

Collective Robotics

IAR Lecture 12

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Collective robotics

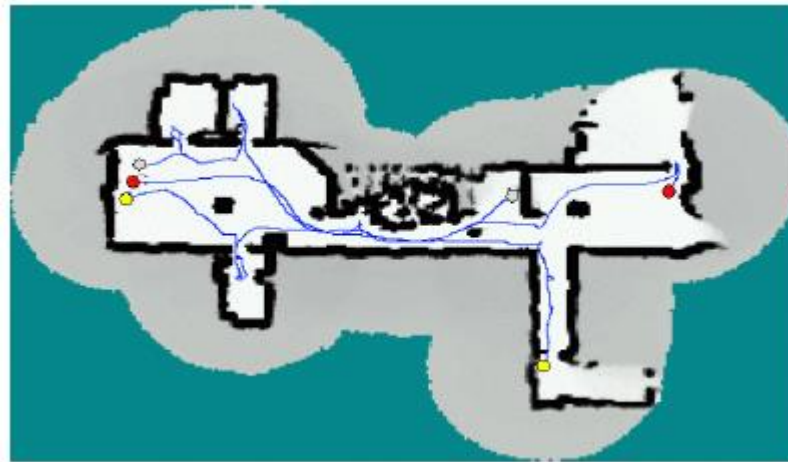
Different approaches (Kernbach, 2013)

- **Co-operative:** distributed sensing and actuation, but centralised control.
- **Networked:** higher individual autonomy, but still high level of communication and common knowledge.
- **Swarm:** no common knowledge, only local communication, or interaction via effects on the world.
- **Small world:** minimalist capabilities of individual, collective computation.

E.g. exploring with multiple robots



- Provided robots can merge their maps, can explore faster with multiple robots.
- Potential speed up is $2*k$, as single robot would need to spend time traversing known space to get to new frontier.



- But need to co-ordinate exploration.

