Introduction to Swarm Robotics

By Andrew Vardy
Associate Professor
Computer Science / Engineering
Memorial University of Newfoundland
St. John's, Canada

Brief Bio

* B.Eng in Computer Engineering @ MUN
* M.Sc in Evolutionary and Adaptive Systems @ University of Sussex, UK
* Ph.D in Computer Science @ Carleton, Ottawa
* 2005-10 Visual navigation
* 2011-15 Swarm robotics and autonomous underwater vehicles

What is a Swarm?

A swarm is a group of mobile agents (e.g. animals or robots; real or virtual) which exhibit the following properties:

1. There is no centralized control or synchronization between agents
2. The agents sense and communicate locally

Lets take a look at some examples of swarms...

A swarm of honeybees looking for a new nest

Leafcutter ants retrieving building materials

Termite mounds taller than a Computer Scientist!

Chains of robots showing the path from point A to B

Spontaneous lane formation in human crowds

Which of the following satisfies our definition for a swarm? (There are two correct answers and you must select both!)

a	A group of animals ruled by a Queen that dictates the behaviour of all her subjects.
b	A group of animals that operate independently, without any coordination by the Queen.
c	A group of robots that share messages by flashing lights that nearby robots can see.
d	A group of robots that can capture a complete view of their environment from an overhead camera.

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ANSWER: B and C

What is Swarm Intelligence?

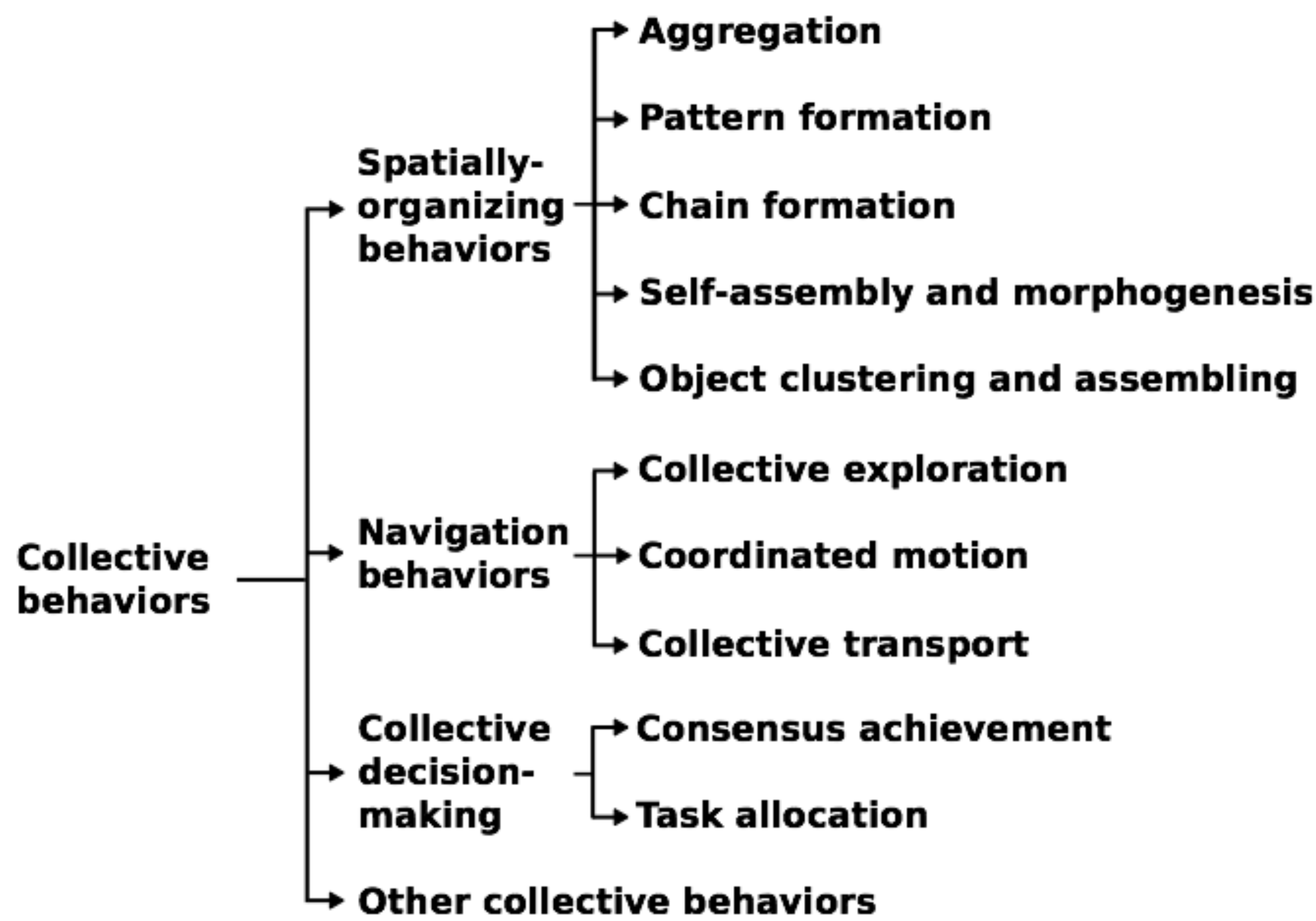
Swarm intelligence (SI) refers to the ability of a swarm to solve a problem collectively.

- We assume that a single agent cannot solve this problem on its own (at least not very well)
- We won't get bogged down on what it means to be intelligent—if the swarm can be interpreted to be solving a collective problem, then that is sufficient

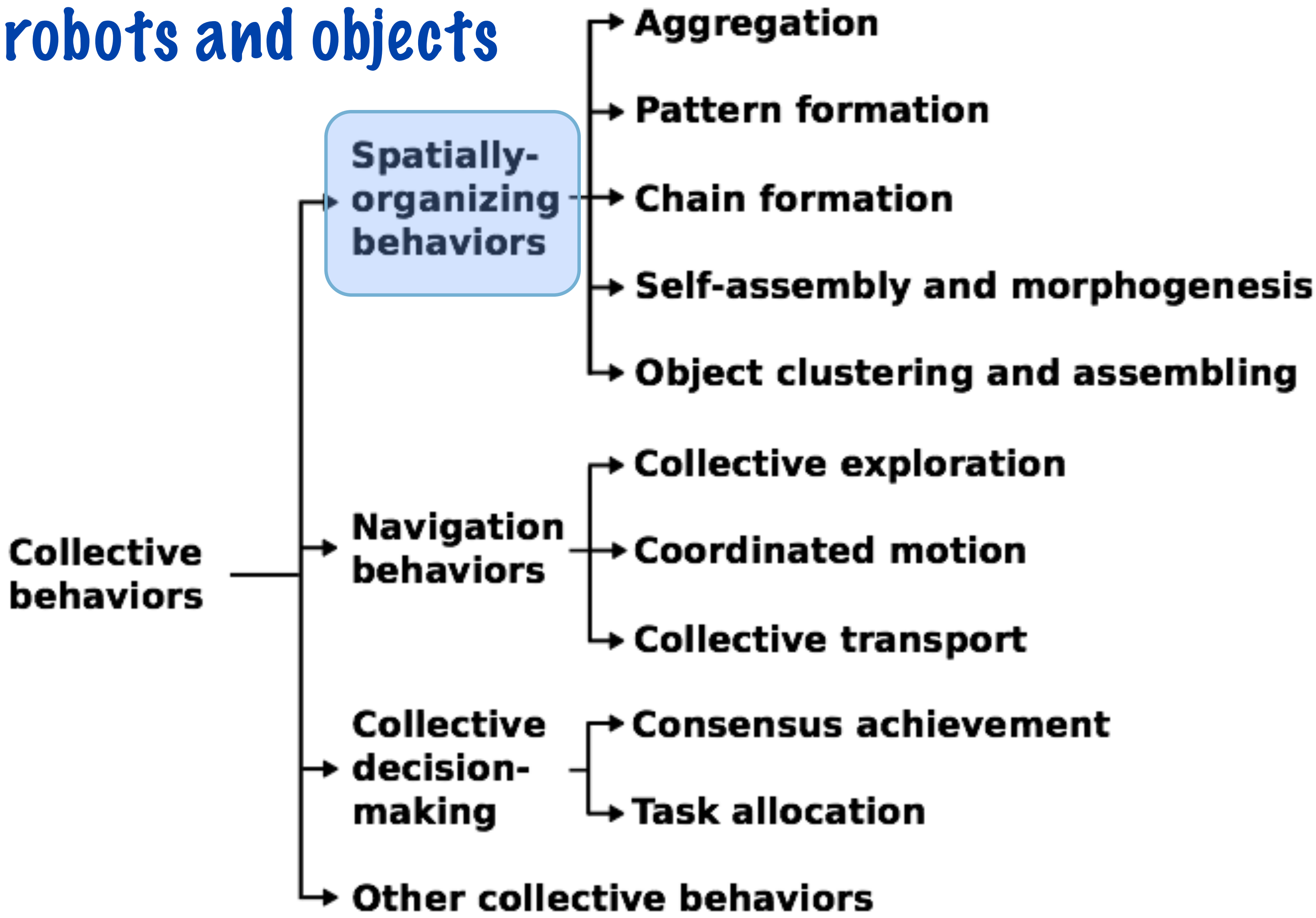
Advantages of SI over other problem-solving methods:

