Collective Robotics
Part 2: Short Journey Through Nearly Everything

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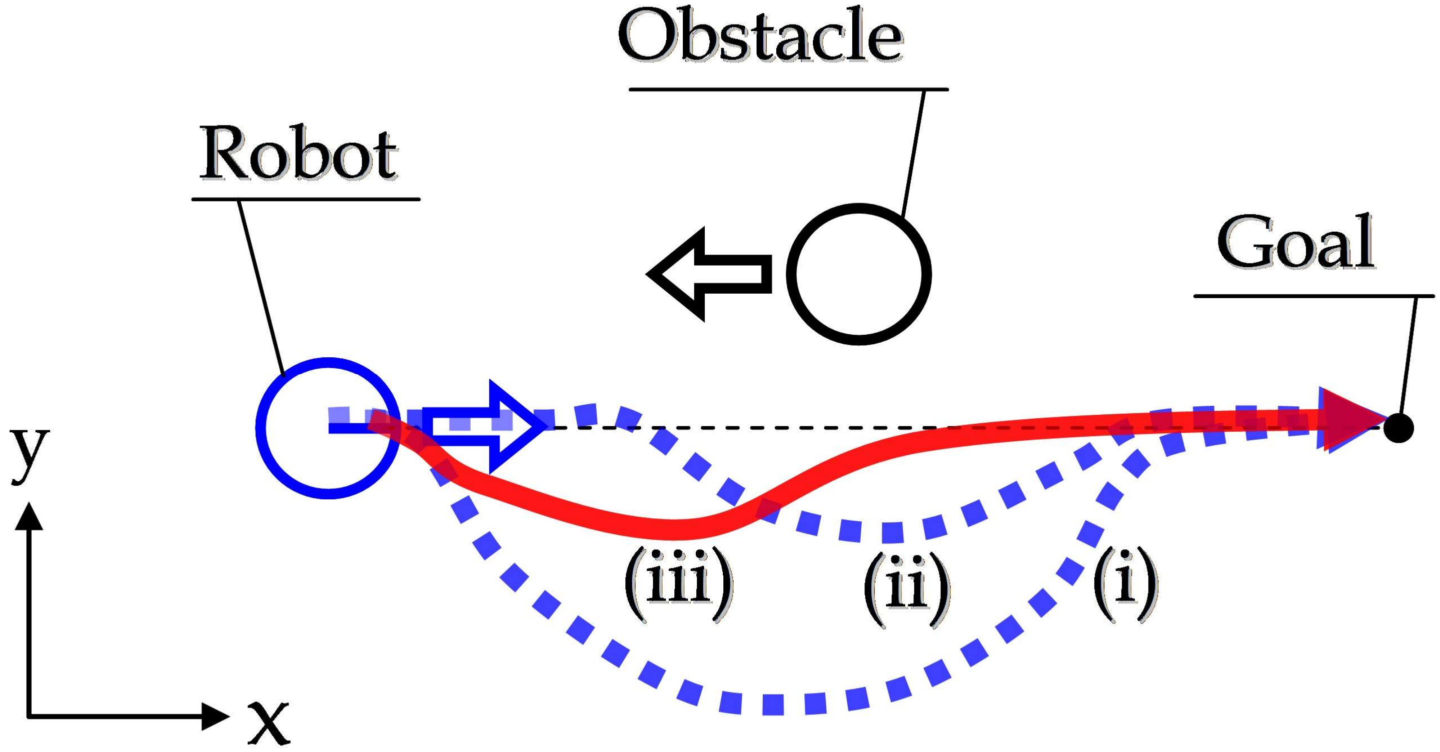
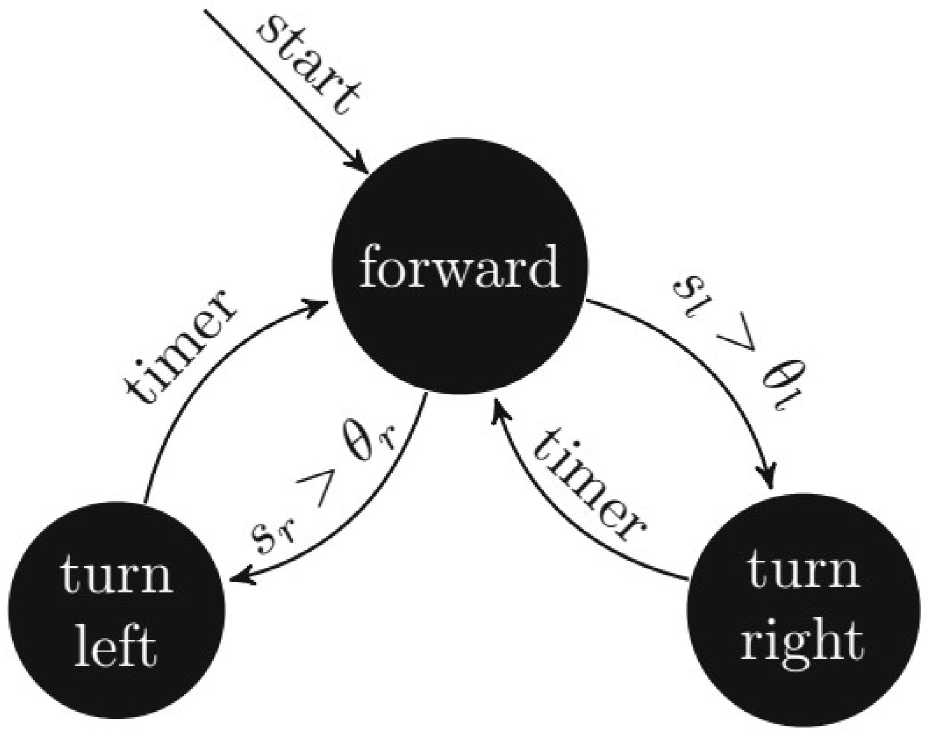
Simple task: collision avoidance



