Autonomous agents
Lecture 5, 20160201

Animal behavior: Lessons for robotics

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Today’s learning goals

- After this lecture you should be able to
  - Describe and exemplify the bottom-up and top-down approaches to animal behavior
  - Define and exemplify the concept of reflexes
  - Define and exemplify the taxis and kinesis concepts
  - Define and describe a model of E. Coli behavior
  - Define and exemplify the concept of fixed action patterns
  - Describe the navigation behavior of *Cataglyphis Fortis*

Why study animal behavior

- Animal behavior is highly relevant to (behavior-based) robotics, since
  - .. the behavior-based approach is inspired by biological systems in the first place.
  - .. (simple) animal behaviors can often be translated to implementable sets of equations for autonomous robots.
  - .. animals are experts at allocating their time in a near-optimal way (relevant for decision-making)

Bottom-up vs. top-down approaches

- Approaching animal behavior in two different ways:
  - Bottom-up: Consider the level of individual neurons in the brain of the animal. Example: Habituation and sensitization in Aplysia (studied in the SOA course).

Bottom-up vs. top-down approaches

- Approaching animal behavior in two different ways:
  - Top-down: Model the behavior by a simple set of equations (a phenomenological model).
  - Generally the most useful approach in robotics, and the one we will use in this course.
  - Examples of this approach will be given below (E. Coli behavior) as well as in the next lecture.

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Ethology

- The study of animal behavior.
- Four different kinds (levels) of behaviors:
  - Reflexes
  - Taxes and kineses
  - Fixed action patterns (FAPs)
  - Complex (adaptive) behaviors

Reflexes

- Automatic, involuntary reactions to stimuli.
- Not completely stereotyped:
  - Warm-up: Maximum intensity reached only after a while. (Example: scratch reflex in dogs)
  - Fatigue: Reduced intensity even if the stimulus remains unchanged. (Example: The movement of Sarcophagus larvae).

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Kineses

- Kinesis: Non-directional movement in response to a stimulus.
- Movement rate (rather than direction) dependent on the level of the stimulus.
- Example: Wood lice: Move less if the level of humidity is high.

Taxes

- Taxis: Orientation of motion towards some stimulus.
- Examples:
  - Phototaxis : Moving towards or away from light (cf. robots finding a charging station using an IR beacon!)
  - Chemotaxis: Moving towards a higher (or lower) concentration of a chemical. (Example: trail-following ants).
  - Thermotaxis: Movement along a temperature gradient (Example: Nematode worms searching for optimal soil).

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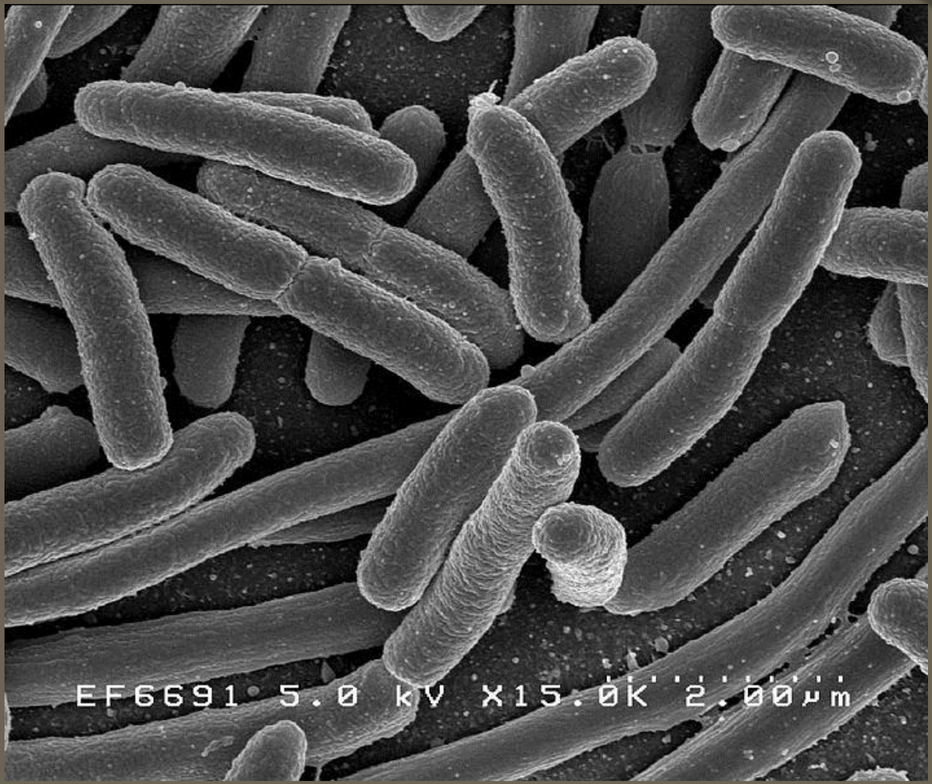
Top-down model of E. Coli behavior