- Robustness to failure or malfunction of individual agents and external disturbances
- Flexibility to tackle many similar problems
- Scalability to tackle large and small problems

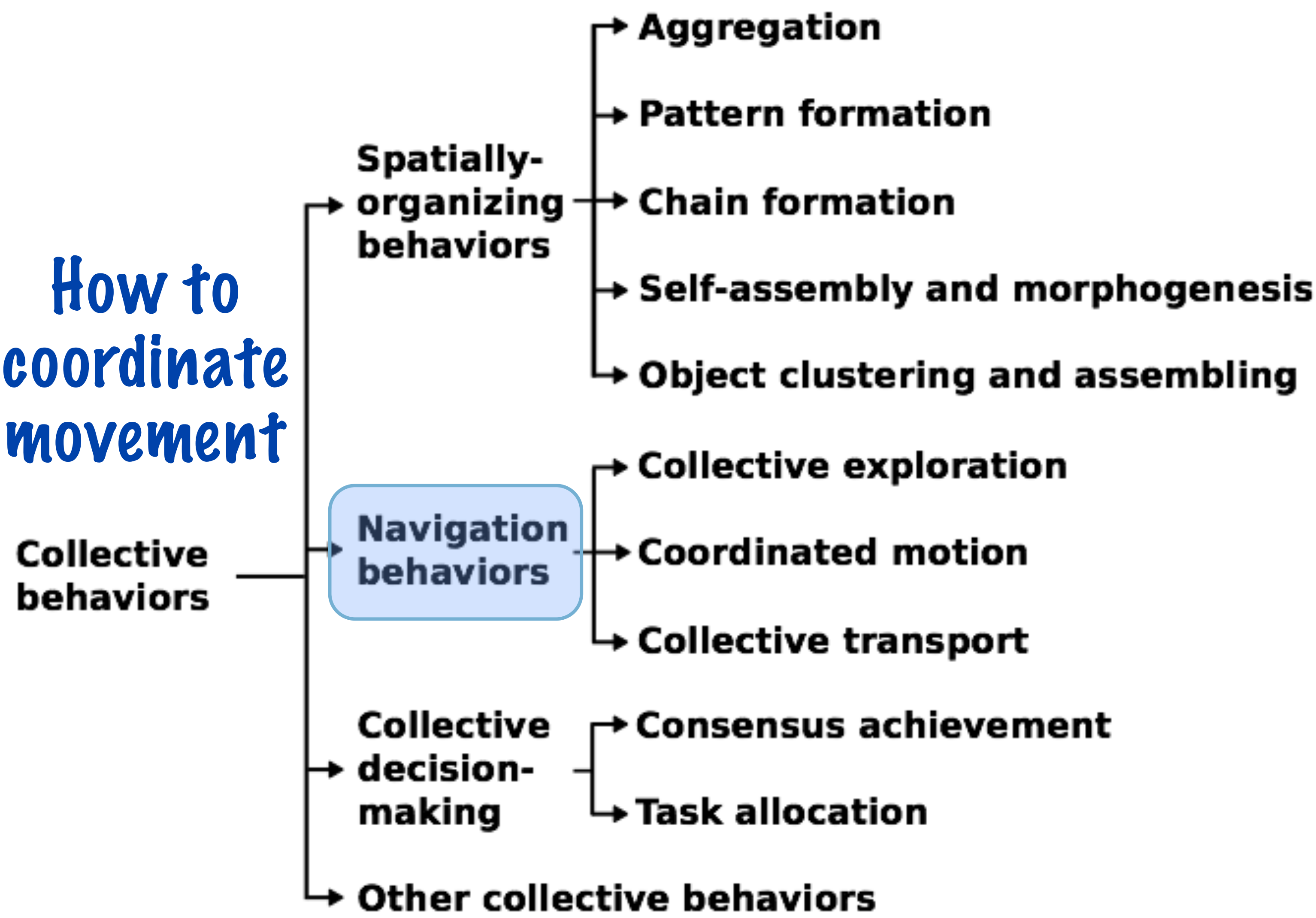
* We'll now go through a tour of various different behaviours exhibited so far in swarm robotics...

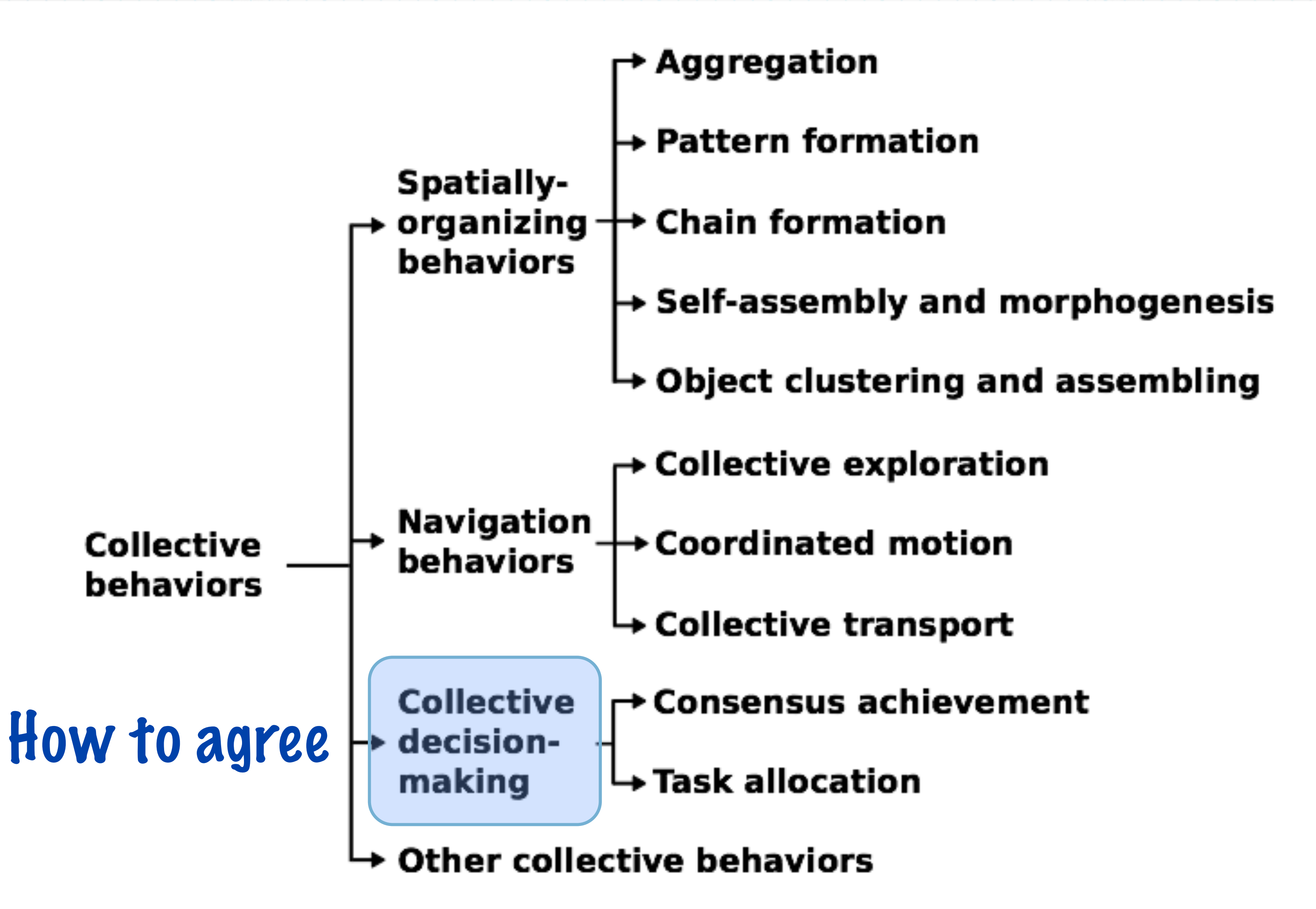

Collective behaviors
Spatially-organizing behaviors
Aggregation
Pattern formation
Chain formation
Self-assembly and morphogenesis
Object clustering and assembling
Navigation behaviors
Collective exploration
Coordinated motion
Collective transport
Collective decision-making
Consensus achievement
Task allocation
Other collective behaviors