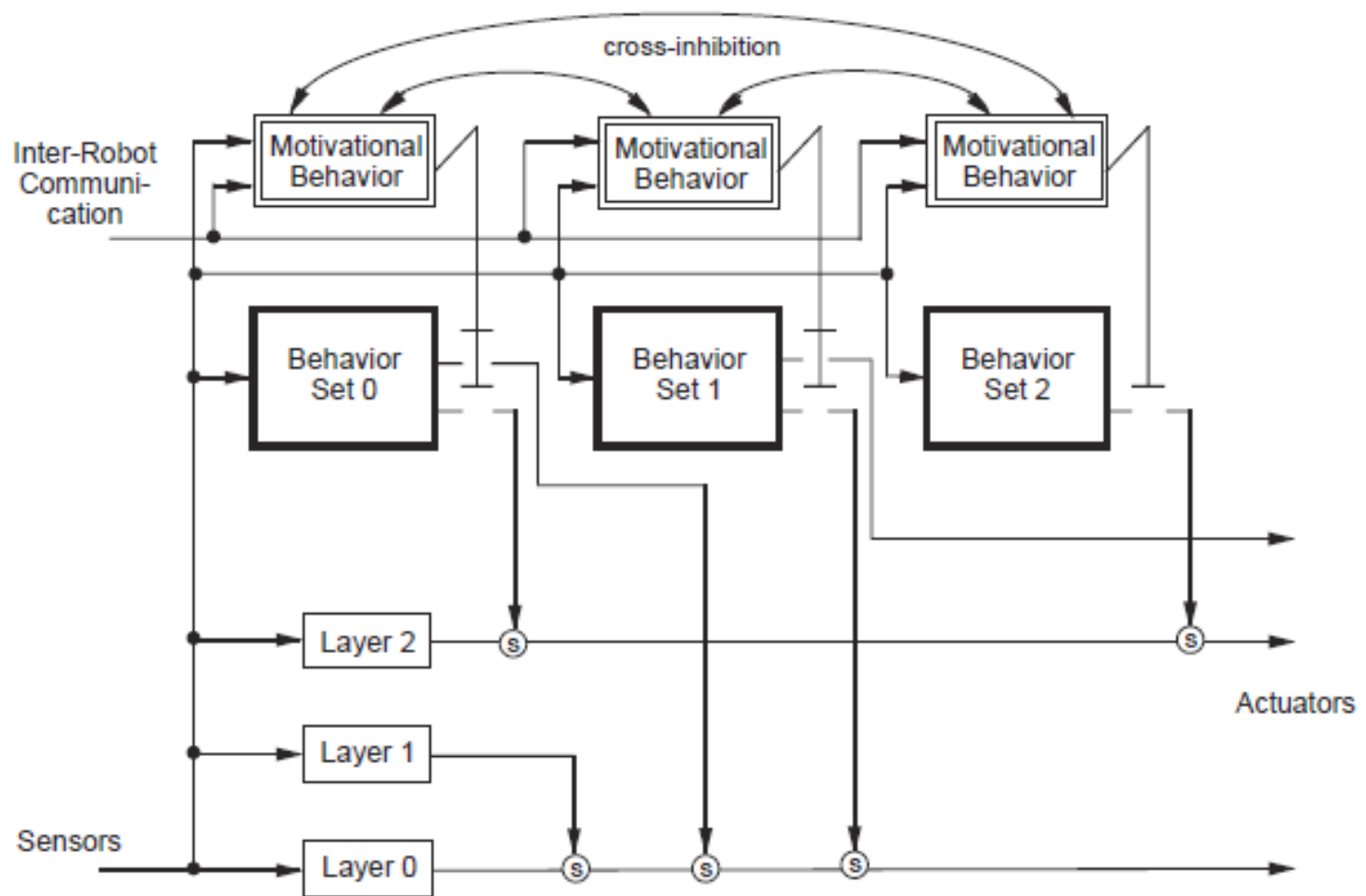
Active mapping for k robots

- For each robot, obtain cost function of moving from current position to other possible grid positions.
- Use binary representation of potential information gain: cell is 0 if explored, 1 if unexplored.
- For each robot in turn, set goal as unexplored grid location that has minimum cost to reach, and mark that location as explored (so not available for next robot).
- More sophisticated approach would allow robots to swap goals if this reduces the overall cost, e.g. using auction mechanism.
- Generalised, this is the problem of task allocation.

E.g. Behaviour based task allocation

- ALLIANCE architecture (Parker, 1998)
 - Robots have motivation systems determining action selection:
 - Impatience: will choose a task not being completed by other robots
 - Acquiescence: give up a task if failing to complete
 - Broadcast periodic messages to each other indicating what they are doing.
 - Sensory feedback to monitor progress on tasks.

The ALLIANCE Architecture



Emergent co-operation

- Holland (1995) ‘Stigmergy’
- Robots:
 - Front scoop tends to collect pucks
 - Lever triggers switch if pushing two or more, makes robot back up, leaving pucks behind
 - Also avoid walls and each other using IR.
- Result is gradual aggregation of pucks in a single pile

