Swarm Robotics
Part 6:

Review of Collective Behaviours

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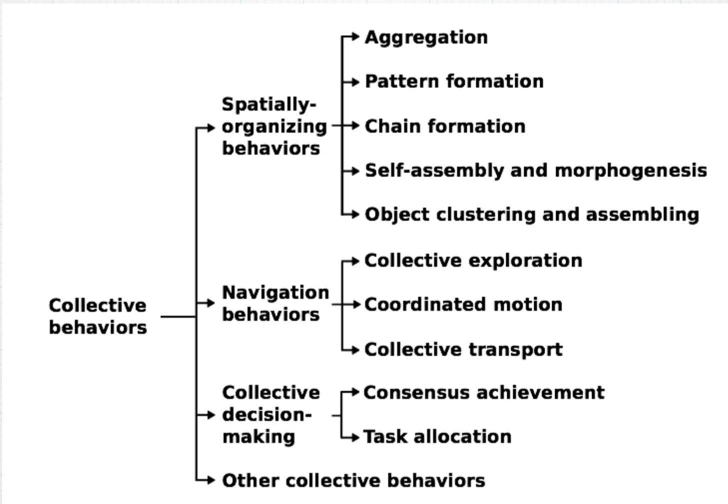
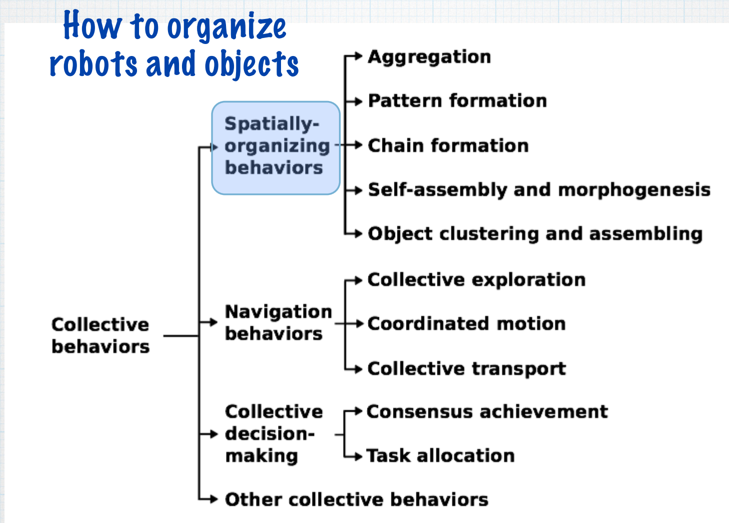
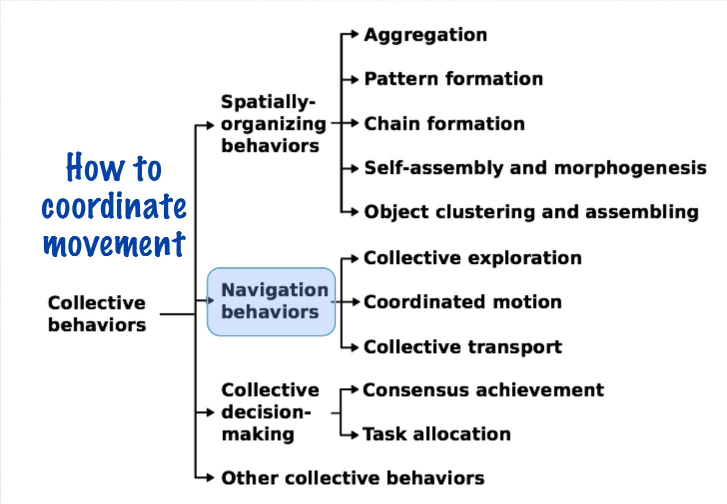
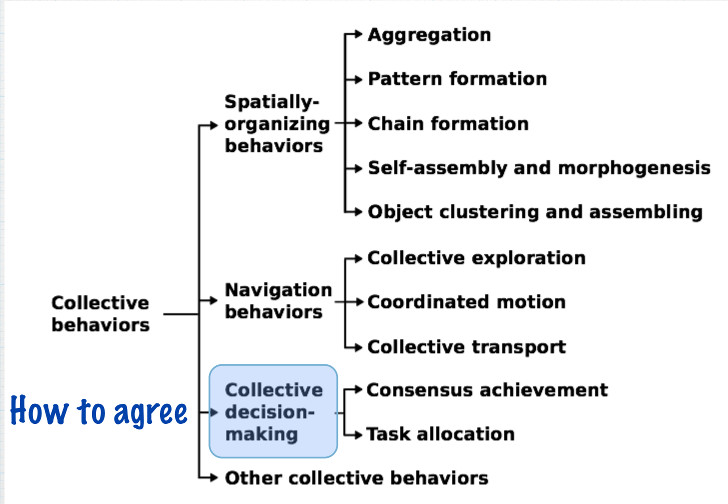
Collective Behaviours