How to organize robots and objects



How to coordinate movement

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Spatially-Organizing Behaviours

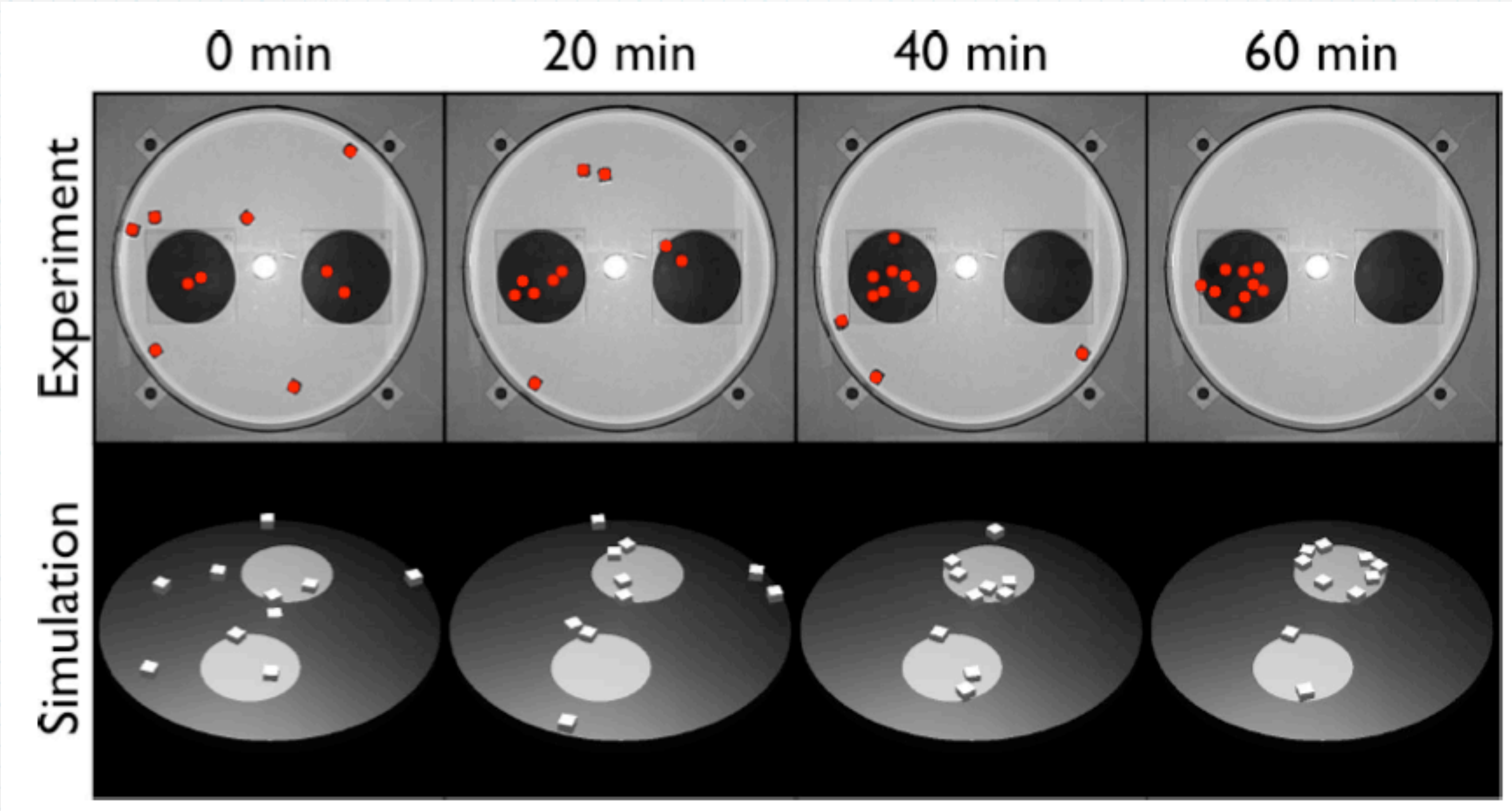
Aggregation:

* "The goal of aggregation is to group all the robots of a swarm in a region of the environment"
* Useful as a building block for other behaviours
* Aggregation in nature: bacteria, fish, birds,...
* We will look at the cockroach-inspired aggregation model proposed in:
  * S. Garnier, C. Jost, R. Jeanson, J. Gautrais, M. Asadpour, G. Caprari, and G. Theraulaz. **Aggregation behaviour as a source of collective decision in a group of cockroach-like robots.** In Advances in Artificial Life, volume 3630 of LNAI, pages 169-178. Springer-Verlag, Berlin, Heidelberg, 2005.

Aggregation in Cockroaches

* Aggregation behaviour in cockroaches can be modelled as follows:
    * Move randomly (correlated random walk)
    * Stop moving with probability that increases according to the number of stopped cockroaches nearby
    * Start moving with probability that decreases with the number of stopped cockroaches
    * Cockroaches may stop only in sheltered (i.e. darkened areas)

* Adding platforms to provide shelter from the light gives the cockroach-inspired robots a choice...



* (Red dots added by AV to improve clarity)
* The robots consistently choose one shelter over the other (they do not oscillate back and forth)

Pattern Formation

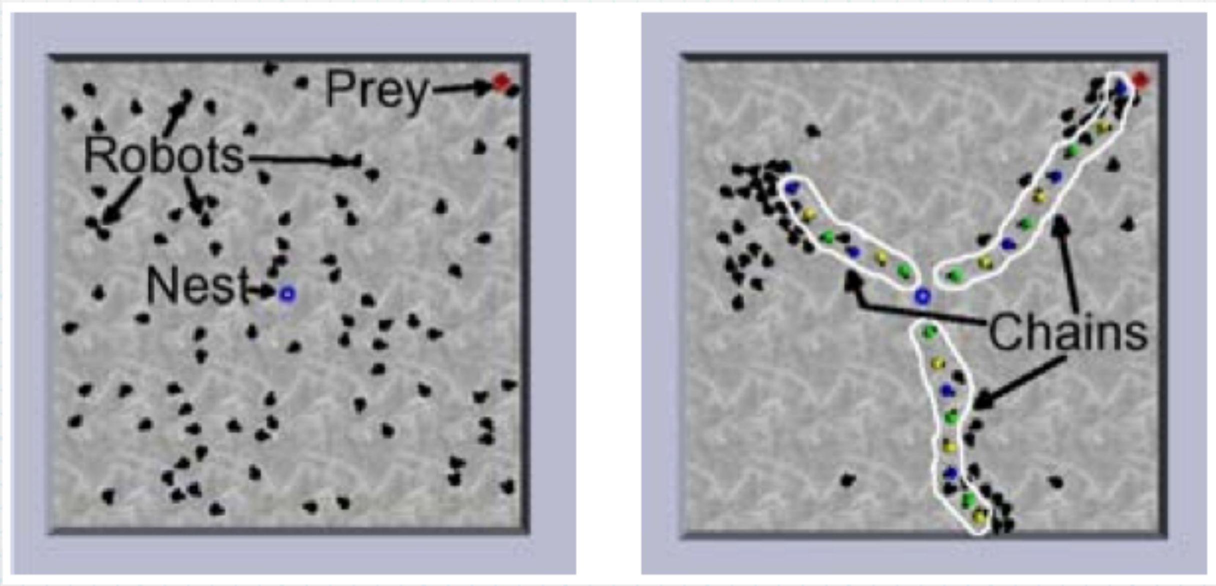
* "Pattern formation aims at deploying robots in a regular and repetitive manner."
* Robots keep specific distances between each other
* Inspired by biology and physics: distribution of molecules, growth of crystals

* Robots moving in a hexagonal formation:

* Another perspective is to move each robot to equalize the forces from virtual springs connected to the other robots
* SHOW VIDEOS FROM SPEARS AND SPEARS

Chain Formation

* Robots form a chain connecting two places in order to navigate or gather resources
* We will consider work from the following paper:
  * S. Nouyan, A. Campo, and M. Dorigo. **Path formation in a robot swarm: self- organized strategies to find your way home.** Swarm Intelligence, 2(1):1–23, 2008.