Emergent co-operation

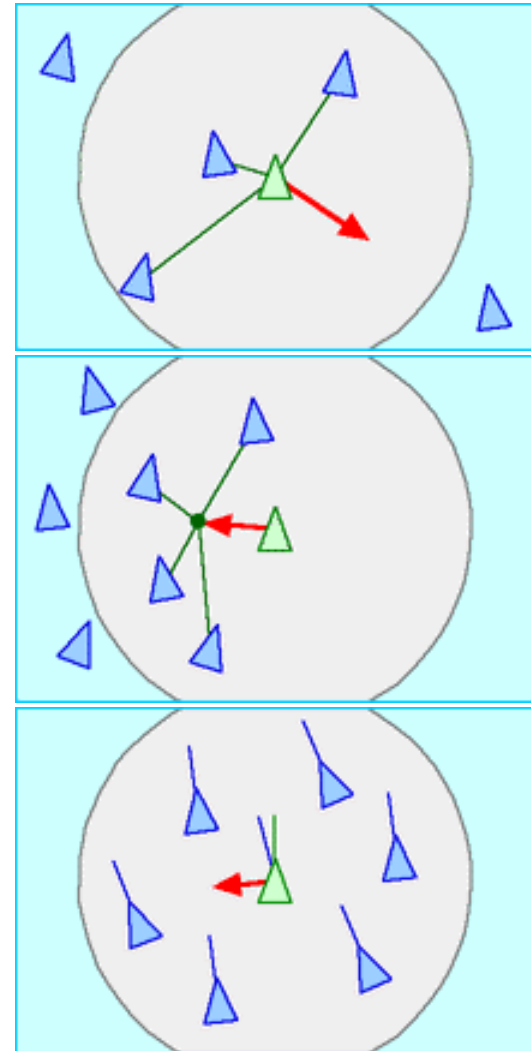
- Melhuish et al (2000)
- Robots can carry puck, detect gradient and notice if cross a boundary line.
- Simple rules:
 - If hit another object, drop puck
 - If cross boundary going up gradient, move short distance and drop puck
 - If cross boundary going down gradient, back-up short distance and drop puck

Emergent group behaviour

Flocking: (Reynolds 1987)

Assumes all 'boids' are identical and follow the same local rules:

1. **Collision Avoidance:** Separate from other boids.
2. **Centering:** Stay close to other boids.
3. **Velocity matching:** travel in same direction.



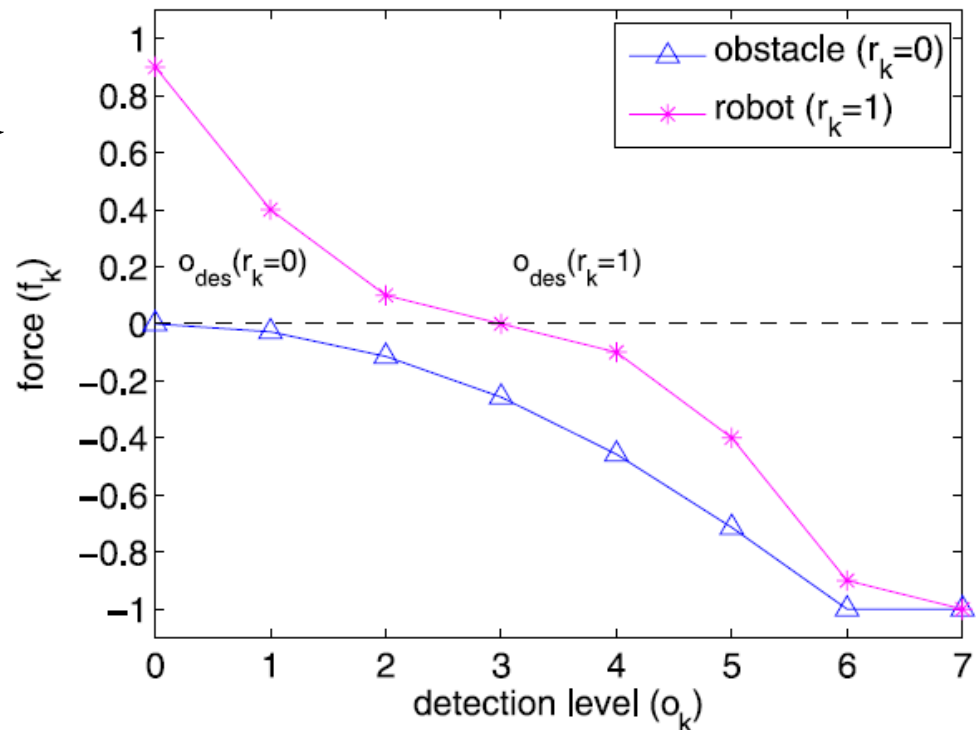
Emergent group behaviour

Flocking in real robots is difficult:

- various attempts, but needed to include virtual or explicit leader, or all robots sensing goal
- also problem of how to make individual robot able to sense relative position and bearing of neighbours
- Recent example addresses some of these limitations (Turgut et al., 2008)

Turgut et al. 2008

- IR sensors used to detect other robots (when not active) and obstacles (when active)
- Use virtual heading sensor: each robot has a compass and wirelessly broadcasts its direction to neighbouring robots.
- Desired heading alignment is calculated as average of detected neighbours
- Proximal control is calculated as a virtual force with respect to detected robots or obstacles



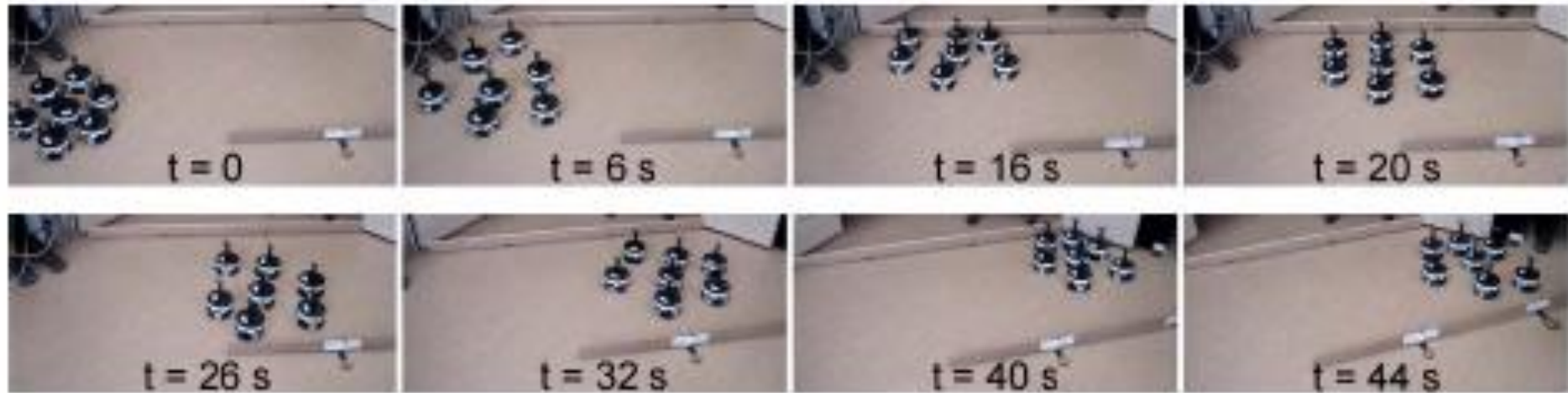
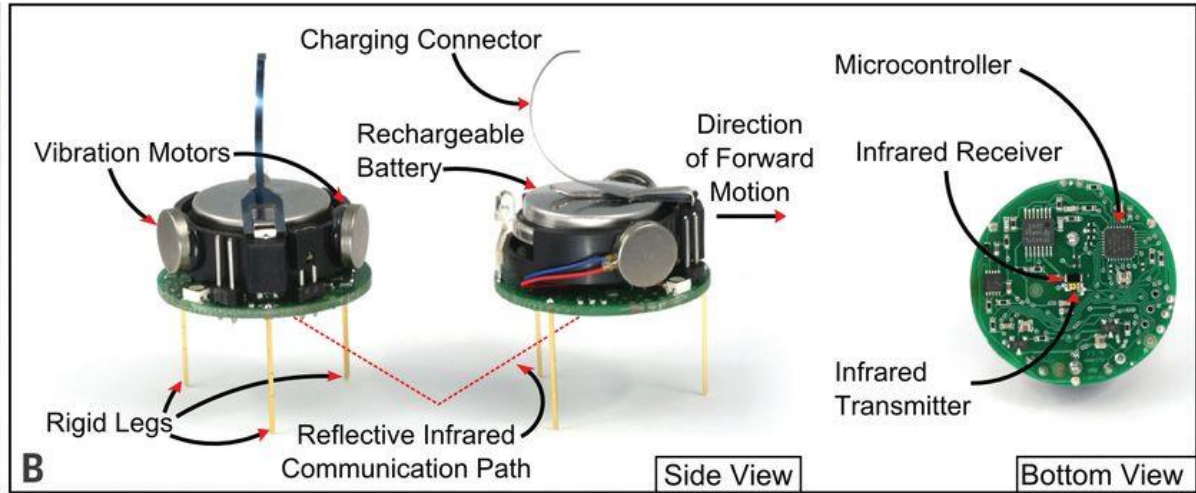
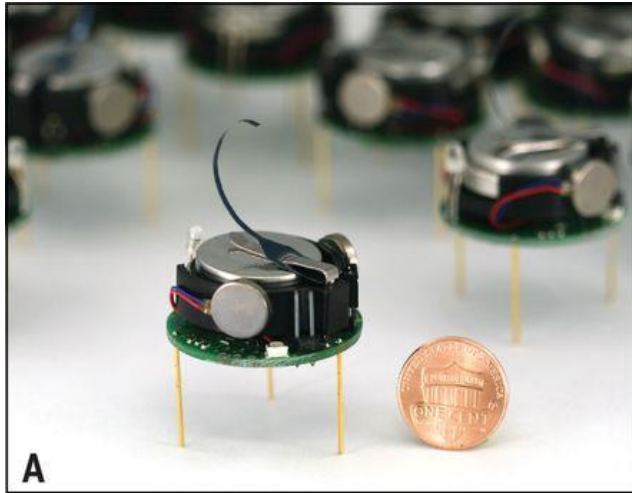


