SWARM ROBOTICS: PART 2

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PRINCIPLE:

SELF-ORGANIZATION

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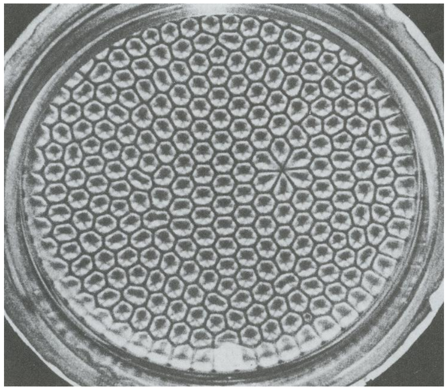
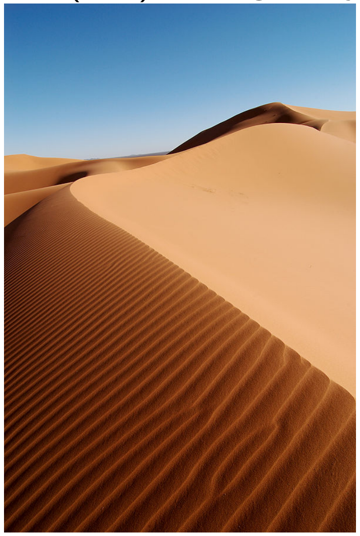
- "Self-organization is a set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lower-level components."
  - Bonabeau, E., Dorigo, M., & Theraulaz, G. (1999). Swarm intelligence: from natural to artificial systems
- Individual ants, bees, termites, and robots interact locally… yet a global pattern emerges

SO in Non-Biological Systems

Self-Organization can be observed in non-biological systems, for example in the formation of Bérnard convection cells (left) or regularly space ridges in dunes (right).





The difference in biological systems is that the interacting components in biology are typically much more complex than in non-biological systems (oil molecules, sand grains). Also, physical laws are in effect for both, but biological systems also adhere to behaviours that are learned and/or genetically programmed.

Mechanisms for SO

SO is supported by the following mechanisms:

Positive feedback (amplification) Mechanisms that encourage certain quantities or patterns to grow. Recruitment of other members of the swarm to join in some activity is an example.

Negative feedback (inhibition) Mechanisms that encourage certain quantities or patterns to shrink. Negative feedback can be explicit such as when one agent causes another to inhibit their behaviour, or it can be an implicit result of resource limits.

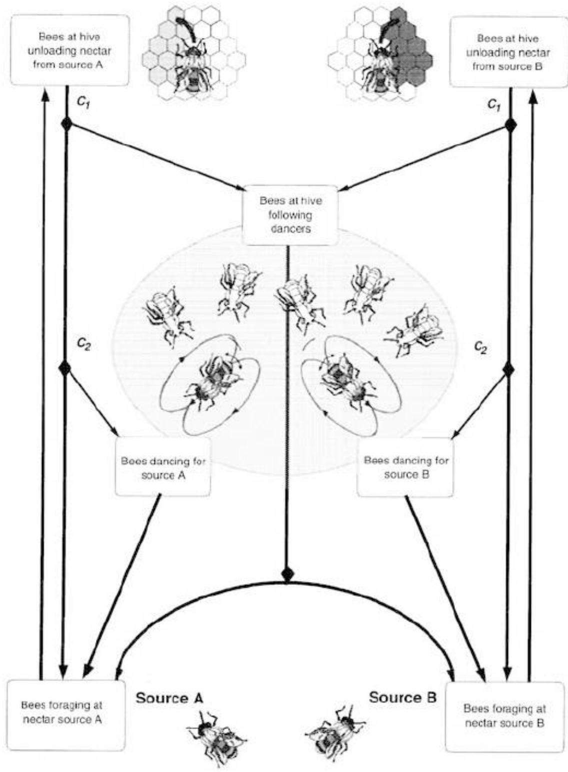
Multiple interactions The global structure or pattern arises over time through multiple interactions between components/agents.

We will see instances of these mechanisms in the following examples...

Example: Honeybee Foraging

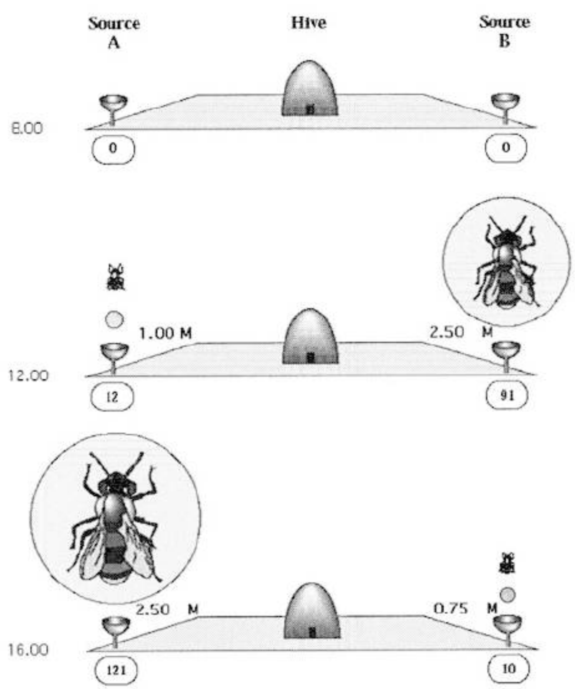
Honeybees gather nectar from flowers then return to the hive, give up the nectar to another bee. The bee will then do one of the following:

- Perform a ‘waggle dance’ (see right) indicating the direction and distance of the nectar source which tends to recruit other bees to that source.
- Continue to forage from her previous source without dancing.
- Abandon her previous source and follow another bee’s waggle dance, leading her to that source.



This schematic illustrates the choices (c_1 and c_2) open to a bee returning to the hive from a food source.

These choices are influenced by the perceived quality of the two food sources. Bees returning from high-quality food sources have a higher probability of dancing to support that source.



Performing the waggle dance to lead other bees to the same food source is an example of positive feedback that amplifies the selection of a large food source over a small one.

In this experiment food source B is more plentiful in the morning (8:00-12:00) but food source A is more plentiful in the afternoon (12:00-16:00). Consequently, B attracts more bees in the morning and A attracts more in the afternoon.

