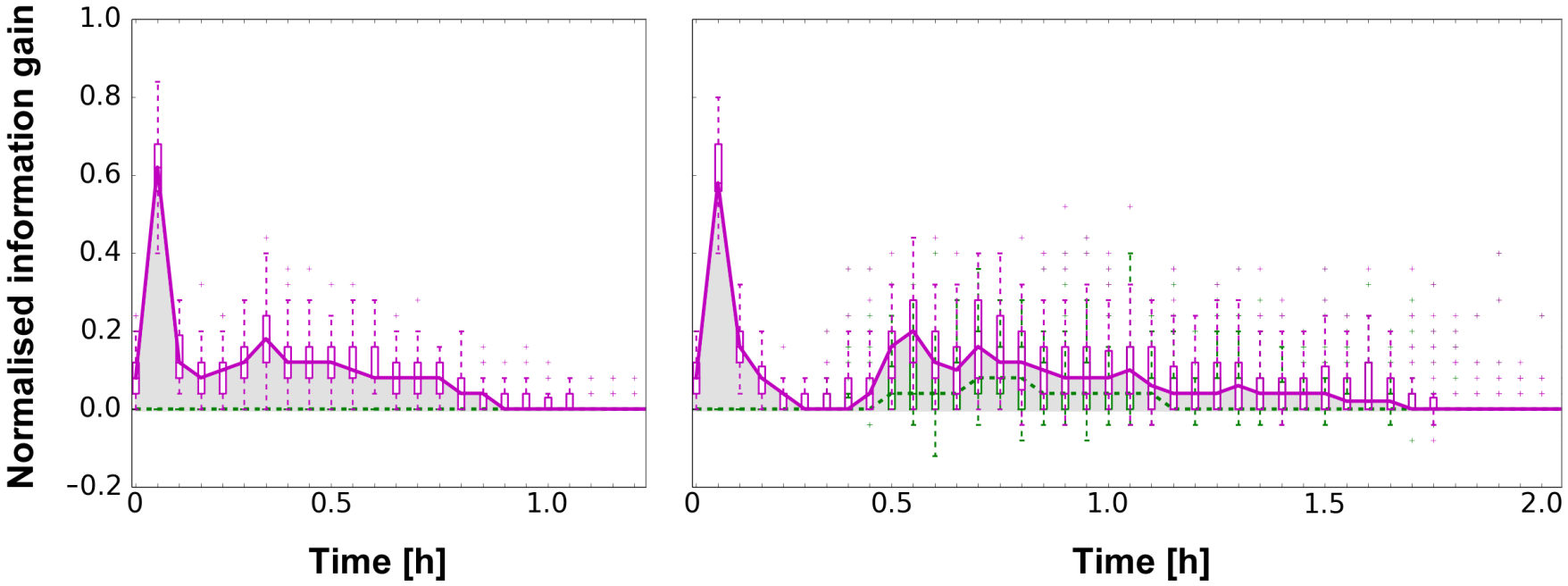
- **Solitary**: no communication between robots
  - Very simple, most animals are solitary foragers
- **“Local broadcasters”**: communication while near worksite
  - Sheep, birds
- **Bee inspired**: recruitment waggle dancing in the nest
  - Local interactions in a central place

- Different controllers are favoured in different environments and tasks (scouting strategy, communication overheads, ...)