* In this set of notes we will review the various collective behaviours demonstrated so far in SR
* Material for this review comes from the following paper and its sources:
    * Brambilla, M., Ferrante, E., Birattari, M., & Dorigo, M. (2013). Swarm robotics: a review from the swarm engineering perspective. Swarm Intelligence, 7(1), 1-41.
    * (This paper also provides a taxonomy of SR design and analysis which is not reviewed here)









Spatially-Organizing Behaviours

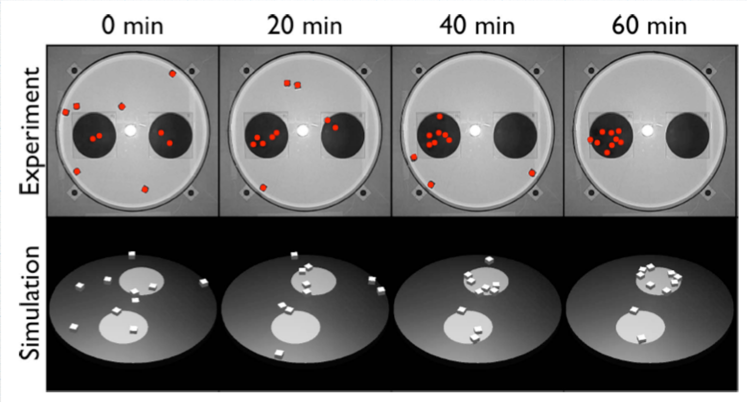
Aggregation:

* "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

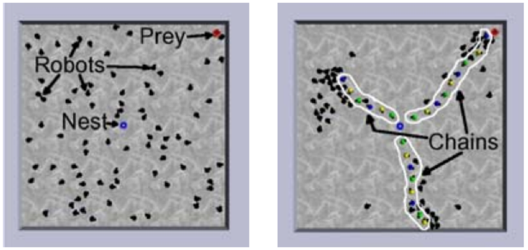
* "Pattern formation aims at deploying robots in a regular and repetitive manner."
* Robots keep specific distances between each other
* Inspired by biology and physics: distribution of molecules, growth of crystals

* Robots moving in a hexagonal formation:

* Robots move to equalize the forces from virtual springs connected to the other robots

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.