OBJECT CLUSTERING

ANT CEMETARY CONSTRUCTION

- Biologists have noticed many fascinating examples of social insects organizing their environments
- e.g. Colonies of ants will cluster dead ants together, seemingly without any planning or supervision
- A computational model was proposed to explain this behaviour:
  - [Deneubourg, J. L., Goss, S., Franks, N., Sendova-Franks, A., Detrain, C., & Chrétien, L. (1991, February). The dynamics of collective sorting robot-like ants and ant-like robots. In *Proceedings of the first international conference on simulation of adaptive behavior on From animals to animats* (pp. 356-363).]

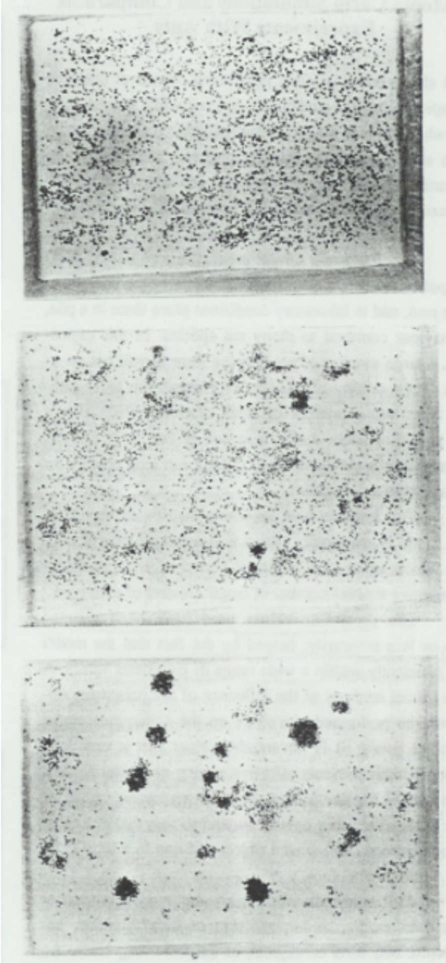
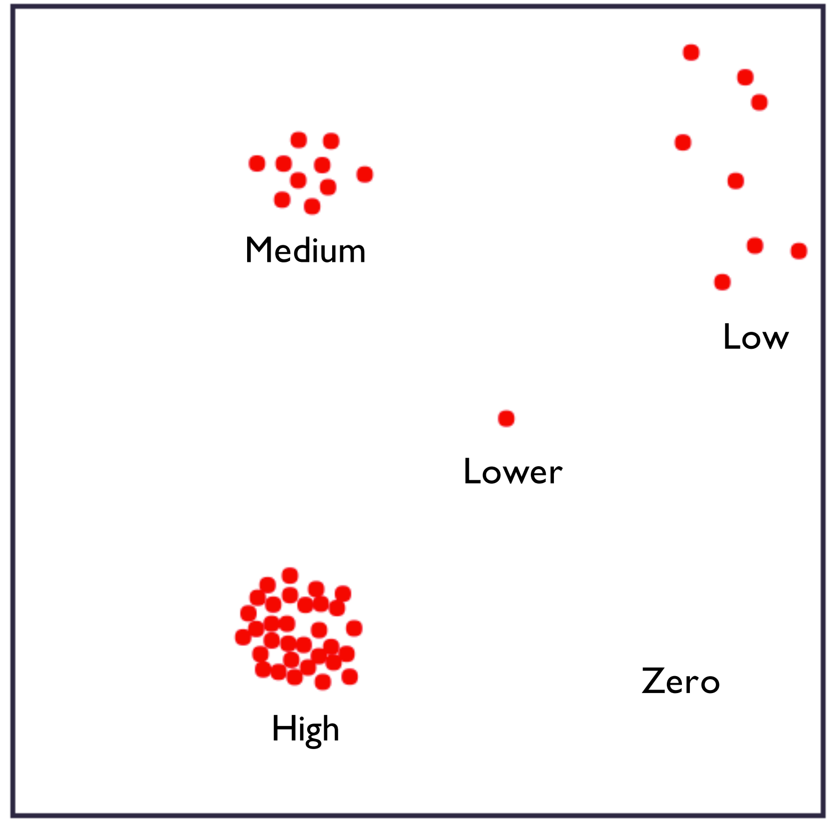


Fig. 2. Clustering in a colony of *Pheidole pallidula.* 4000 corpses were placed on a 50x50cm arena, and photos taken at time 0, 20 and 68 hrs. Small evenly spaced clusters rapidly form, and later merge into fewer larger clusters.

- Deneubourg et al's model:
  - Agents measure **local object density** by maintaining a short-term memory and counting the number of recent object appearances
  - Agents walk randomly and pick-up or deposit objects as a probabilistic function of local object density

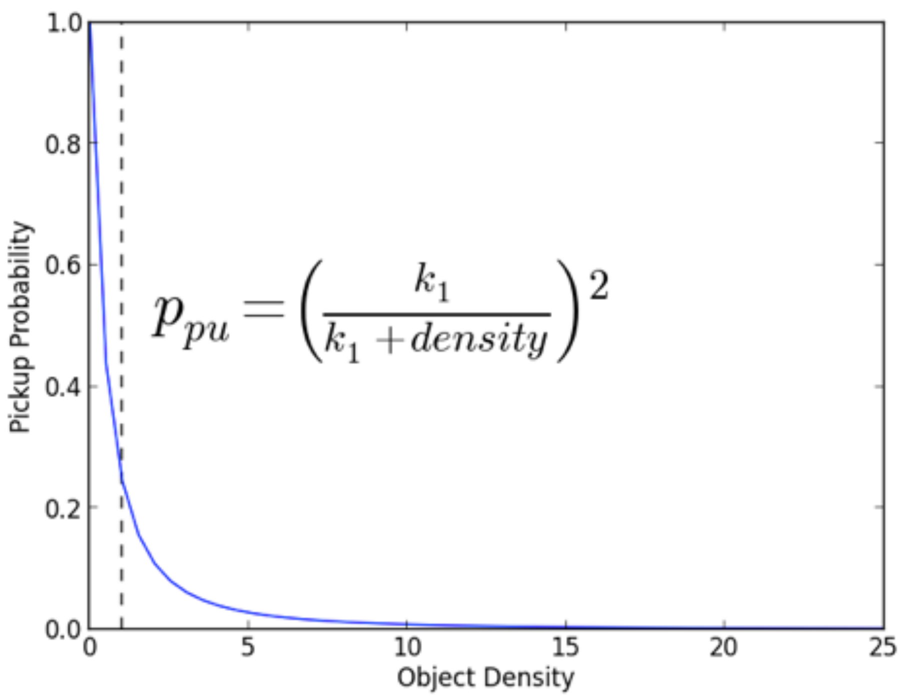
Density	Pick-up Probability (if not carrying)	Deposit Probability (if carrying)
Low	High	Low
High	Low	High