Fig. 14 Self-organized flocking with seven Kobots. Starting from a connected but unaligned state, Kobots negotiate a common heading and move as a group in a constrained environment and bounce off a wall without losing their cohesion

- Is robust to noise, but find coherent swarm size depends on virtual heading sensor range: noise in system prevents long-range order emerging from short-range interactions.
- Large flocks possible with just a few long-range interactions or with some common homing information.

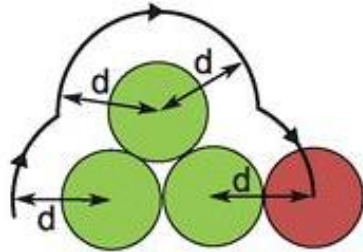
Self organised construction Kilobots (Rubenstein et al.2014)



Local communication to localise and navigate

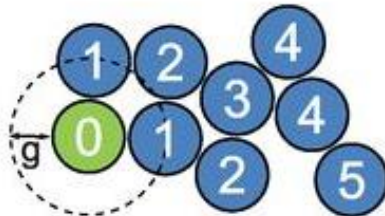
Edge-following

A robot (red) moves by maintaining a fixed distance 'd' to the center of the closest stationary robot (green).



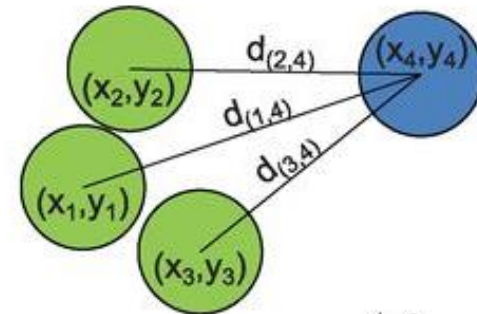
Gradient formation

Each robot sets its gradient value to 1 + the minimum value of all neighbors closer than distance 'g'. The source robot (green) maintains a gradient value of 0.