Top-down model of E. Coli behavior

- Escherichia Coli (E. Coli) are rod-shaped bacteria.
- Commonly found, for example, in the lower intestine of animals (including humans).
- E. Coli are able to move towards a higher concentration of food, despite being to small to detect a spatial gradient! How do they do this?

Top-down model of E. Coli behavior

- E. Coli exhibit two distinct behaviors:
  - Straight-line movement (B1)
  - Tumbling (randomly) (B2)
- Usually tumbling, but move in a straight line if there is an increase in food. How...?
- ...Answer: They use the *temporal* gradient (gradient in time), by comparing the food concentrations at two different times.

Top-down model of E. Coli behavior

- Model: Introduce a variable U(t) and activate B1 if U > T, where T is a fixed threshold.
- Otherwise, use B2.
- X(t) = attractant concentration.
- For computational simplicity introduce V(t) = X(t) – U(t).
- Leaky integrator model:

$$\frac{\mathrm{d}V(t)}{\mathrm{d}t} + aV(t) = bX(t).$$

Top-down model of E. Coli behavior

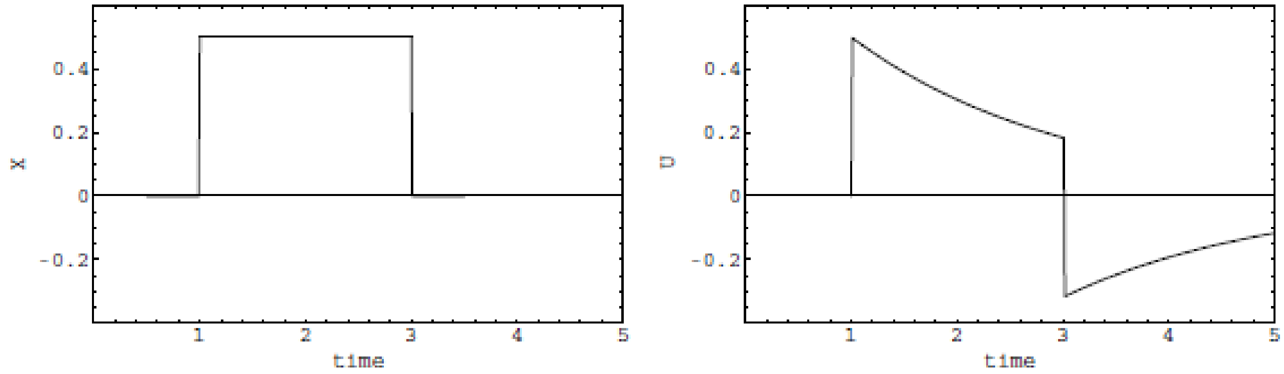


Figure 4.1: *An illustration of the switch between straight-line swimming and tumbling in* E. Coli *bacteria, based on a model with a single leaky integrator given in Eq. (4.1). The left panel shows the variation of the attractant concentration $X(t)$, and the right panel shows $U(t)$. The straight-line swimming behavior (B_1) is active between $t = 1$ and $t = 3$.*