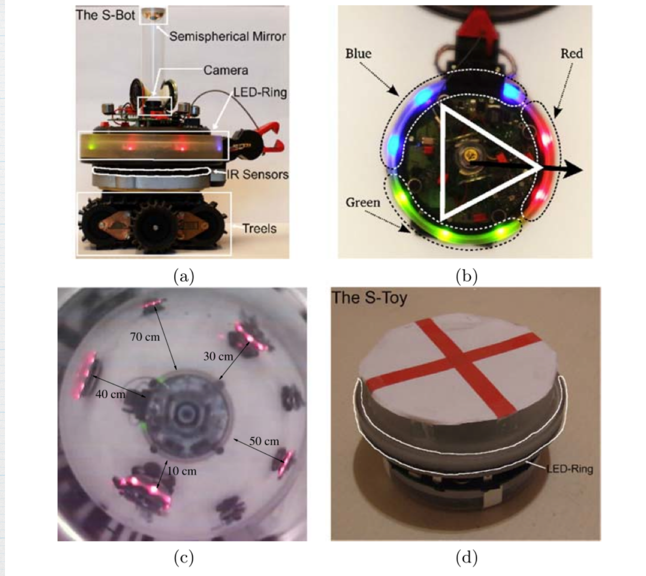
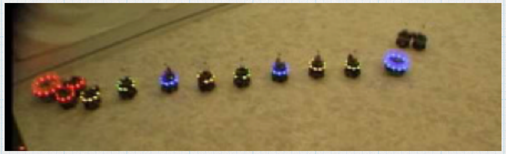
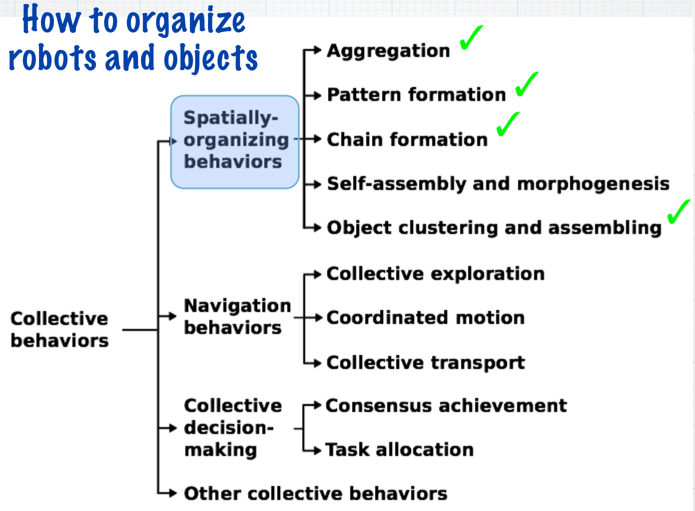


Fig. 2 The hardware. **a** The *s-bot*. **b** A robot activating its LEDs to indicate a direction as employed by the vectorfield controller. **c** An image taken with the omni-directional camera of the *s-bot*. It shows other *s-bots* and an *s-toy* activating their red LEDs at various distances. **d**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

* Robots form a chain connecting two places in order to navigate or gather resources
* In (Nouyan et al, 2005) approach there are robots that fill two different roles:
  * Explorer: Searches for chain members or the goal; Upon finding either, becomes a chain member
  * Chain member: Stay still; Become an explorer if no other robots are perceived
* Robots advertise their state by a pattern of LED's



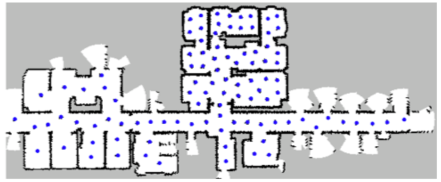
How to organize robots and objects



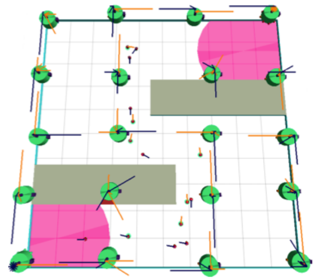
Navigation Behaviours

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.

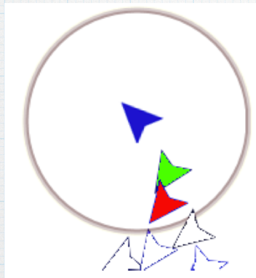


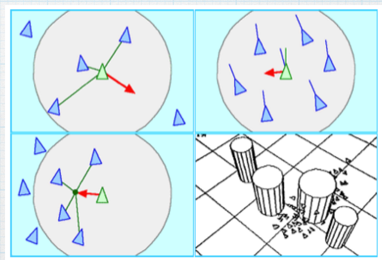
(b) From Ducatelle et al. (2011b), reprinted with permission.