(Takafumi Suzuki and Masaki Takahashi)

Finite state machines as robot controllers (1/2)



Left sensor s_l

Right sensor s_r

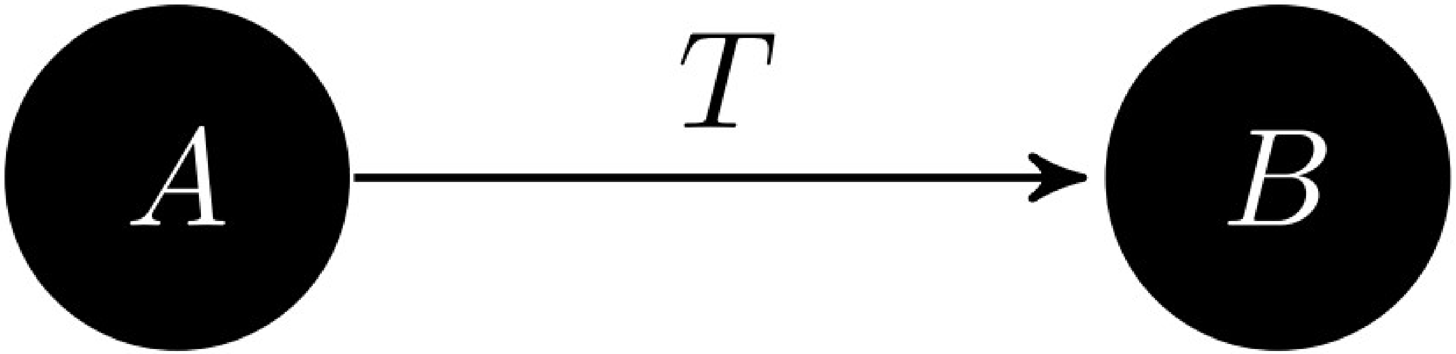
Threshold θ_r, θ_l

(big values mean a close-by object was detected)

