SWARM ROBOTICS
PART 5:
MICRO/MACRO PERSPECTIVE

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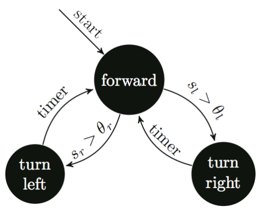
MICRO/MACRO PERSPECTIVE

- Here we follow the arguments and model presented in Chapter 3 of "Swarm Robotics: A Formal Approach" by Heiko Hamann.
- An essential question is to understand the relationship between the following two perspectives:
  - Microscopic: The behaviour of individual robots
  - Macroscopic: The behaviour of the swarm

MICRO PERSPECTIVE

- The micro perspective concerns the direct encoding of behaviour into the robot's controller.
- This behaviour could be encoded as a finite-state machine (FSM), neural network, decision tree, or any other similar framework.
- On the right is a FSM for a collision avoidance behaviour:
  - s_l and s_r are the left and right sensors and the theta values are thresholds which indicate that an object is too big (i.e. too close to the robot)



EXAMPLE: COLLECTIVE DECISION-MAKING

- Say there are two states: A and B
- The goal is to be in the majority state, whether it is A or B
- We define some useful quantities:
  - **N**: Number of robots
  - **a**: Number of robots in state A
  - **b**: Number of robots in state B
  - (Note that **N = a + b**)
  - **α = a / N**: Proportion of robots in state A

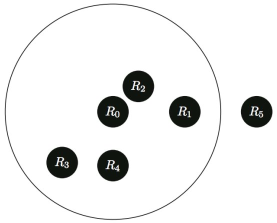
- Assume the states of neighbouring robots within a circle of radius r can be determined.
- For the example on the right, this is the neighbourhood of R_0:

$$\mathcal{N} = \{R_1, R_2, R_3, R_4\}$$

- The proportion of robots in state A is

$$\hat{\alpha} = \frac{\hat{a}}{|\mathcal{N}|+1}$$

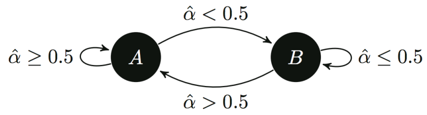
- Note that this includes whether the robot itself is in state A
- This is a local estimate of the global α which the robot can not measure directly



- If the system is "well-mixed" then perhaps $\alpha \approx \hat{\alpha}$
- But in general, $\alpha \neq \hat{\alpha}$

THE MICRO PERSPECTIVE

- The robot wants to be in the same state of the majority: state A or B
- It transitions to the other state based on whether A or B is in the local majority, as indicated by this FSM:



THE MACRO PERSPECTIVE

- First assume for simplicity that every robot has 2 neighbours: $|\mathcal{N}| = 2$
- Consider the probability of switching from state B to A, given by

$$P_{B \to A}(\alpha) = (1-\alpha)\alpha^2$$

- The first term is the probability of a robot being in state B (only robots in state B can switch to state A))
- The α^2 term indicate the probability that both neighbours are in state A
- Similarly, we have the probability of switching from A to B:

$$P_{A \to B}(\alpha) = \alpha(1-\alpha)^2$$

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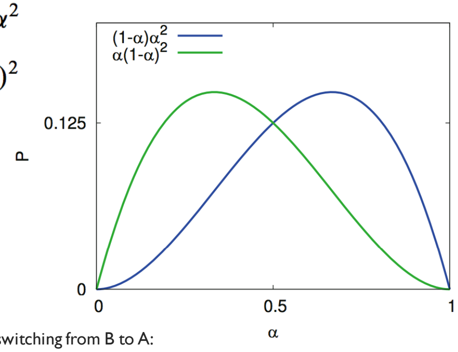

- Blue curve: Probability of switching from B to A:
  - Decreases after maximum because with a high proportion of A robots, there are fewer available to switch
  - Decreases before maximum because with a low proportion of A robots, local majorities are less likely

- Define a time step Δt such that about one robot switches state per step
- The change in proportion of A's evolves according to this equation:

$$\frac{\Delta\alpha(\alpha)}{\Delta t} = \frac{1}{N}((1-\alpha)\alpha^2) - \frac{1}{N}(\alpha(1-\alpha)^2)$$

- Left half:
  - The proportion of A's will decrease, eventually reaching zero
- Right half:
  - The proportion of A's will increase, eventually reaching N
- This simple system will always tend to favour the initial majority, but not all systems function in this way