Understanding swarm foraging

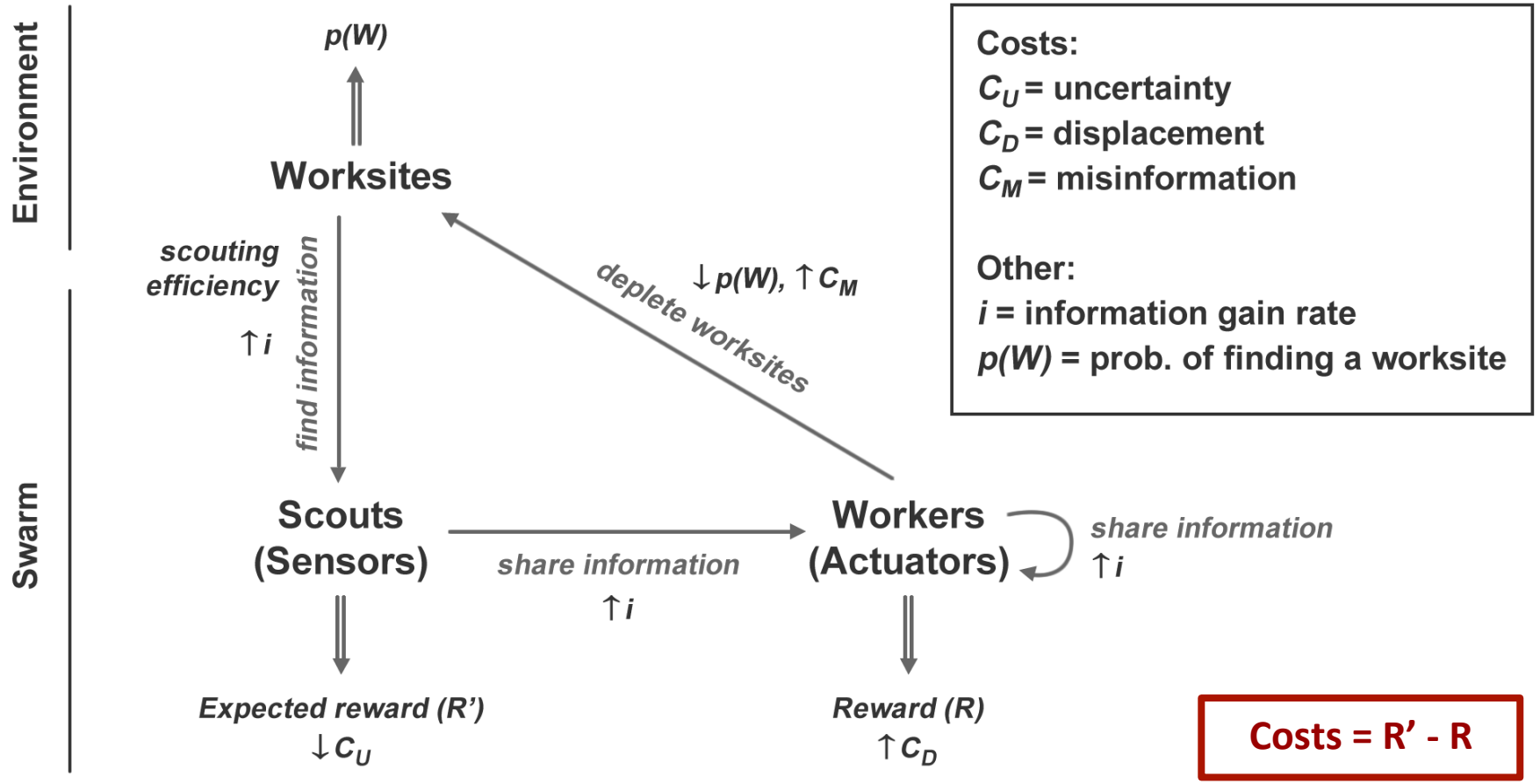
- **Information gain:** Change in the amount of information



Solitary swarm: evenly spread out

Bee swarm: recruitment in the base

- **Costs**: How is information utilised?
- **Information-Cost-Reward framework**



ICR framework applications:

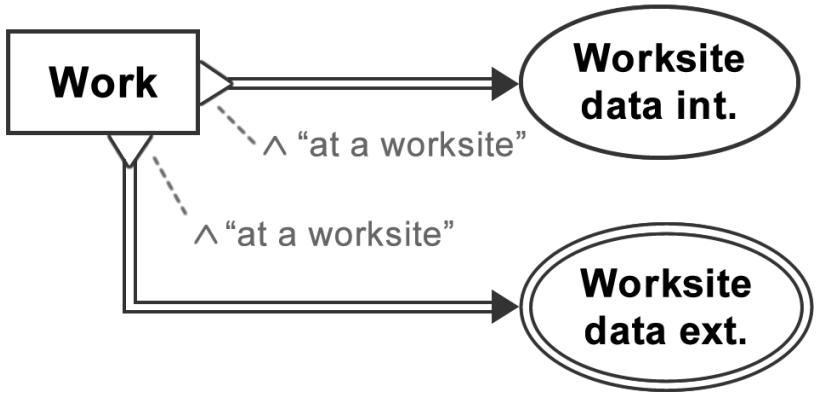
- Identify reasons for observed swarm performance
- Abstract understanding: Design behaviour to minimise potential costs