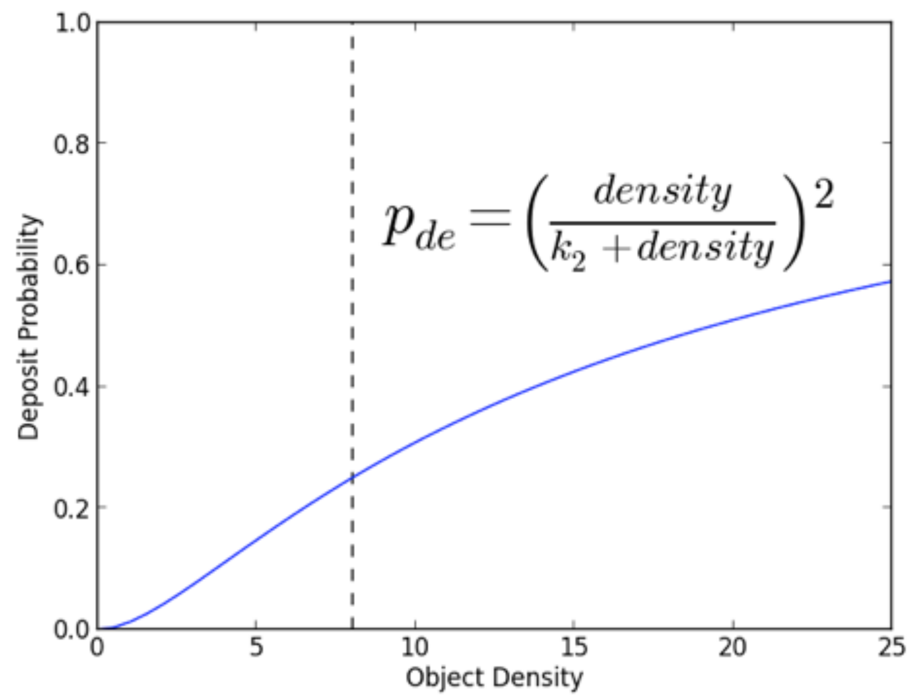
Local object density (cartoon version)



Not carrying

Carrying





- Experiments on the computational model closely match the results of biological experiments
- But we have to be careful:
  - Similarity of results does not necessarily imply similarity of method

Left: Computer Model

Right: Biological Experiment

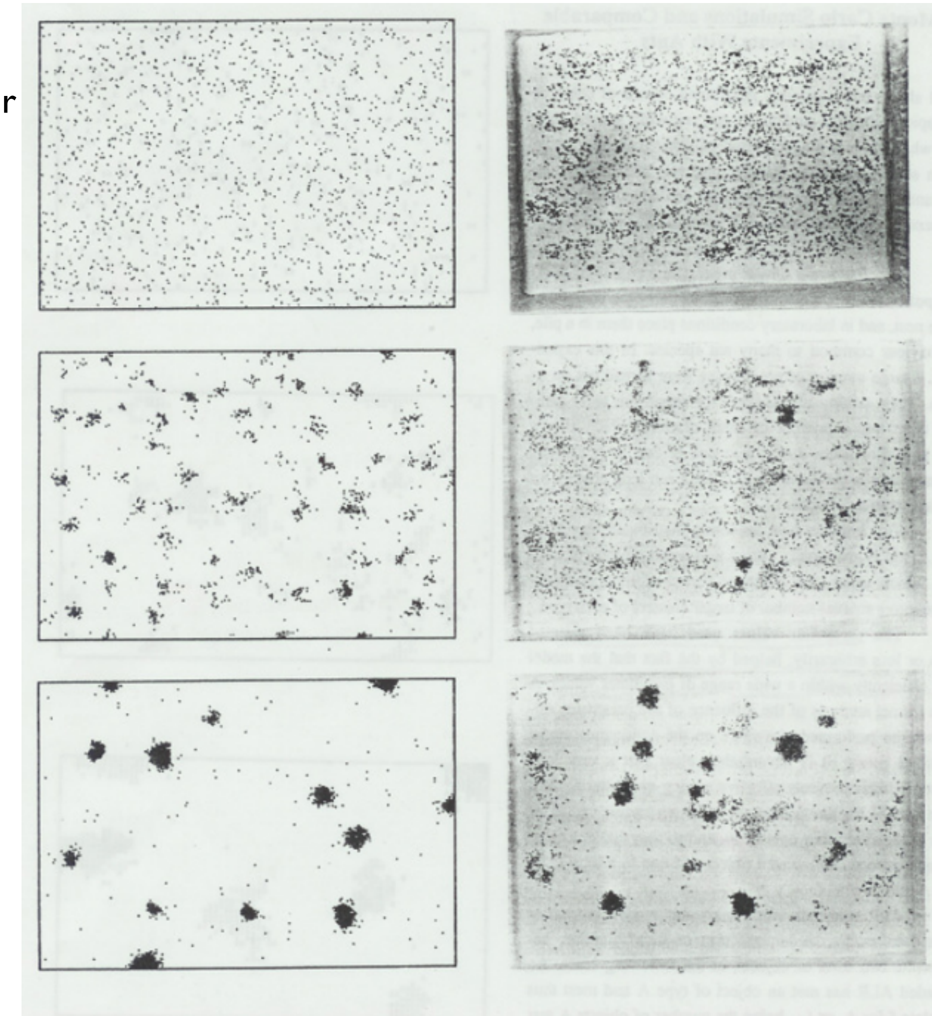


Fig. 1. Clustering after 1, 100000 and 2000000 steps. 100 ALRs, 1500 objects, $k^{+}=0.1$, $k^{-}=0.3$, m=50, e=0, space=290x200 points. Small evenly spaced clusters rapidly form, and later merge into fewer larger clusters.