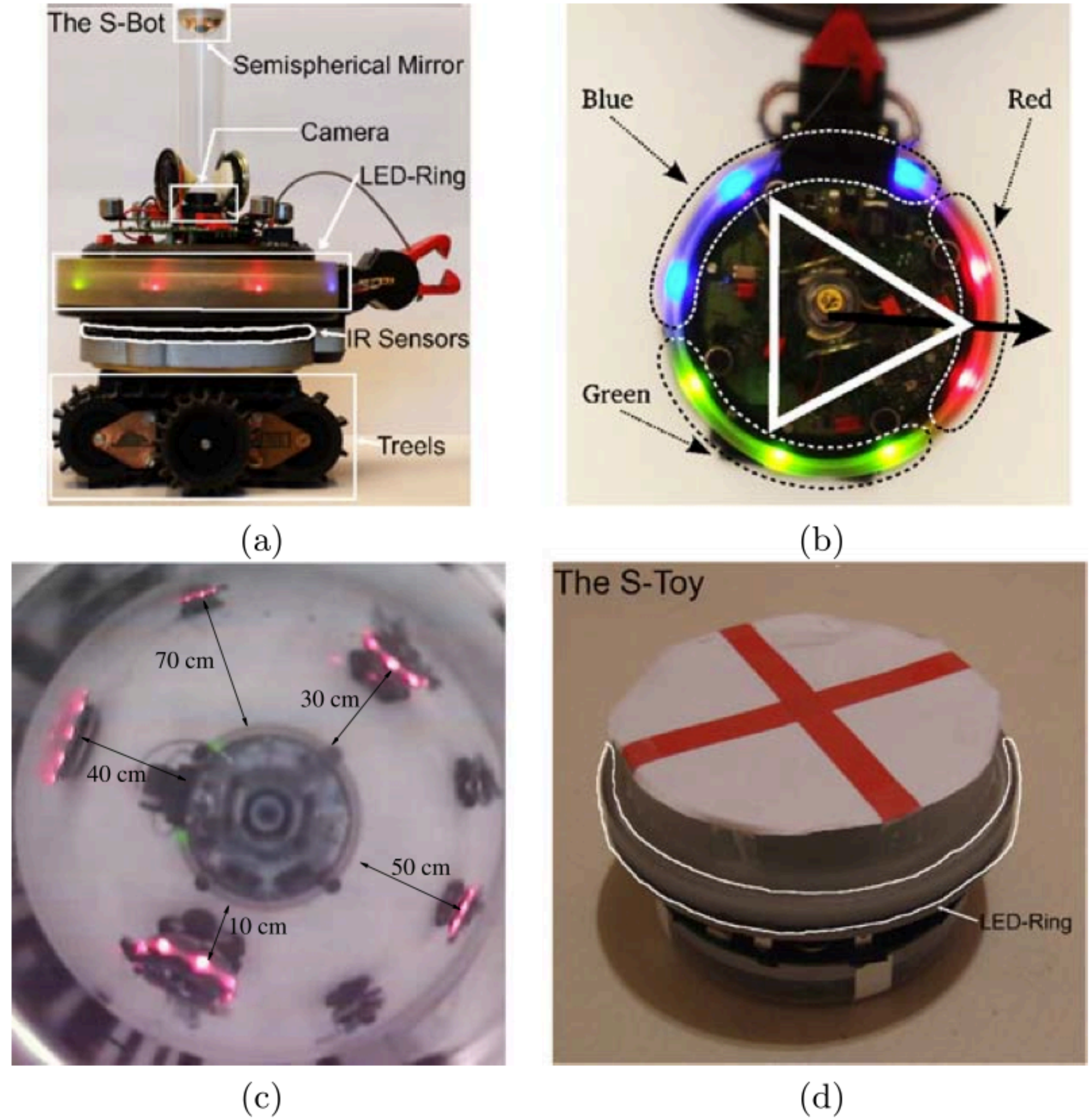
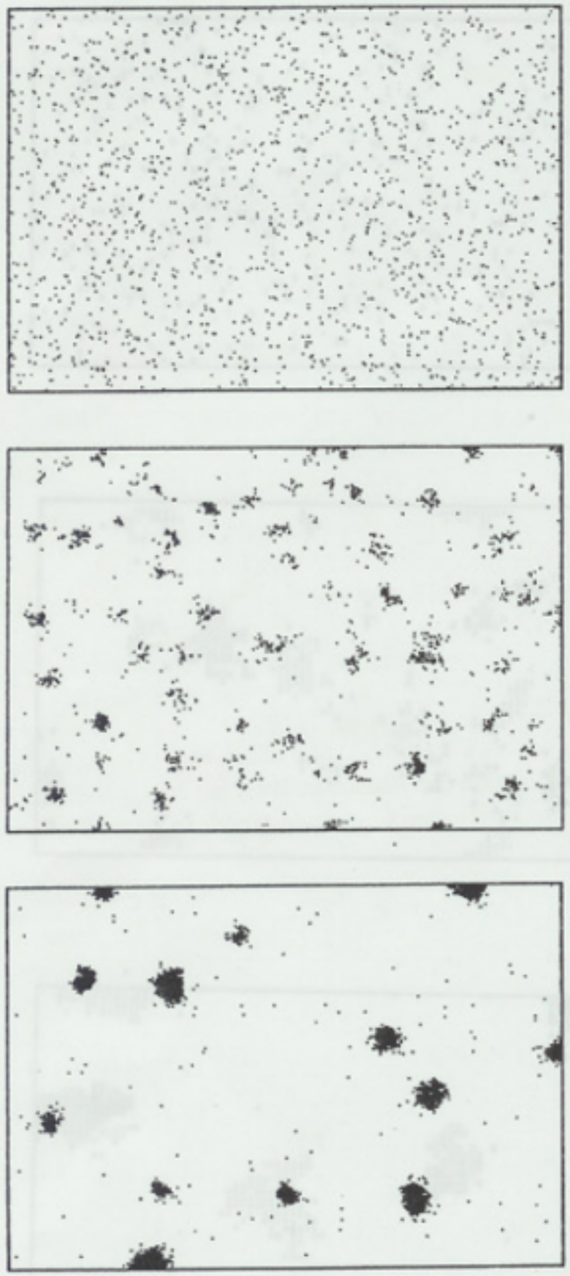


Fig. 2 The hardware. **a** The *s-bot*. **b** A robot activating its LEDs to indicate a direction as employed by the vectorfield controller. **c** An image taken with the omni-directional camera of the *s-bot*. It shows other *s-bots* and an *s-toy* activating their red LEDs at various distances. **d** The *s-toy* which is used both as nest and as prey

Object Clustering

* Inspired by observations of ant behaviours that create global order through local action
    * Dead ants moved into "cemetery clusters" that aggregate over time
    * Nest contents organized into distinct piles
* Deneubourg et al's model:
    * Agents walk randomly and pick-up or deposit objects as a probabilistic function of local object density