Localization

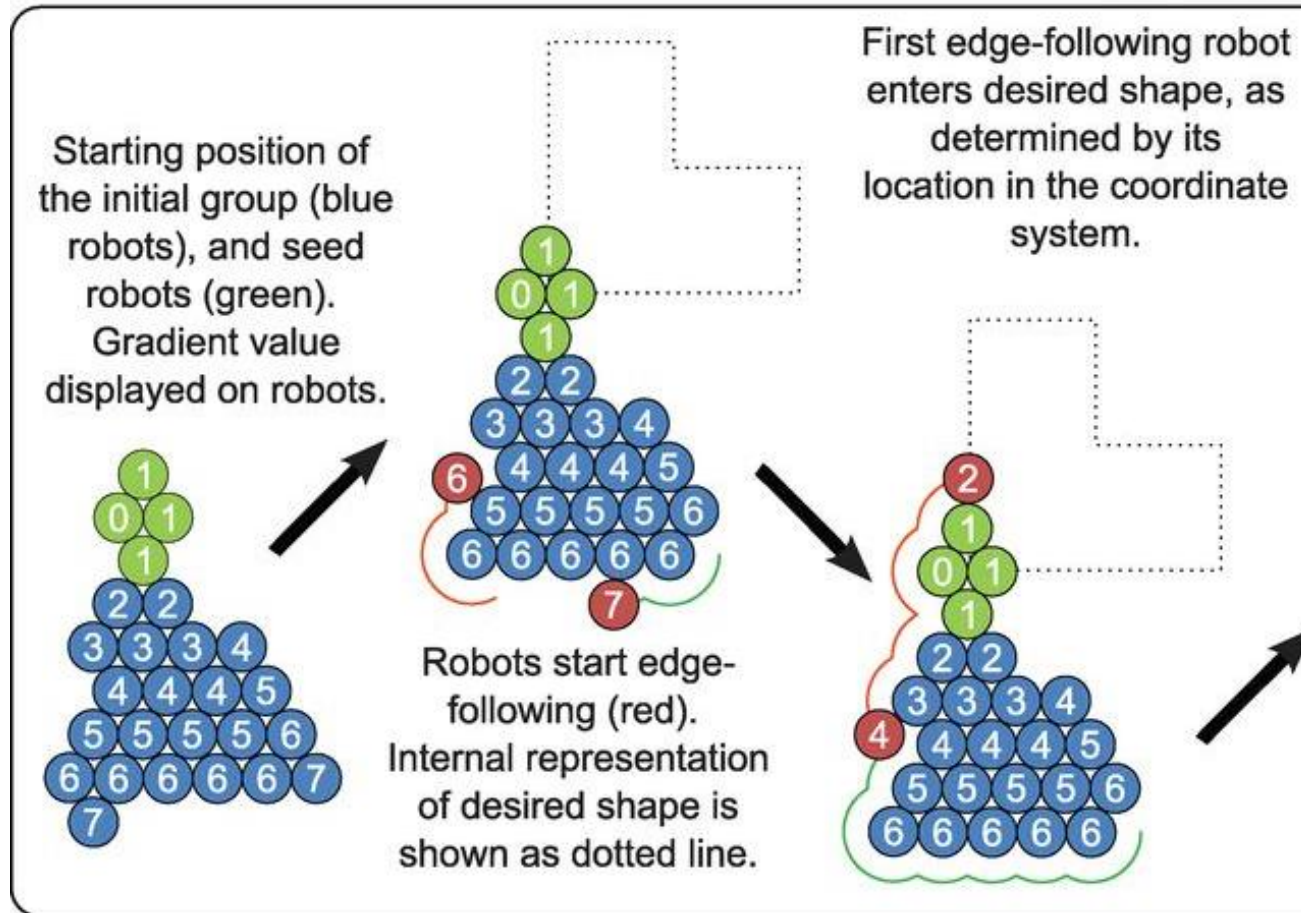
A robot (blue) determines its position in the coordinate system by communicating with already localized robots (green).