'timer' : the state is left when a certain time period has elapsed

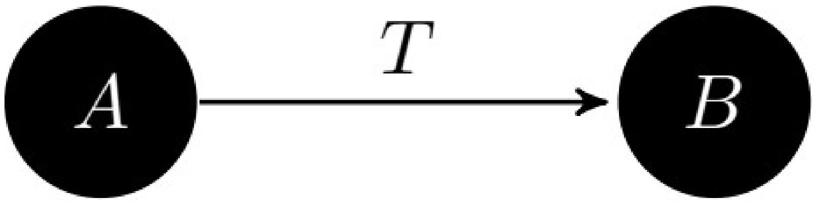
Finite state machines as robot controllers (2/2)

general case:



any condition T for the transition is possible

Simple population model



swarm size N

only two possible states: A and B

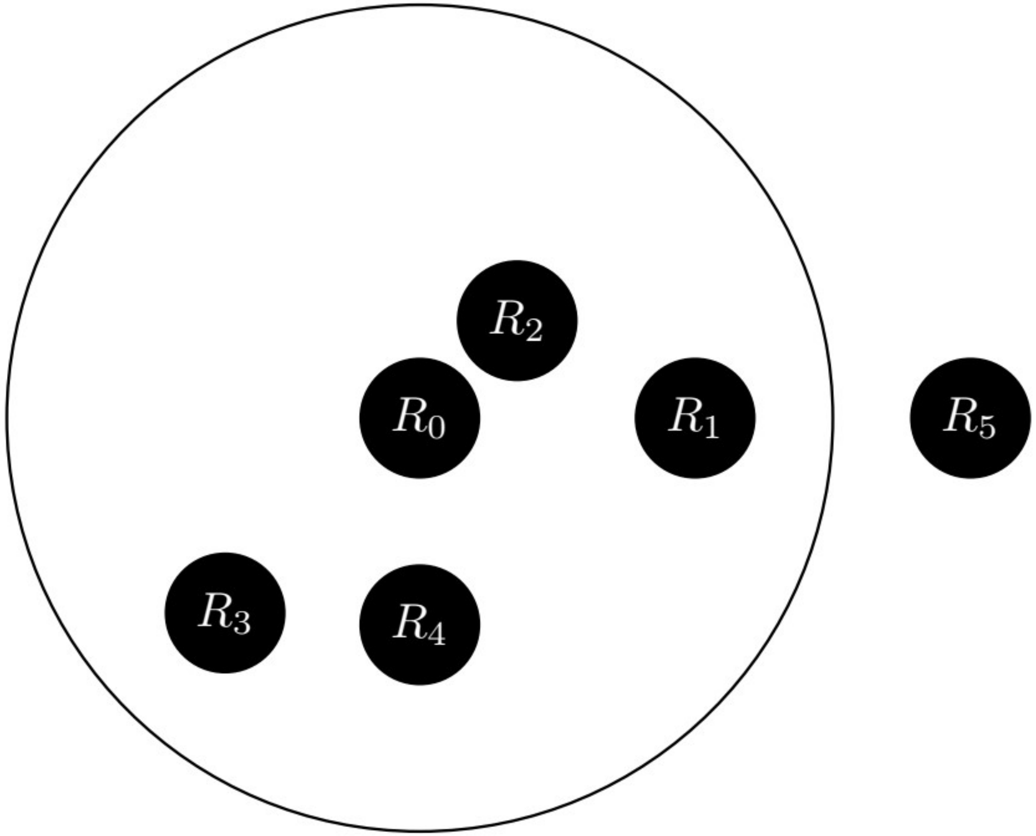
variable a counts robots currently in state A

variable b counts robots currently in state B

$N = a + b$

fraction of robots that are in state A: $\alpha = \frac{a}{N}$

State transitions & robot-robot interactions (1/2)



sensor range r

neighborhood of robot R_0 is:

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

State transitions & robot-robot interactions (2/2)

$\hat{a}$ gives the number of neighboring robots of robot R_1 plus itself that are currently in state A

$\hat{b}$ for state B

|N| is size of neighborhood

$$|N| + 1 = \hat{b} + \hat{a}$$

fraction of robots in state A :

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

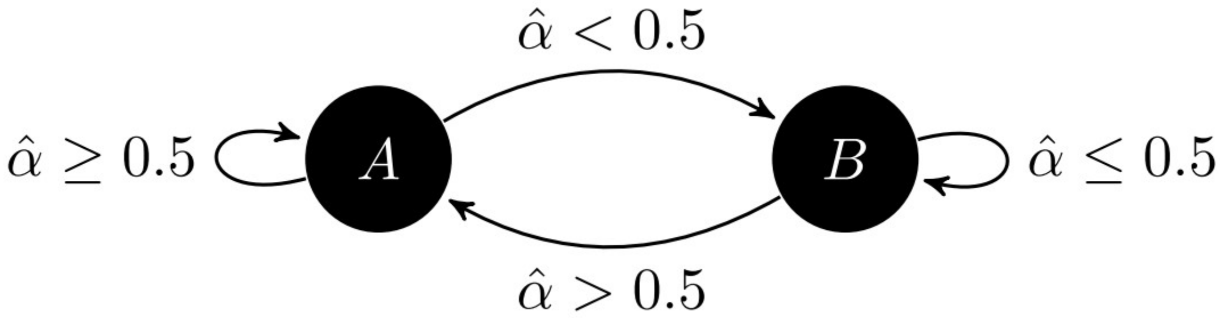
next:

say, a robot's state transitions between A and B

depend exclusively on $\hat{\propto}$

Minimal example: collective decision-making

task in collective decision-making: find a consensus
(100% of the robots in the swarm agree on a decision)
we use $\hat{\alpha}$ and a threshold of 0.5:



majority rule: reinforce the current majority

Towards a macroscopic perspective

What's the effect on the swarm level?
we can interpret $\hat{\alpha}$ as a local measurement of the global situation α
⇒ local sampling (later)

generally: $\alpha \neq \hat{\alpha}$

could we hope for $\alpha \approx \hat{\alpha}$?
for a so-called 'well-mixed' system (without bias) we can assume in average: $\alpha \approx \hat{\alpha}$
but well-mixed assumption does often not hold!

this is a small taste of the ⇒ micro-macro problem (later)

A macroscopic perspective (1/2)

Measurement of $\hat{\alpha}$ is probabilistic

State transitions for a given $\hat{\alpha}$ are deterministic

We have a look into the combinatorics of all possible neighborhoods

For simplicity, small neighborhood of |N| = 2

probability $P_{B\to A}$ to switch from B to A is

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

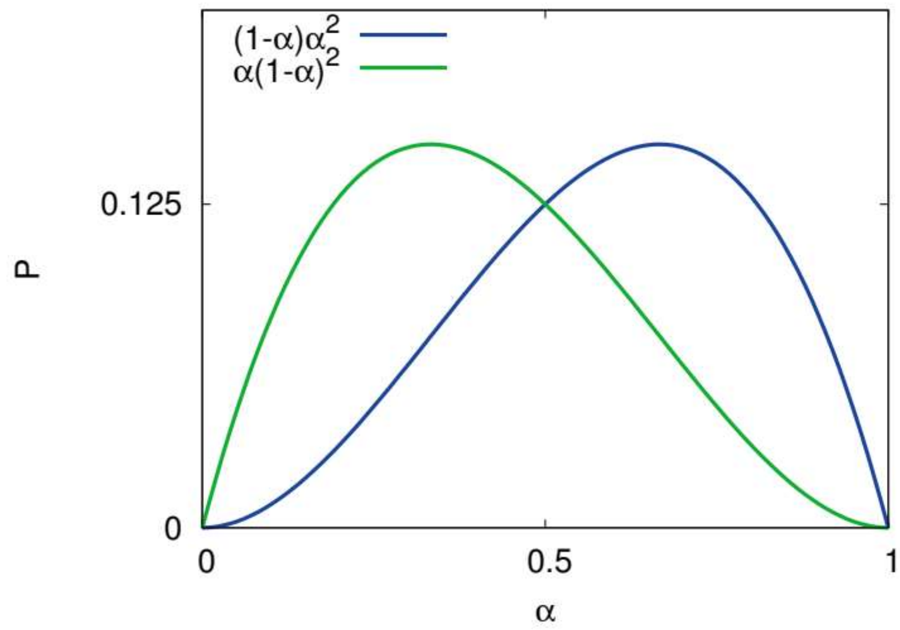
probability to switch from A to B is fully symmetric