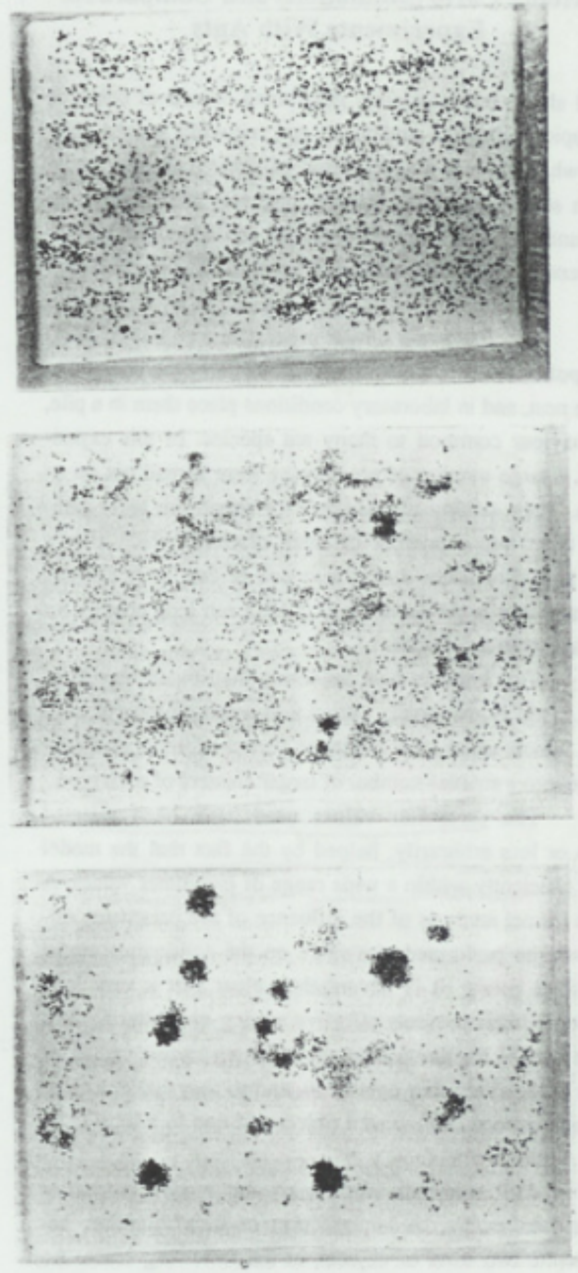
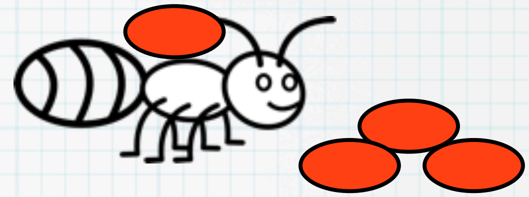
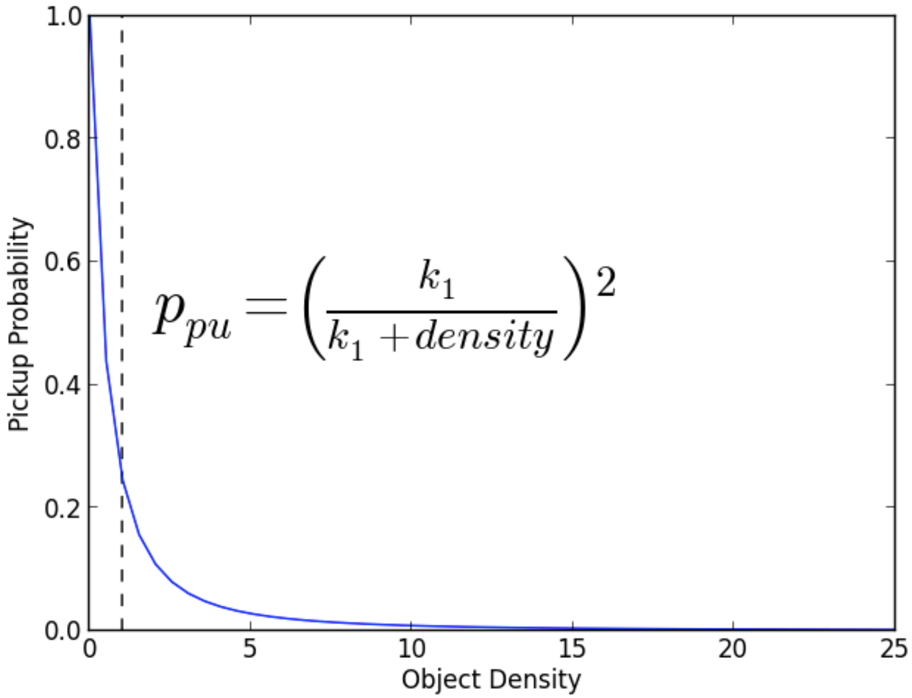
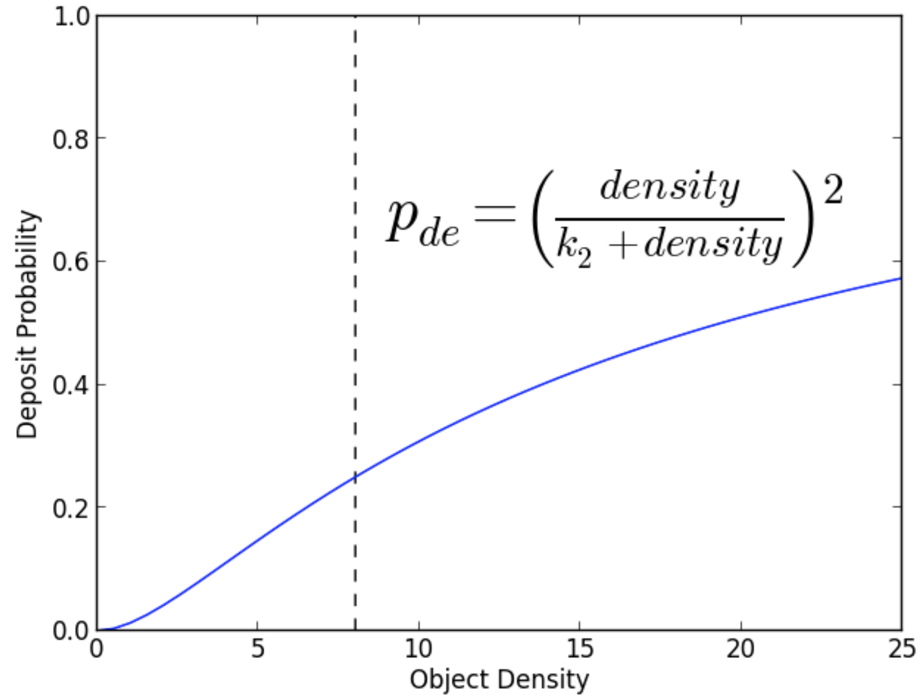


Fig. 1. Clustering after 1, 100000 and 2000000 steps. 100 ALRs, 1500 objects, $k^+=0.1$, $k^-=0.3$, m=50, e=0, space=290x200 points. Small evenly spaced clusters rapidly form, and later merge into fewer larger clusters.

Fig. 2. Clustering in a colony of *Pheidole pallidula*. 4000 corpses were placed on a 50x50cm arena, and photos taken at time 0, 20 and 68 hrs. Small evenly spaced clusters rapidly form, and later merge into fewer larger clusters.