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.

BECKERS ET AL

- Beckers et al. wrote a paper detailing their experiments in swarm robotic clustering
  - Beckers, R., Holland, O. E., & Deneubourg, J. L. (1994, July). From local actions to global tasks: Stigmergy and collective robotics. In *Artificial life IV* (Vol. 181, p. 189).
- Unlike the [Deneubourg et al., 1990] model, the robot's pick-up / deposit behaviour is implicit

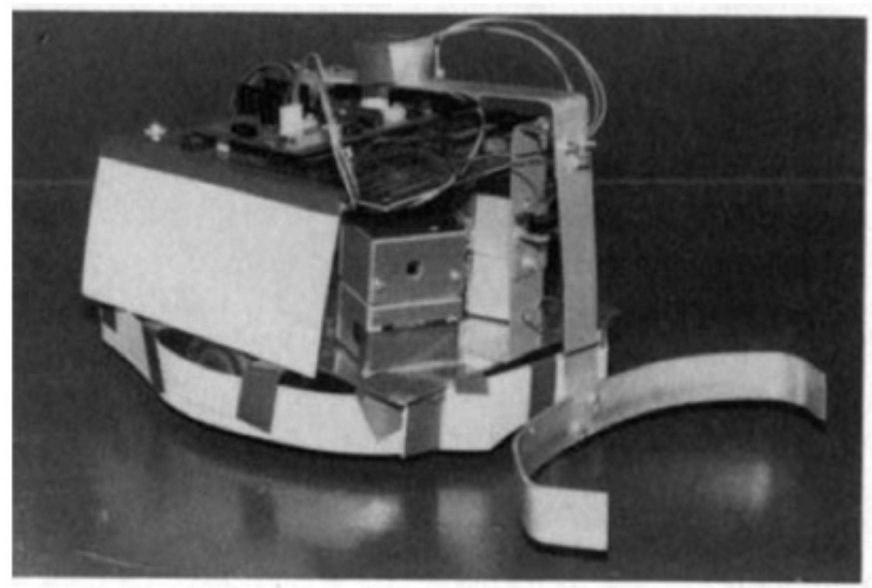


Figure 1: Robot equipped with a gripper for object Gathering. Experiments were carried out with from 1 to 5 robots of the same type,

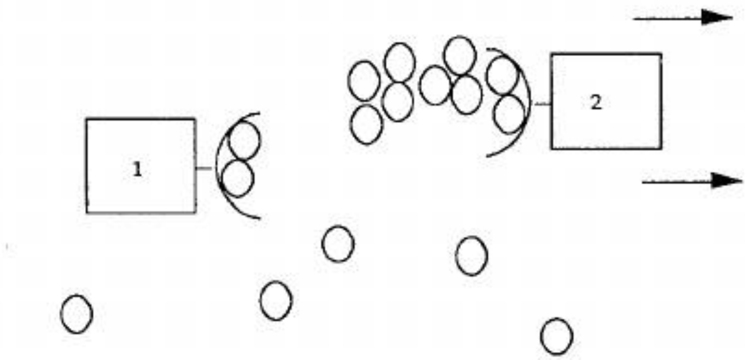


FIGURE 4.15 Robot 1, because it has only two pucks in its C-shaped gripper, continues to move in a straight line. Robot 2, with three pucks in its gripper, is encountering a cluster: its microswitch is activated by the gripper, so that the robot leaves the pucks next to the cluster.

- C-shaped gripper passively collects pucks
- Infrared sensors detect obstacles (walls, other robots)
  - Behaviour: Triggers random turn away from obstacle
- Force sensor detects that gripper is pushing against three or more pucks
  - Behaviour: Triggers backup, then a random turn, resulting in the pucks being left behind (i.e. deposited)
- If no behaviour is triggered, the robot just moves straight