Top-down model of E. Coli behavior

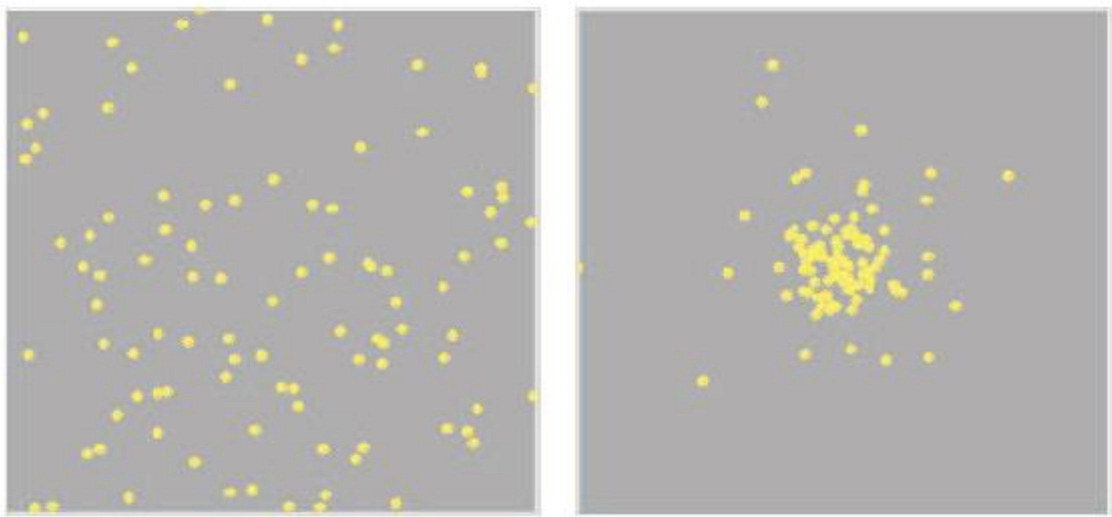


Figure 4.2: *The motion of simulated* E. Coli *bacteria based on the behavior switch defined in the main text. 100 bacteria were simulated, and the parameters a and b were both equal to 1. The attractant had a gaussian distribution, with its peak at the center of the image. The threshold was set to 0. The left panel shows the initial distribution of bacteria, and the right panel shows the distribution after 10 seconds of simulation, using a time step of 0.01.*