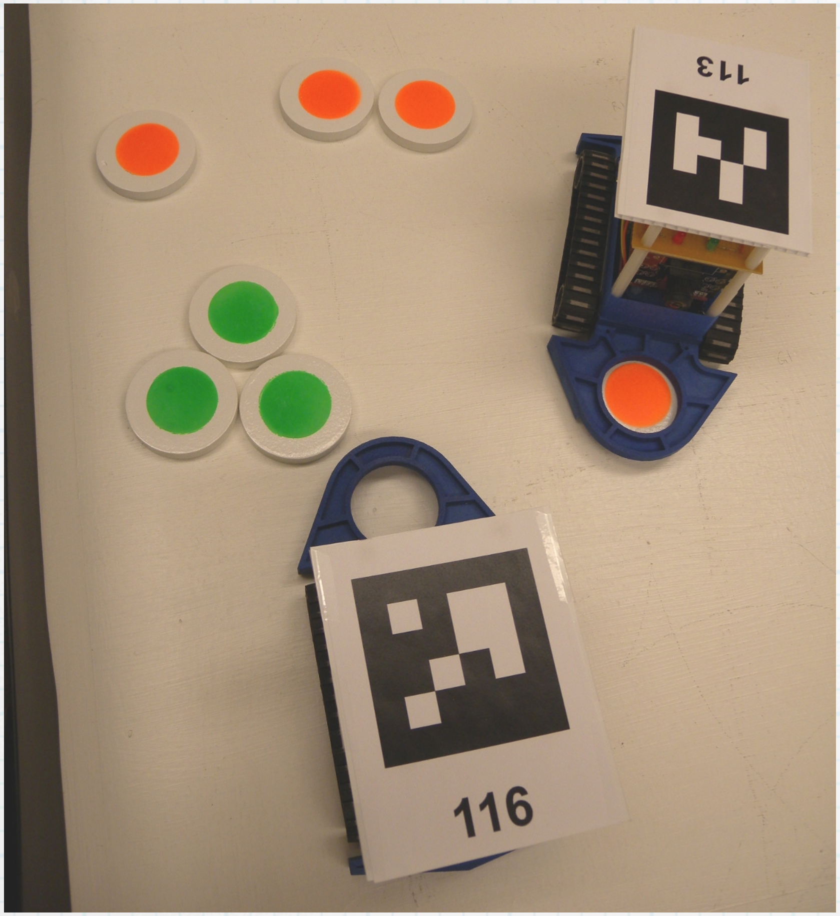


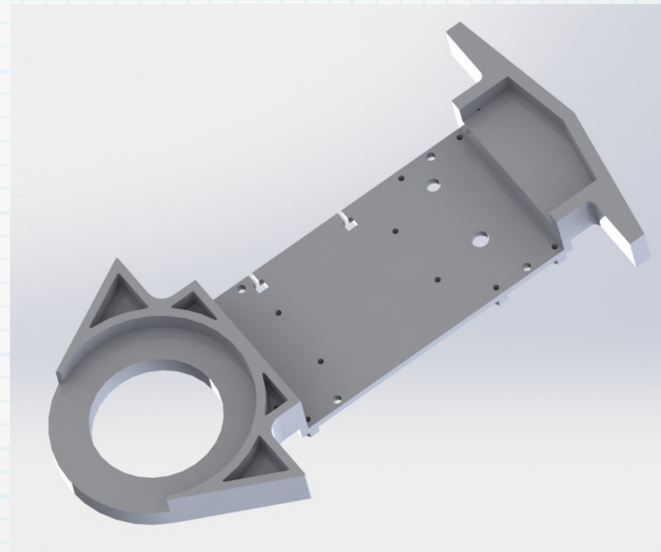




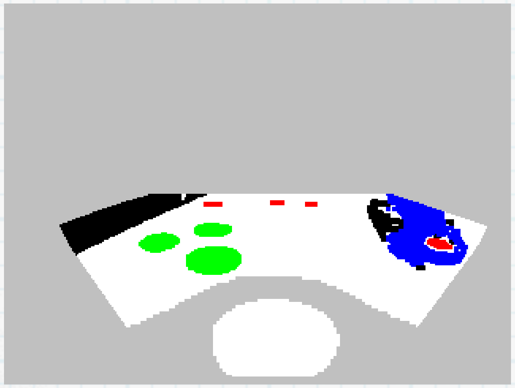
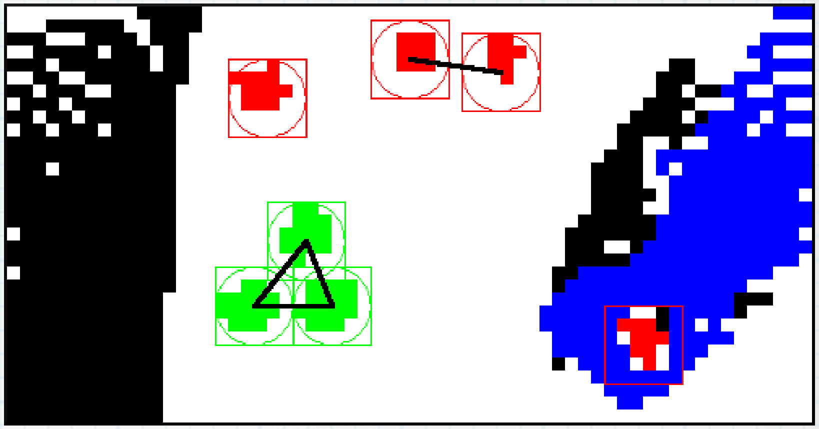
Agents measure density by maintaining a short-term memory and counting the number of recent object appearances

My Work on Object Clustering





* Modified SRV-1 robots (12.5 x 10.8 cm) with forward-facing fisheye cameras and passive grippers, suitable for carrying (and viewing) one puck

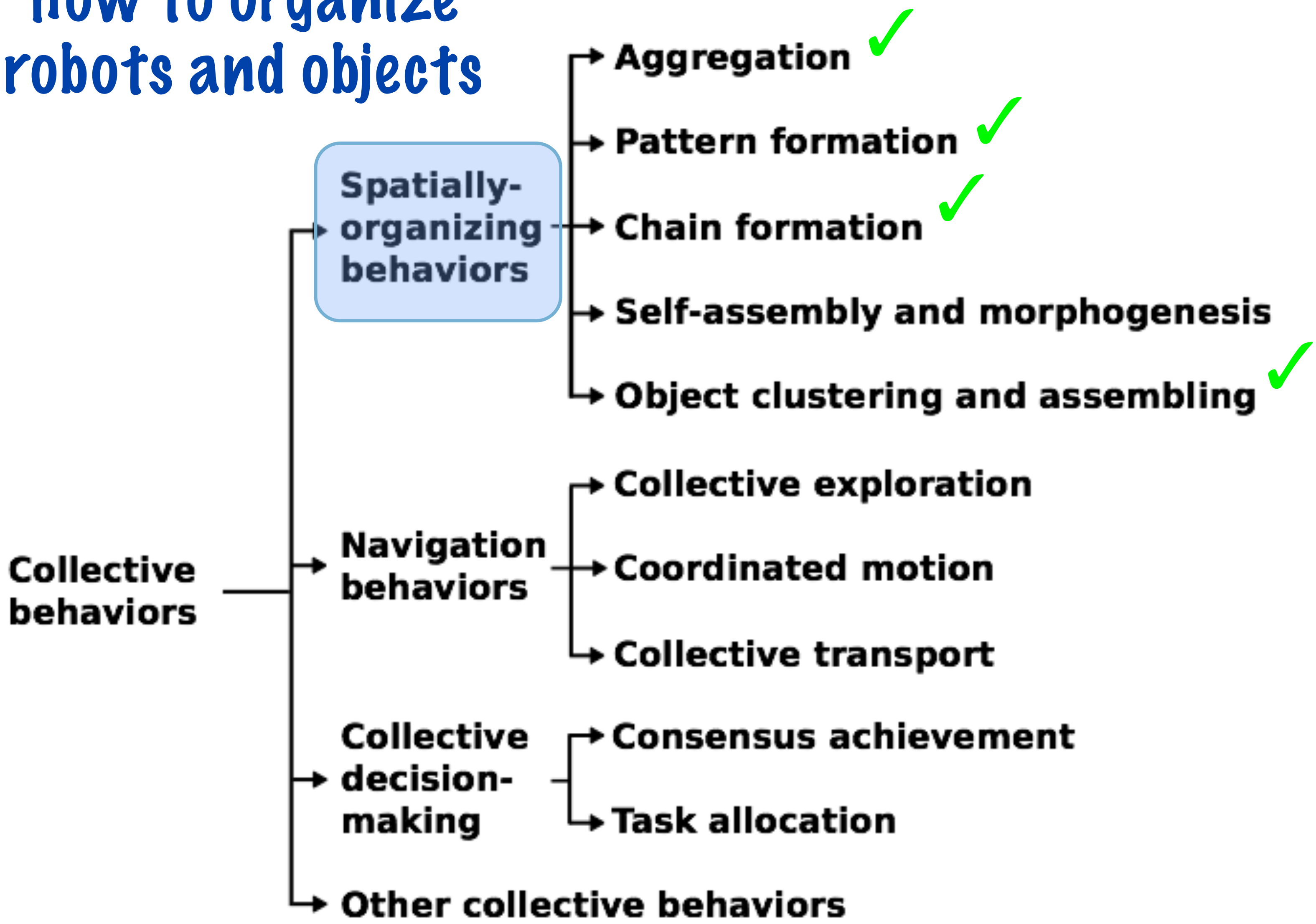
- The robot is not carrying a puck
  - It would <u>consider</u> selecting the solitary red puck as a pick-up target
- If carrying a red puck, it would <u>consider</u> the cluster of two red pucks as a deposit target
- Possible results of the pick-up/deposit attempt handled through the state machine...