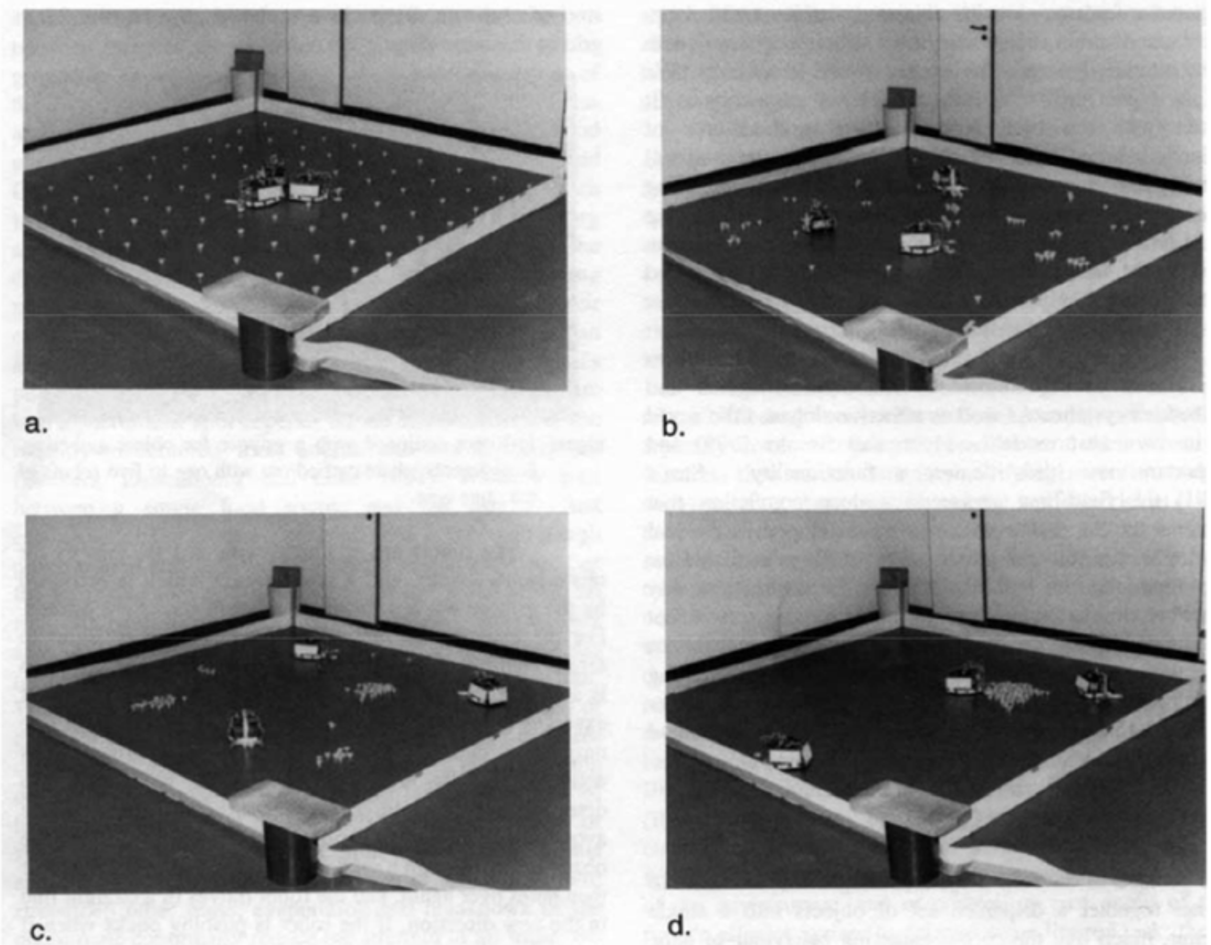


Figure 2. The initial setup (a) and time evolution of a typical experiment involving a group of three robots. Phase 1 (b), occurring after approximately 10 min, is characterised by a large number of small clusters containing from 1 to 10 pucks. In Phase 2 (c), some clusters grow rapidly and the environment becomes more heterogeneous. Finally, Phase 3 (d) is characterised by the competition between a small number (2 – 3) of large clusters and evolves towards the clustering of all objects in one pile.

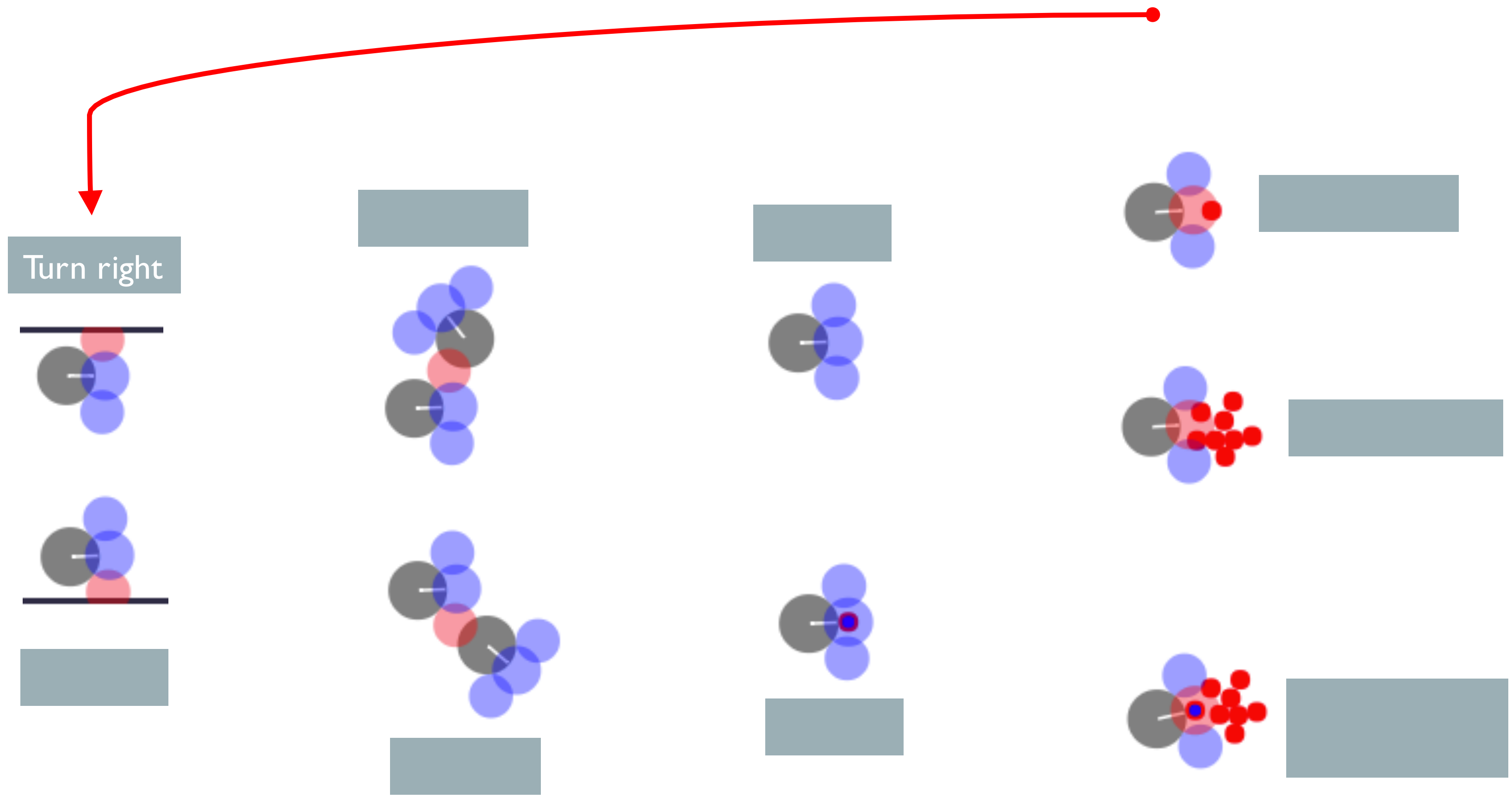
- Unlike Deneubourg et al. there is no explicit sensing of local object density
- Yet when a high density area is encountered, the robot tends to further increase density by backing up and leaving its pucks behind
  - POSITIVE FEEDBACK:
    - Larger clusters are encountered more often, triggering further growth
  - NEGATIVE FEEDBACK:
    - When smaller clusters are encountered their pucks are taken away