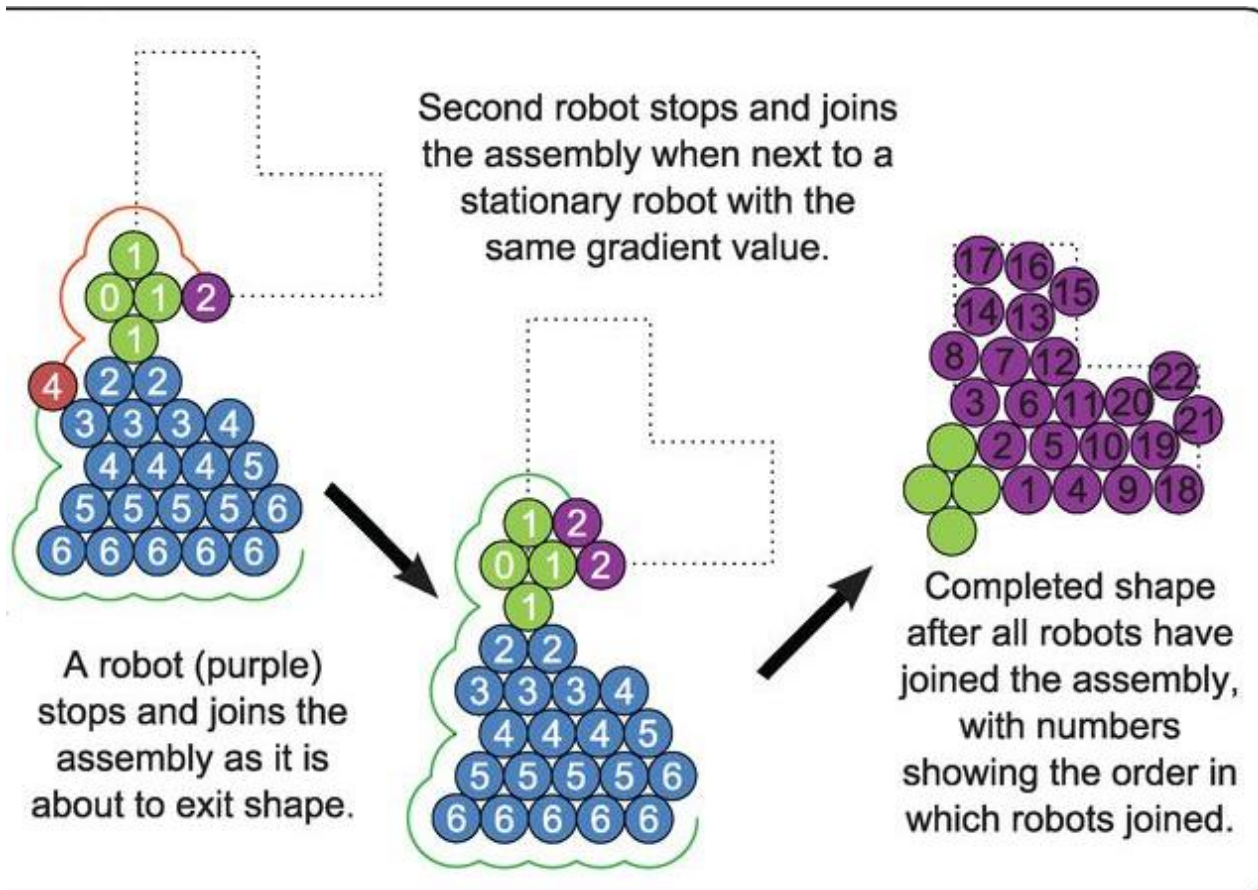
$$(x_4, y_4) = \min_{x_4, y_4} \left(\sum_{i=1}^3 |d_{(i,4)} - \alpha_i| \right)$$