Supplementary Video:

”Rapid object sorting by a robotic
swarm via cache consensus”

Trial 1 / 3

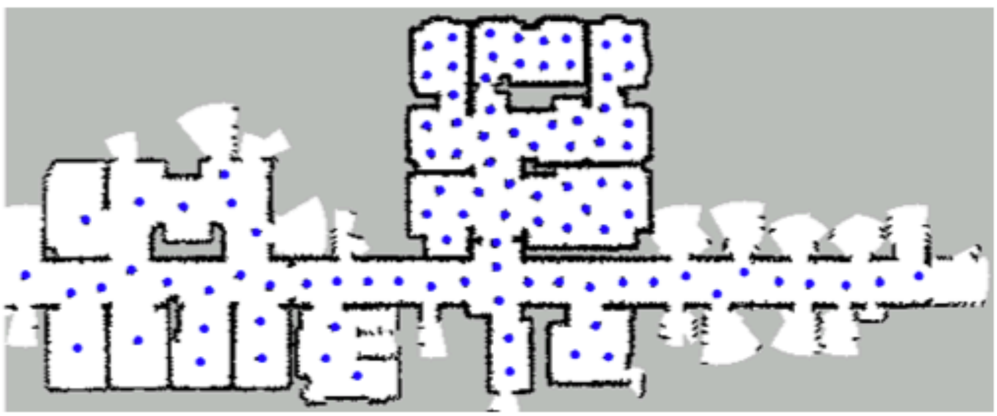
How to organize robots and objects



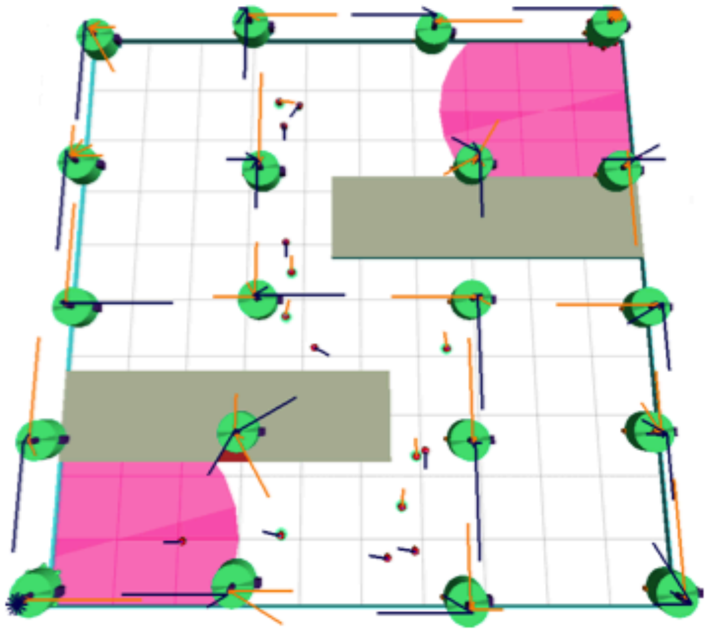
Navigation Behaviours

Collective Exploration

* Move to spread the swarm throughout the environment
* The purpose might be to cover the largest area (left), or to serve as navigation beacons (right)



(a) From Howard et al. (2002), reprinted with permission.



(b) From Ducatelle et al. (2011b), reprinted with permission.

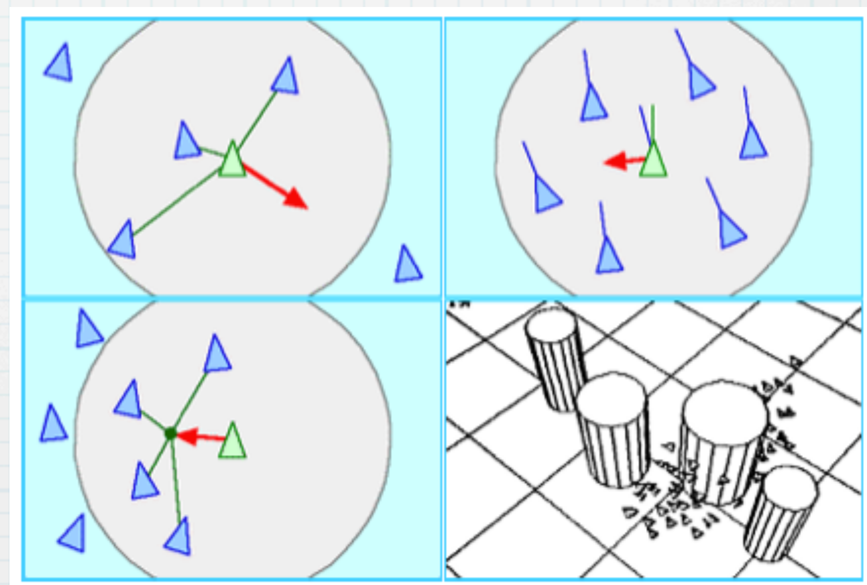
Coordinated Motion

* Also known as "flocking": Robots move together in self-organized formations
* Minimized collisions while staying together and moving coherently
* Examples in biology:
    * Fish (schooling)
    * Birds (flocking)
    * Cattle (herding)
* First flocking algorithm proposed in (Reynolds, 1987) for the purpose of animating virtual characters in movies
* Three simple rules...

1. **Separate:** If the closest neighbour is too close, turn away from it. This would cause the blue agent above to turn away from the green agent by rotating clockwise.

2. **Align:** Turn towards the average heading of nearby agents. This would cause the blue agent above to turn counter-clockwise.

3. **Cohere:** Turn towards the average position of nearby agents. This would also cause the blue agent to turn counter-clockwise.



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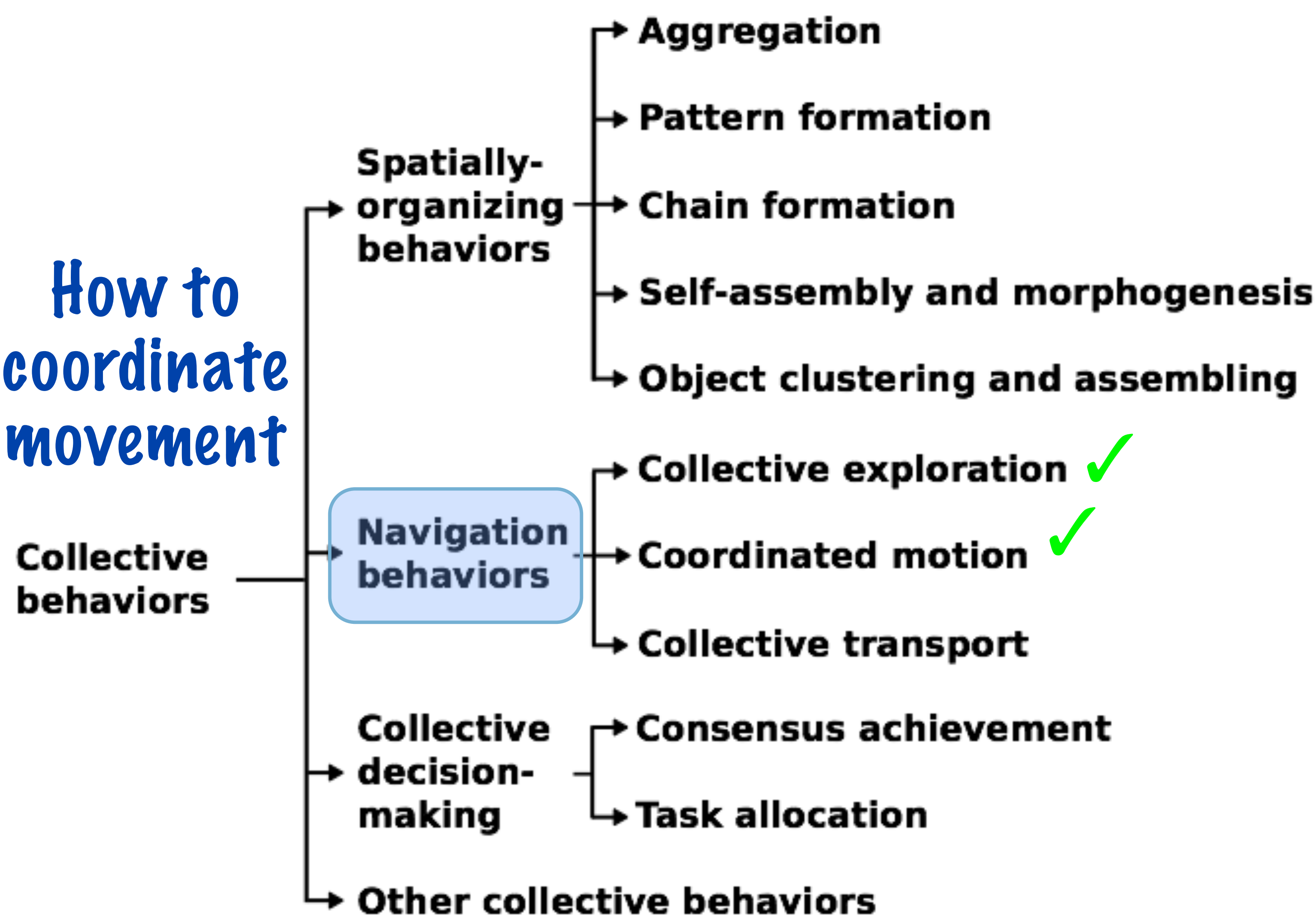