Design patterns for robot swarms

- **Guidelines for programming**, based on experiments and ICR analysis
  - **How** does a particular behaviour look like? (communication, scouting, information updating)

    Textual description + BDRML graph

B = {Work}
D_i = {Worksite data int.}
D_e = {Worksite data int.}
send(Worksite data int., Work) :
{ ∧ ”at a worksite”}
send(Worksite data ext., Work) :
{ ∧ ”at a worksite”}



- **When** is it useful?
  Central-place recruitment is useful in difficult environments

- What **parameters** does it have?
  Communication range, threshold time outs, ...

- What **effects** on swarm behaviour does it have?
  Central-place recruitment increases information gain rate and displacement cost

Design patterns applications:

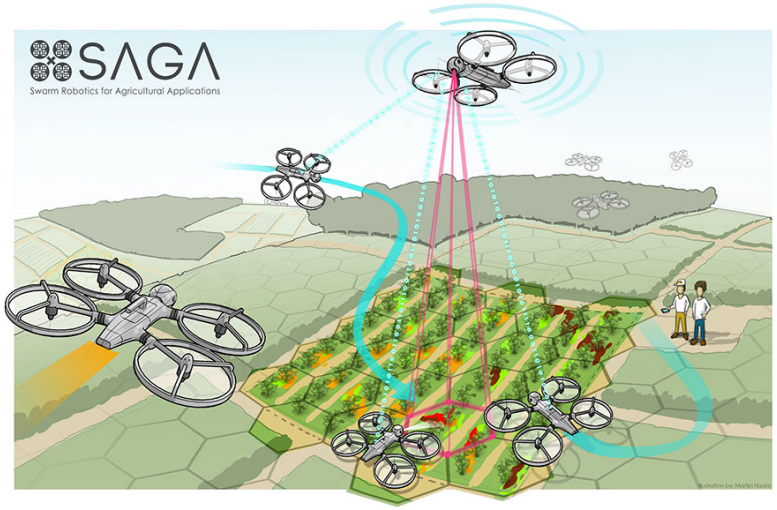
- **Reusing** known solutions to a class of similar problems

- **Checking** whether a particular behaviour is suitable, given hardware constraints
  Can I use a recruitment strategy that relies on large communication range?

- Guide **adaptation**
  Should robots change their behaviour to a more suitable one, given their current environment?

The future of swarms

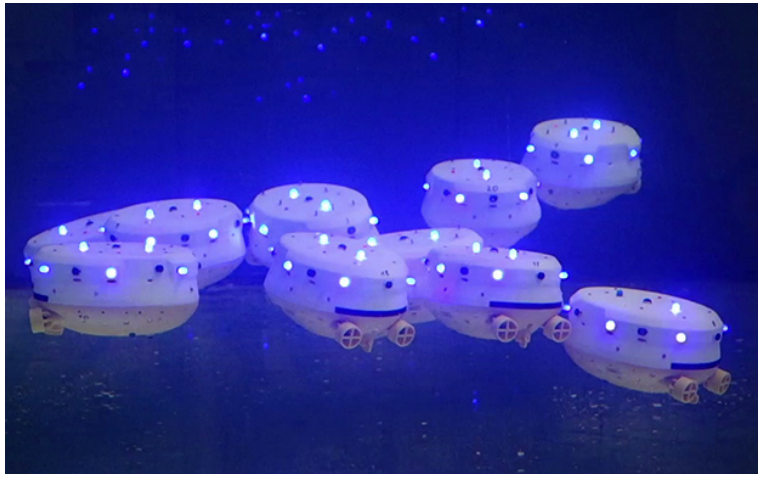
- Automated warehouses, agriculture, ... (boring, hard work)