CLUSTERING IN WAGGLE

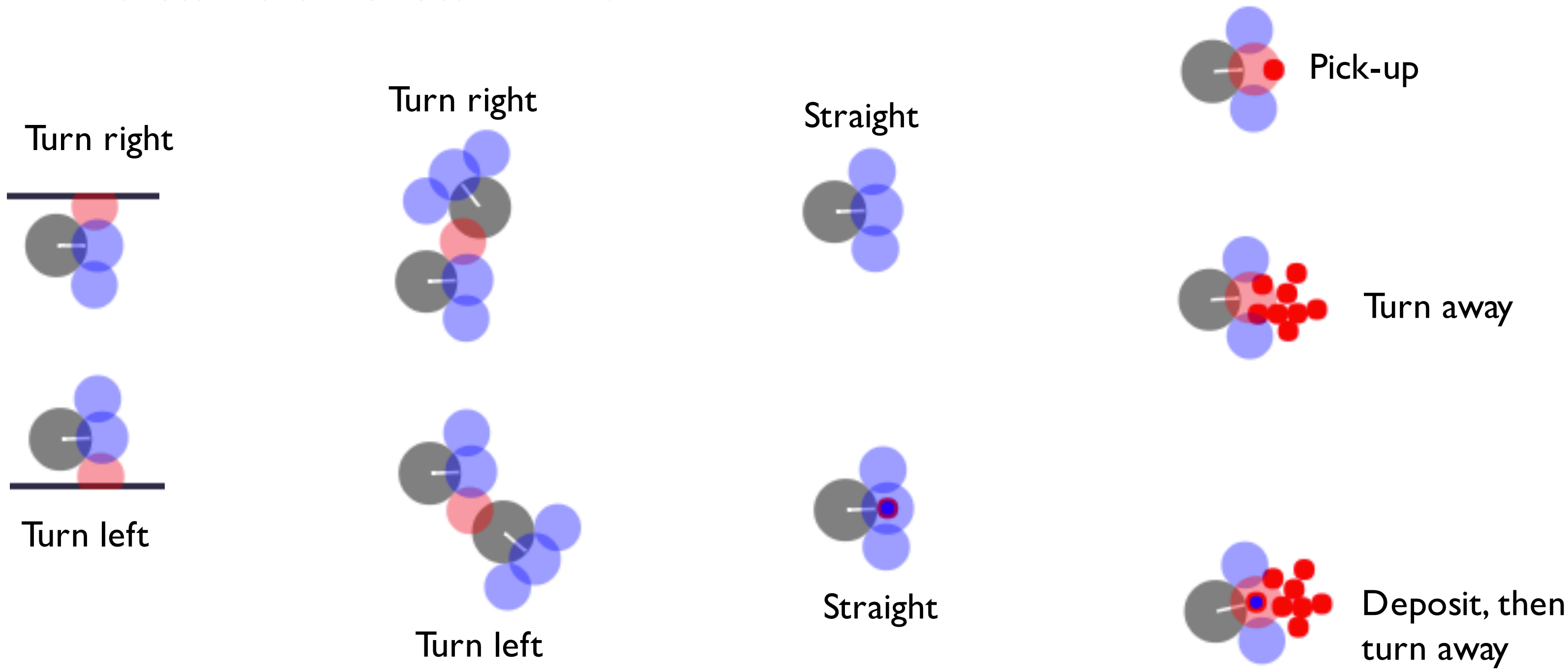
- The next task will be to consider a number of different possible sensor states and decide on reactions for each one
- We'll have to consider different numbers of pucks detected by the robot and decide whether they represent low or high density

- For simplicity, lets say that a single puck is low-density and two or more pucks is high-density

- Fill in the blanks with the choices the robot should make; e.g.