Collective Decision-Making

Consensus Achievement

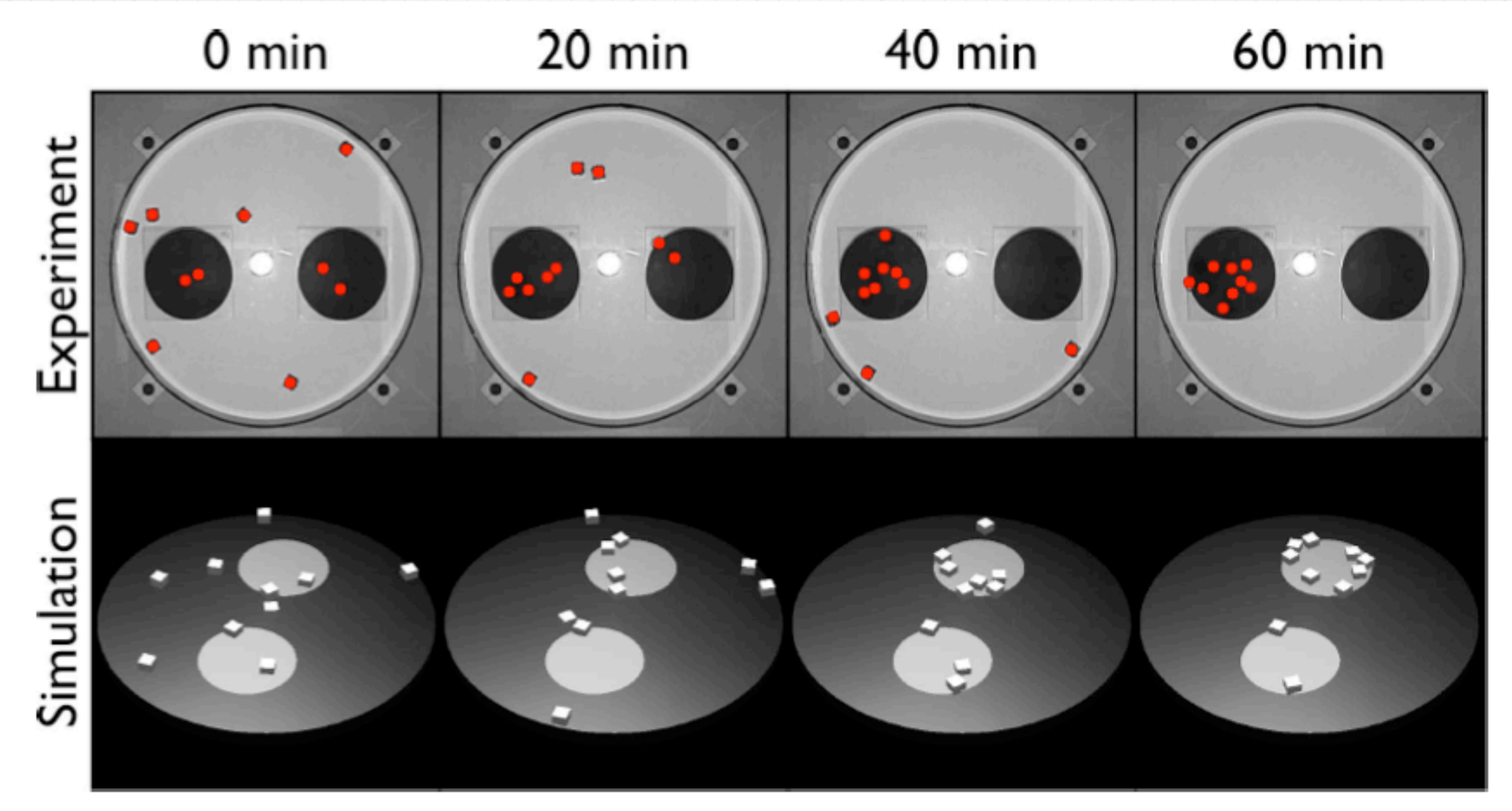
- "Consensus achievement is a collective behavior used to allow a swarm of robots to reach consensus on one choice among different alternatives"
- We have seen examples from biology:
  - Ants achieve consensus on the shortest path from a food source
  - Bees collectively decide which is the best food source

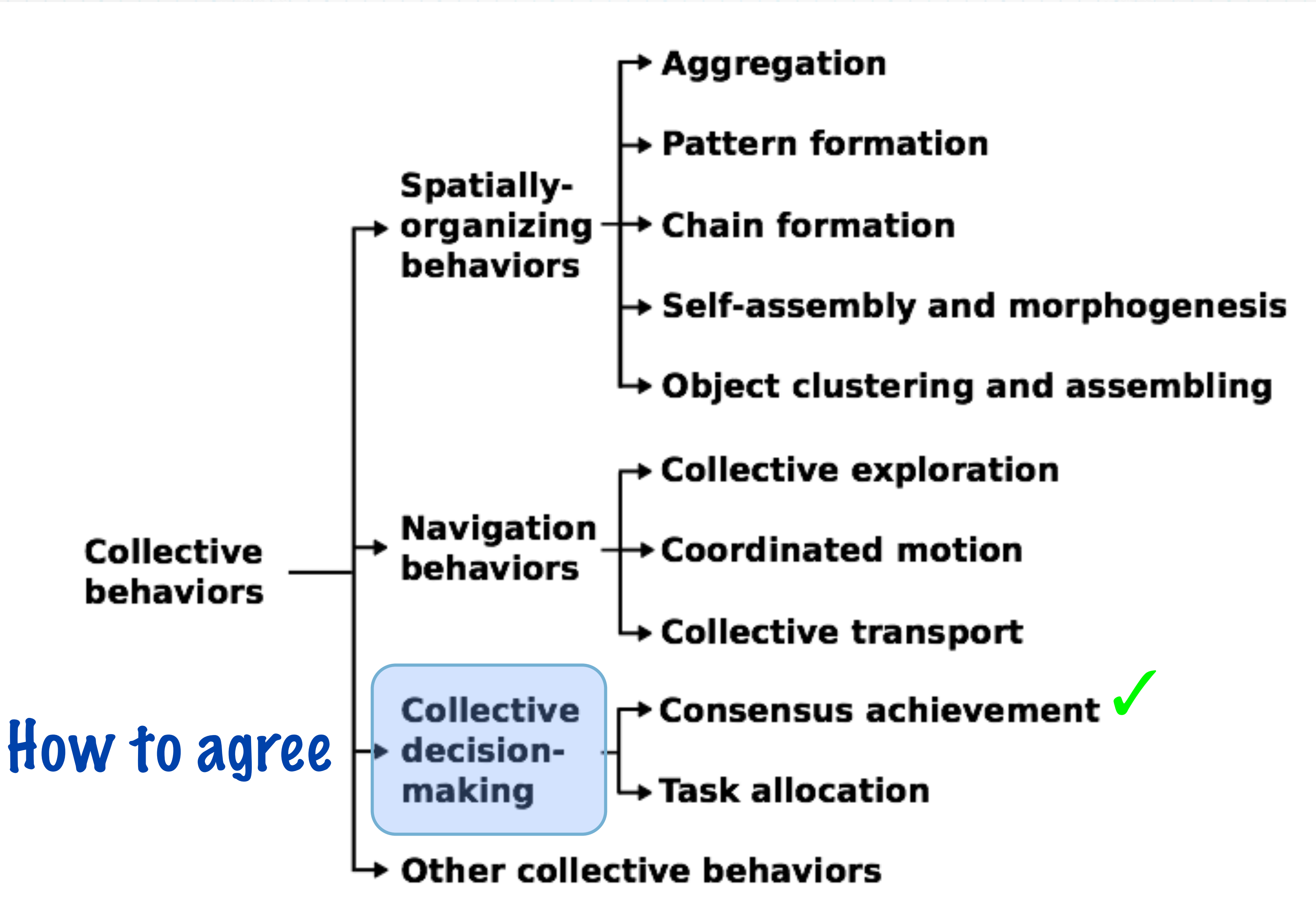
Example: Cache Consensus

* The cache consensus model (Vardy et al, 2014) involves a search for consensus as to where coloured pucks should be deposited:

Example: Aggregation

* (Garnier et al, 2005) showed that simple robots could achieve consensus on the "shelter" they occupied:

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Consensus achievement ✓
Task allocation
Other collective behaviors
How to agree

Summary

* A wide variety of collective behaviours have been explored in swarm robotics
* Many behaviours are merely building blocks (e.g. aggregate, then make a decision)
* The examples shown are just those considered so far
* Increasing computational power and decreasing size opens up the option to explore larger and larger swarms...

The Kilobot Swarm

https://youtu.be/xK54Bu9HFRw