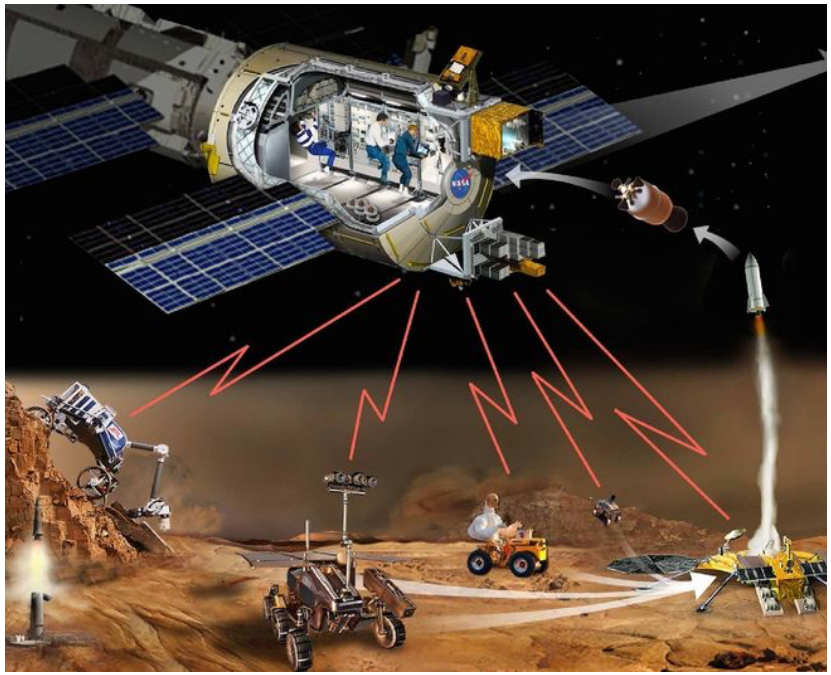
- Package delivery (coordination problem: robots, people, ...)

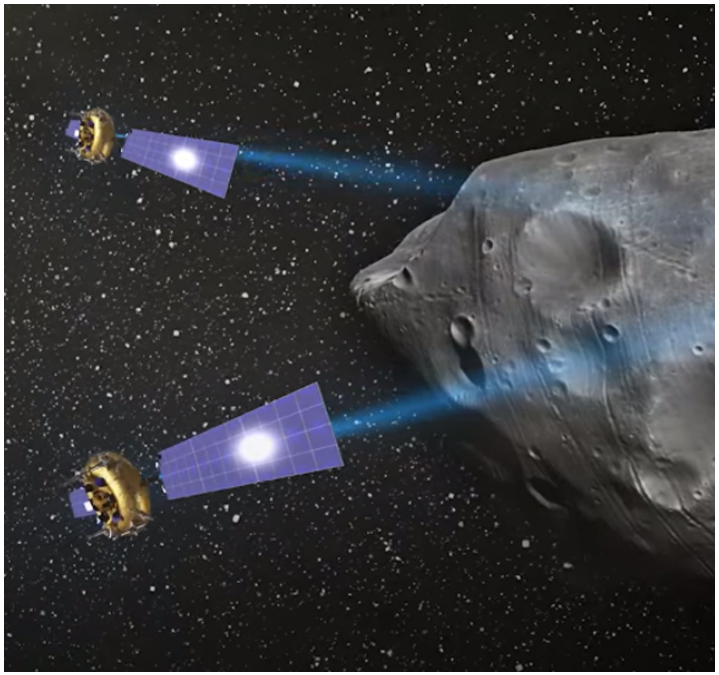
- Autonomous transport, including on-demand

- Dangerous / difficult environments: clean-up of toxic waste, cave exploration, underwater data collection, ...



- Space: Satellite and base construction, exploration, terraforming, asteroid mining





Shifts in the society

- More dangerous or hard work done by robots
  - Cheaper resources, manufacturing, servicing
  - Safer world: less accidents, more resilient systems

- New specialisations for people: engineering, science, creative industries
  - People caught between this and the new world might have difficulties
  - Ultimately, general well-being should increase