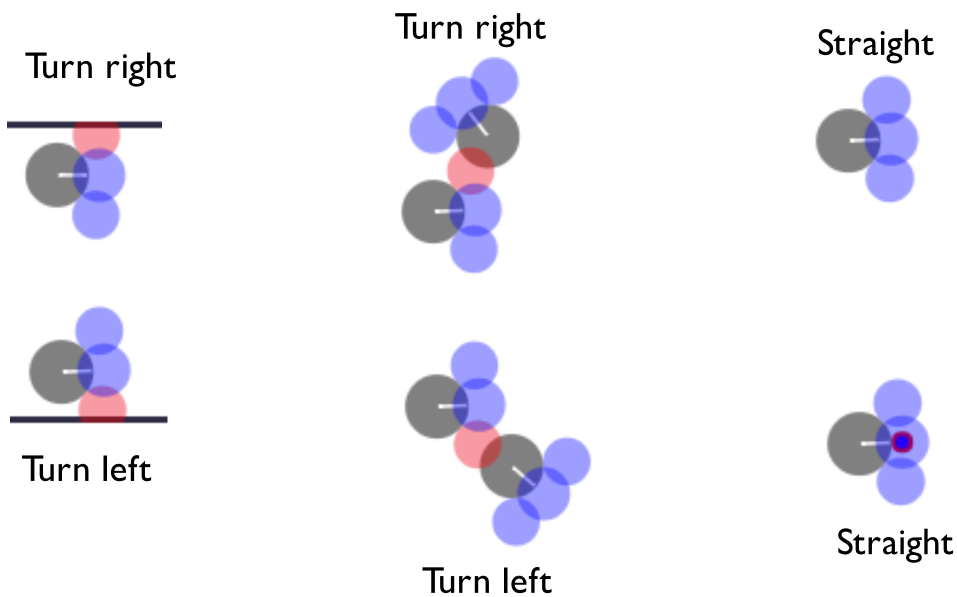


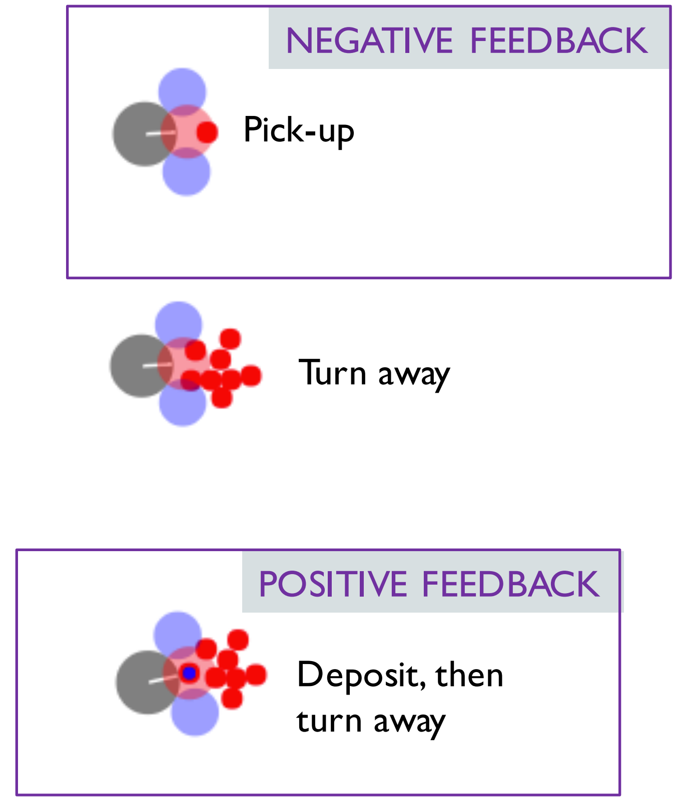
- The answers are shown here:



- Notes:
  - To turn away by a fixed angle, use both “Set speeds” and “Hold speed”
  - There are conditions not shown such as combinations of obstacles and pucks

- Why does this work?





- The other behaviours are necessary but only these two have a direct impact
- Larger clusters attract more deposits than smaller clusters, leading to further growth and the gradual absorption of smaller clusters:
  - Kazadi, S., Abdul-Khaliq, A., & Goodman, R. (2002). On the convergence of puck clustering systems. *Robotics and Autonomous Systems*, *38*(2), 93-117.

EXERCISE #6 / A6, TASK 2

OBJECT CLUSTERING

Conditions:

Any number of robots and pucks

- Create a new controller that has the appropriate response for all of the conditions just described
- Beneath the simulation controls is a new plot called "Percentage Completion"
  - Details:
    - Computes the size of the largest cluster. Let this size be L
    - PC = 100 * L / (number of pucks)
- CHALLENGES:
  - With 10 robots and 30 pucks see how fast you can reach 60% completion

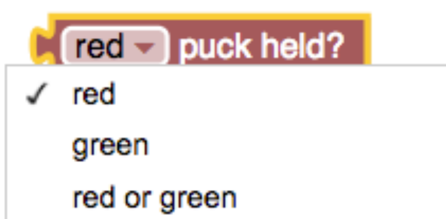
OBJECT SORTING

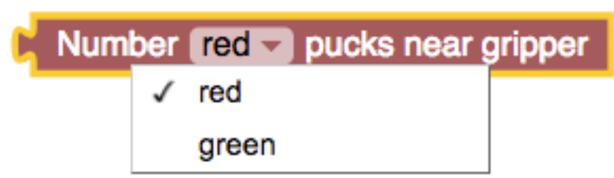
OBJECT SORTING

- Sorting objects is a natural extension of clustering
  - Clustering: One object type
  - Sorting: Two object types
- It has potential applications in recycling, mining, and warehousing
- Vardy, A., Vorobyev, G., & Banzhaf, W. (2014). Cache consensus: rapid object sorting by a robotic swarm. *Swarm Intelligence*, *8*(1), 61-87.