$$\text{where } \alpha_i = \sqrt{(x_i - x_4)^2 + (y_i - y_4)^2}$$

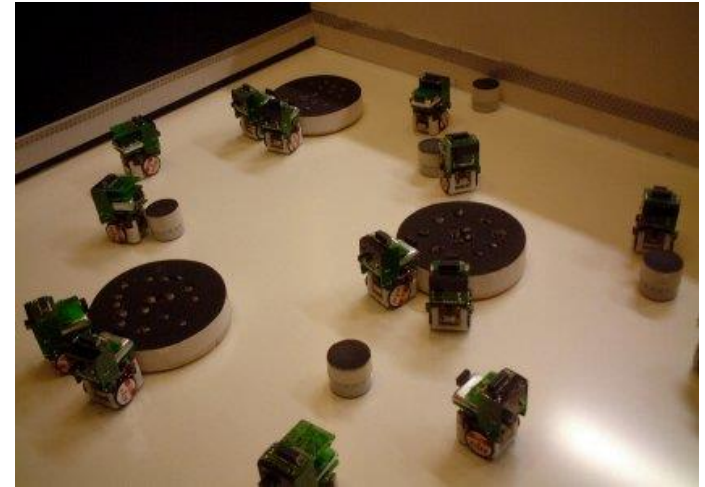
Kilobots (Rubenstein et al.2014)



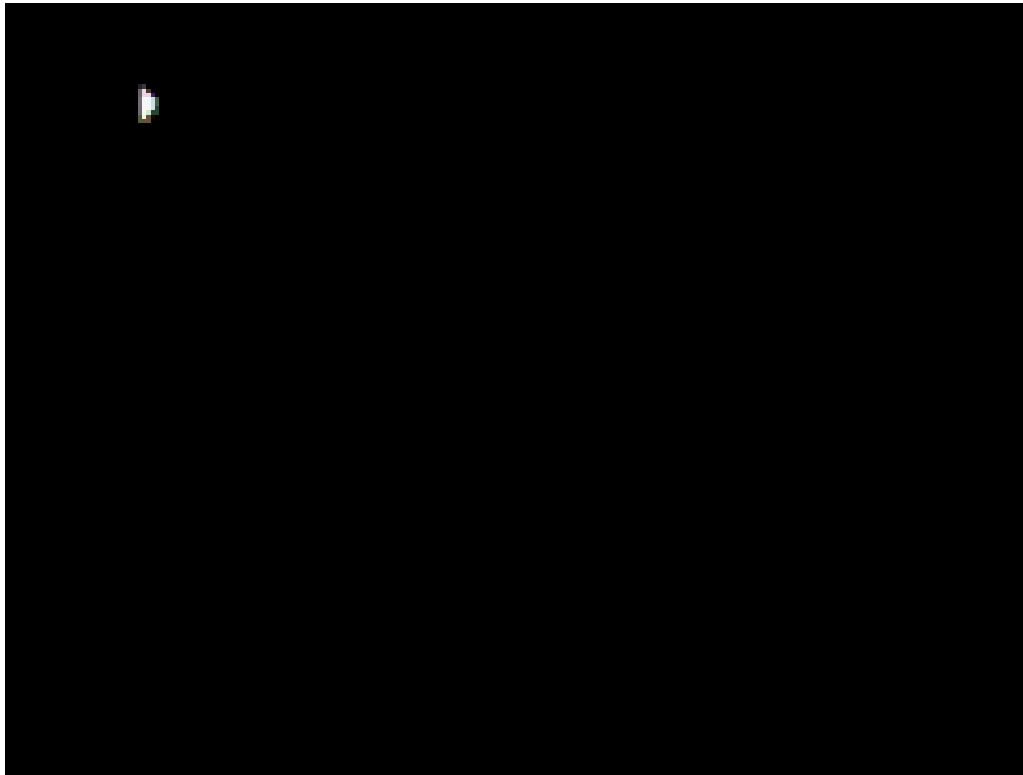
Kilobots (Rubenstein et al.2014)



- Basic task allocation assumes all robots can do all tasks and just need to distribute them effectively, then work separately.
- More complex scenarios:
 - Task might require complex continuous interaction between two or more robots.
 - Robots could be heterogeneous.
 - Robots could be interacting with other technologies, or humans (or animals).



Inverse flocking: modelling duck behaviour by simple flocking rules to produce sheepdog control algorithm
(Vaughan et al 2000)



References

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