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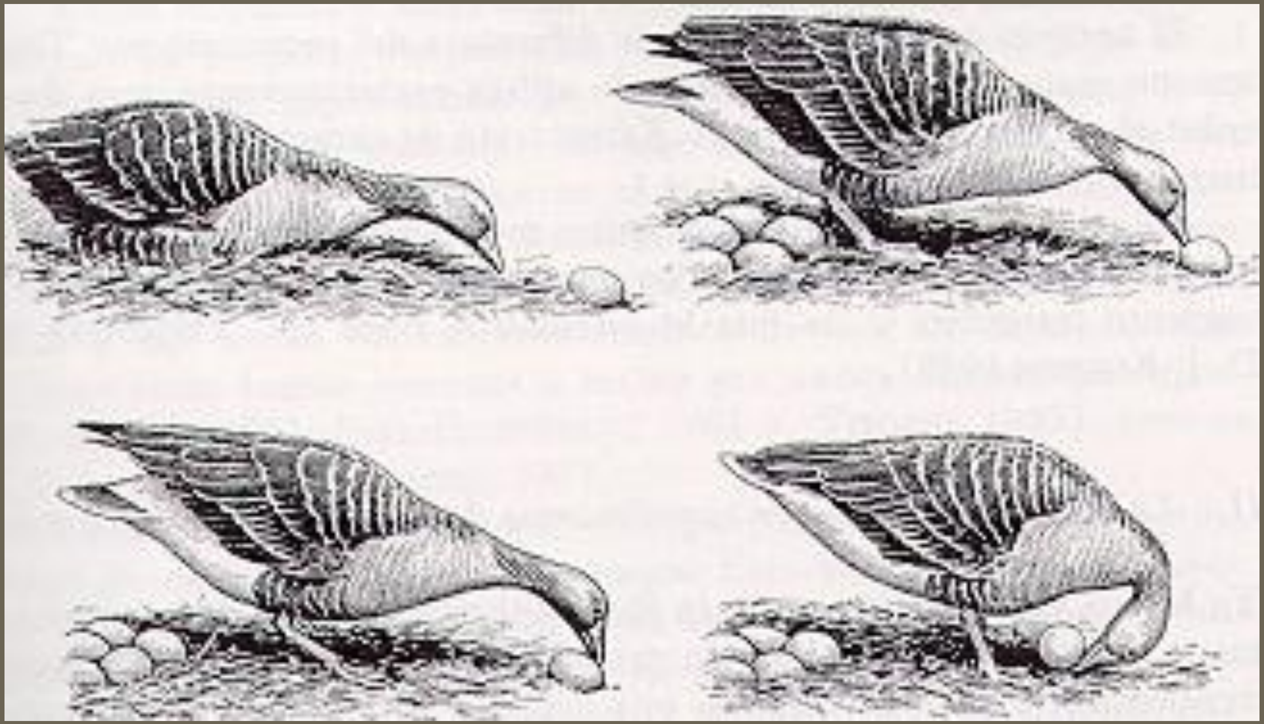
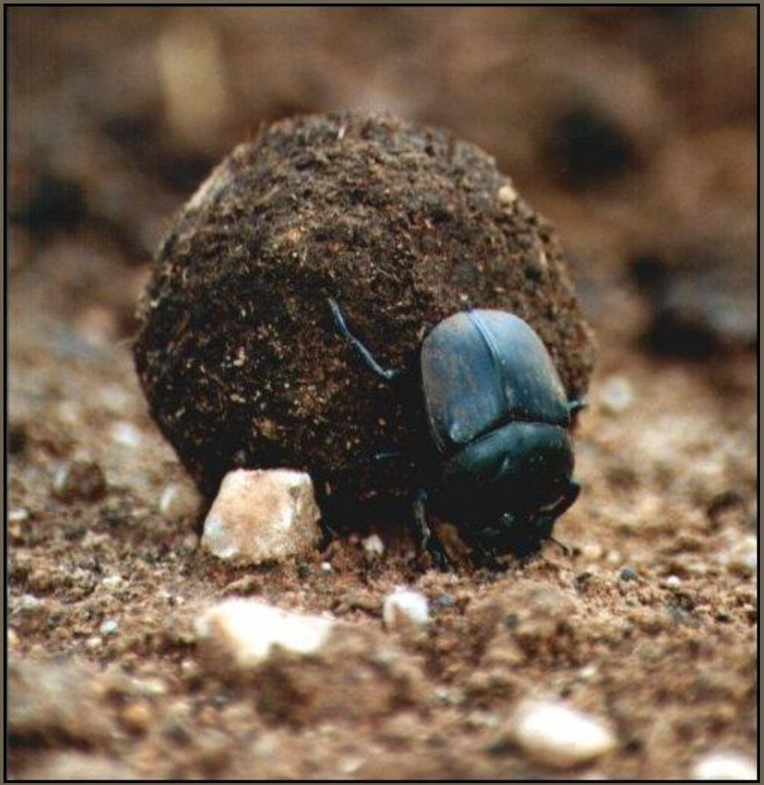
Fixed action patterns (FAPs)

- Sequence of actions
- Temporal extension beyond that of the stimulus.
- Examples of FAPs
  - Egg-retrieval in geese
  - Behavior of dung beetles
  - Attack behavior of the praying mantis
- Note: Some supposed FAPs are not completely fixed, though...