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

A macroscopic perspective (2/2)

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

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



Expected macroscopic dynamics

How does the swarm fraction α develop over time?

normalized by a considered time interval Δt

expected change $\Delta\alpha$ of α :

$$\frac{\Delta\alpha(\alpha)}{\Delta t} = \frac{1}{N}\left((1-\alpha)\alpha^2\right) - \frac{1}{N}(\alpha(1-\alpha)^2) \qquad (3)$$

Dynamics & feedbacks

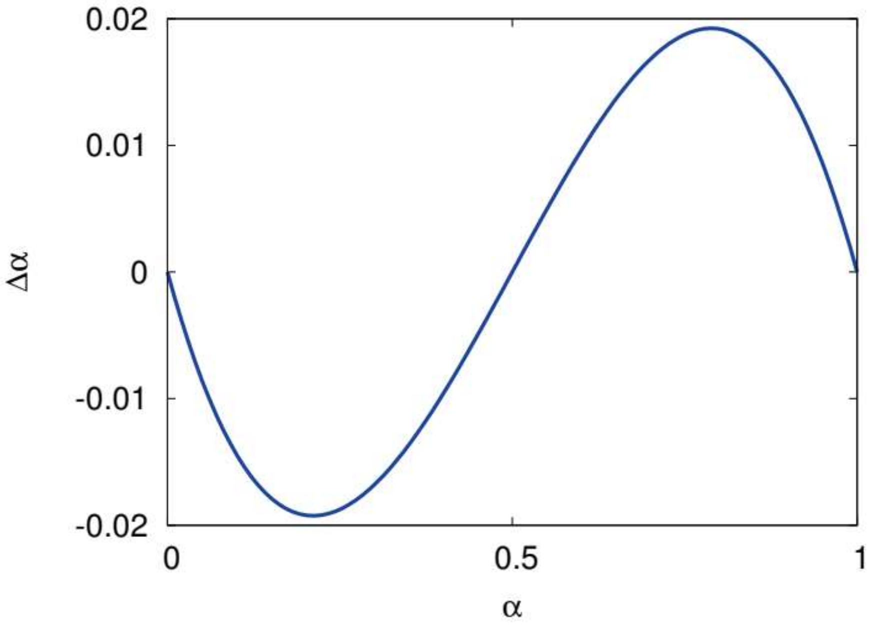
$$\frac{\Delta\alpha(\alpha)}{\Delta t} = \frac{1}{N}\left((1-\alpha)\alpha^2\right) - \frac{1}{N}\left(\alpha(1-\alpha)^2\right)$$

here for Δt = 1, N = 10

1/N : assumed switching rate of one robot per per time step

What kind of feedback do we see here?

positive feedback only!



Self-organizing system

Does this robot swarm qualify as self-organizing system?

positive feedback ✓
negative feedback ✗
initial fluctuations ✓
multiple interactions ✓
balance between exploitation and exploration ✗

Discussion : How could exploration be included?