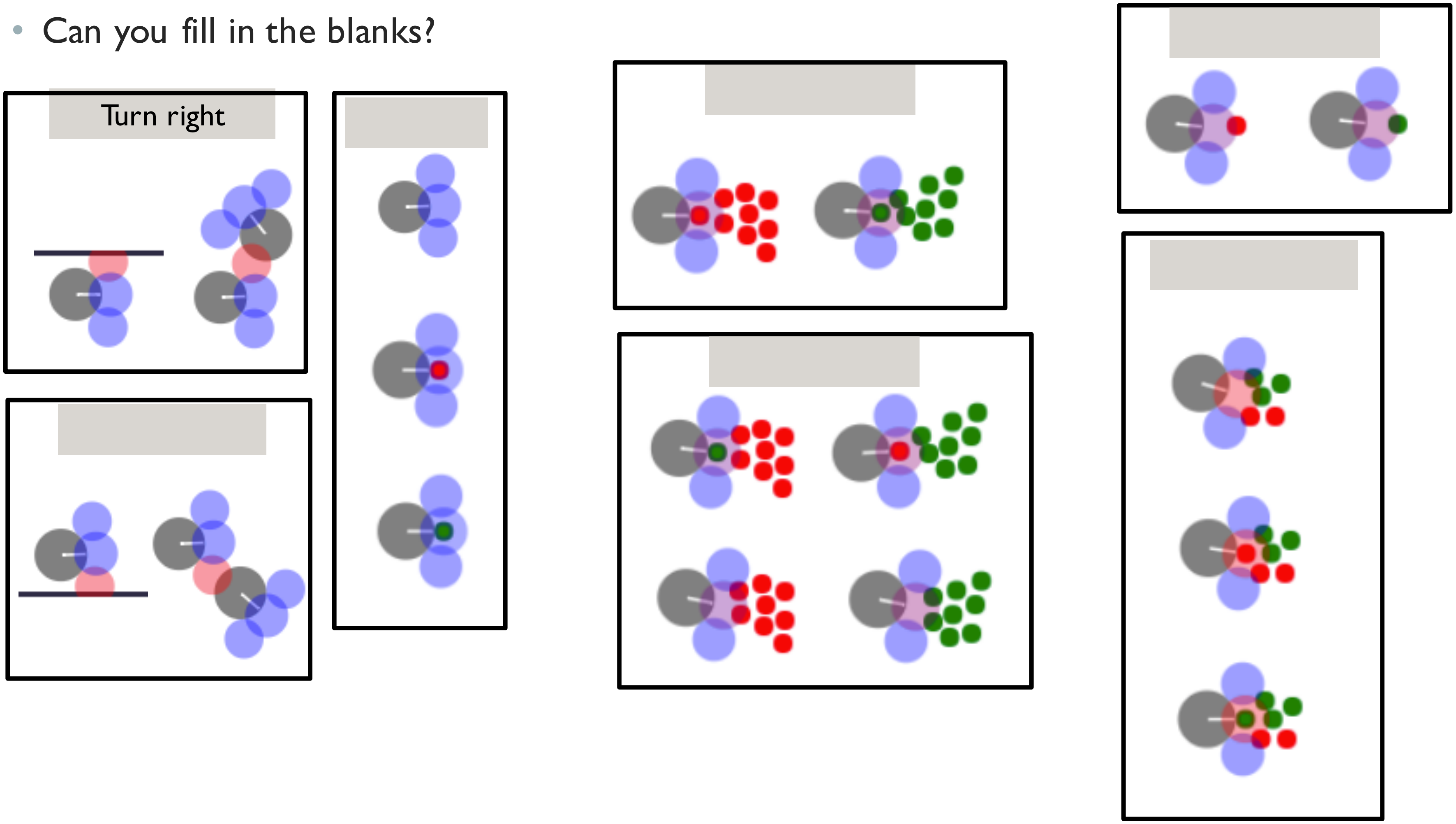
SORTING IN WAGGLE

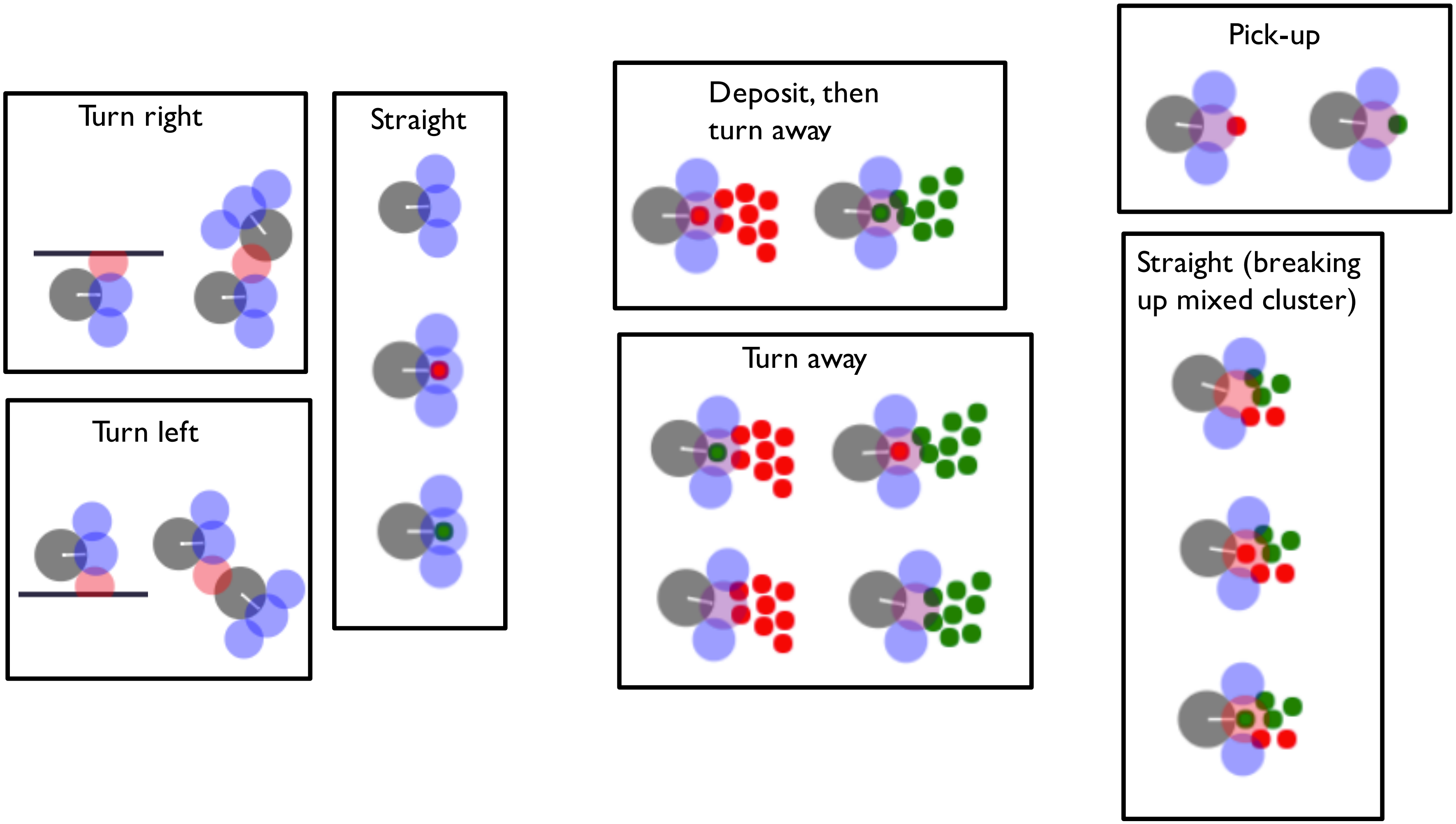
- Go to the main Waggle page (or just hit your browser's back button):
  - http://bots.cs.mun.ca/waggle/
- Select the **Sorting** level. Note that there are now two different colours of pucks available: red and green
- We will use the same sensor and action blocks as before, but will need to customize the "___ puck held" and "Number _____ pucks" blocks:





- When sorting two colors, we have more choices to make
- Can you fill in the blanks?




Turn right
Turn left
Straight
Deposit, then turn away
Turn away
Pick-up
Straight (breaking up mixed cluster)

EXERCISE #7 / A6, TASK 3:

OBJECT SORTING

Conditions:

Any number of robots and pucks

- Create a new controller that has the appropriate response for all of the conditions just described
- CHALLENGE:
  - With 10 robots, 30 red pucks, and 30 green pucks, reach 50% completion within 200 seconds