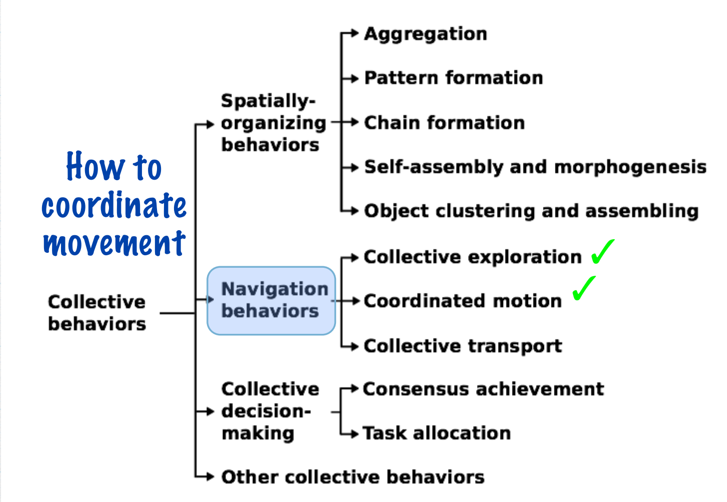
Coordinated Motion

* 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.







Collective Decision-Making

Consensus Achievement

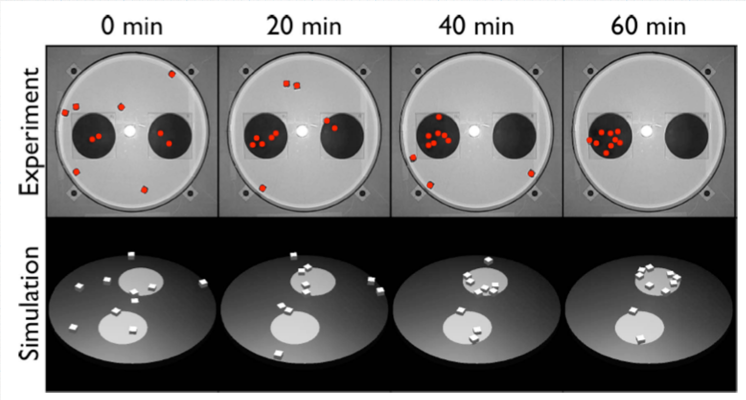
* "Consensus achievement is a collective behavior used to allow a swarm of robots to reach consensus on one choice among different alternatives"
* We have seen examples from biology:
  * Ants achieve consensus on the shortest path from a food source
  * Bees collectively decide which is the best food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

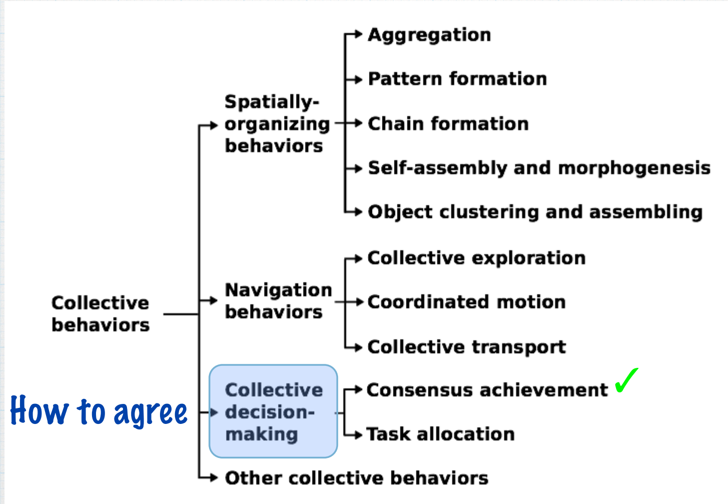
Example: Cache Consensus

* 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:





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...