FAP: Egg-retrieval in geese



FAP: Dung beetle behavior



FAP: Attack behavior of the praying mantis

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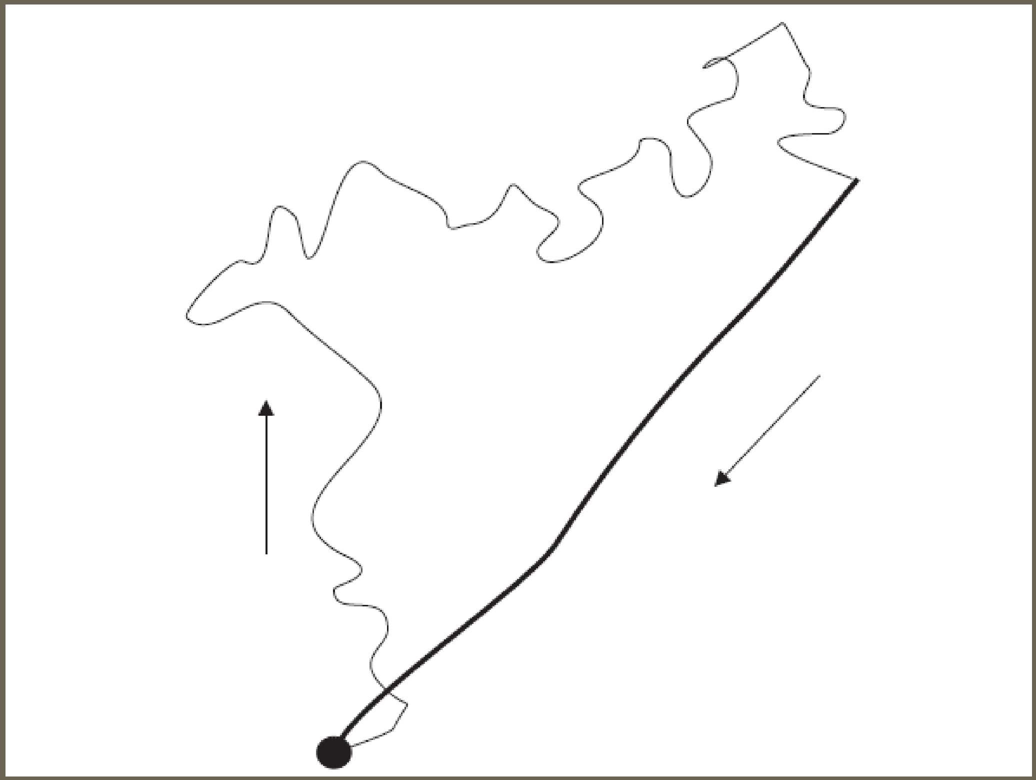
Complex behaviors

- Animals do not only react to immediate stimuli – they also maintain an internal state.
- Motivated behaviors – depend on internal states.
- Case study: Navigation of the desert ant *Cataglyphis Fortis*.

Cataglyphis navigation

- Cannot use pheromones (would evaporate in the desert heat).
- Still capable of moving long distances (100 m or more) from their nest, and then move on an almost straight line back and finding the nest (=tiny hole in the ground) again.

Cataglyphis navigation



Cataglyphis navigation

- How do they do this?
- Desert ants have the ability to
  1. Measure distance travelled (odometry) and
  2. Measure direction (compass, based on light polarization pattern).
- Thus, they can maintain a vector connecting the nest to the current position.
- To return, they simply reverse the vector.
- Ephemeris function: *Cataglyphis* can also compensate for the motion of the sun in the sky.

Cataglyphis navigation

- Still, finding the nest is difficult.
- Near the nest, the ants use pattern matching, i.e. using its eyes to match the current view to a stored snapshot taken when leaving.
- Additional sensory modality: The ants can also use odour recognition to help pinpoint the entrance to the nest.
- This is an example of sensory redundancy – often used in robots as well!

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Home problem 1

- Three problems, maximum score: 10p
- Strict deadline 20160211
- *Read and follow the instructions carefully!*
- For each problem, make sure to answer *all* questions posed, and to provide *all* of the required information. Before starting to solve the problem, carefully read the text and mark all things that you will need to submit or include in the report.
- Write a *clear* report.

1.1: Basic kinematics

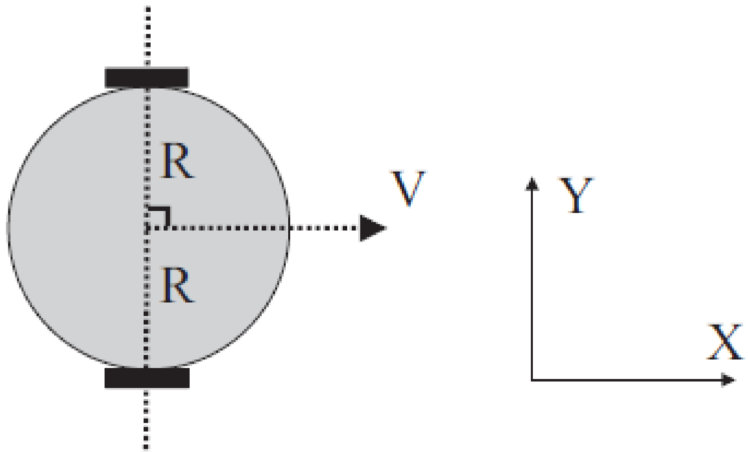

Figure 1: The differentially steered robot considered in Problem 1.1.

1.2: Simple robot behaviors

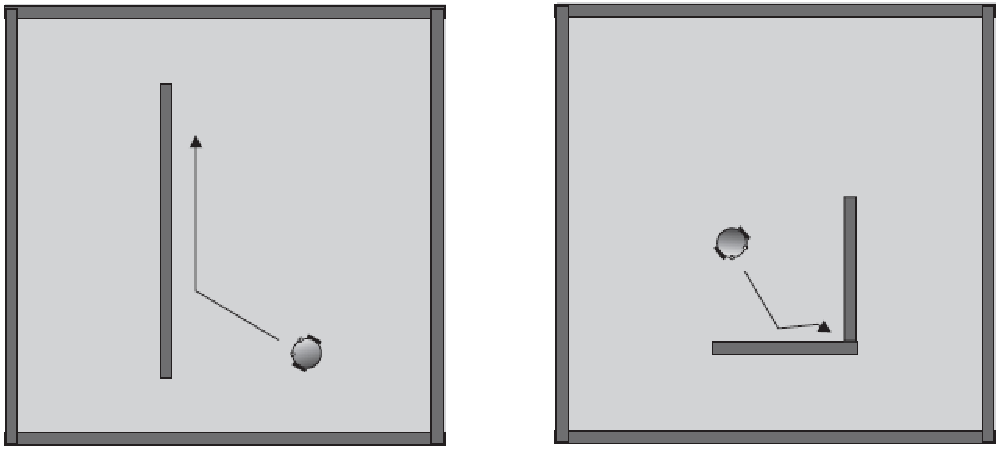

Figure 2: Illustration of the behaviors in problem 1.2.

1.3: Basic navigation

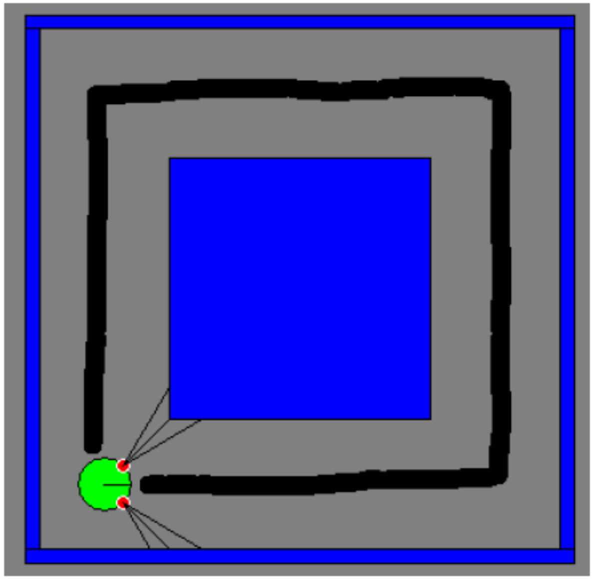

Figure 3: Illustration of the desired path (thick black line) for Problem 1.3.

1.3: Basic navigation

You may modify the number of simulation steps in `TestRunRobot`, but apart from that, you may *only* modify the `CreateBrain` and `BrainStep` functions. It is thus *not* allowed to modify the noise levels in sensors and actuators etc.

All variables (except local variables in `BrainStep`, see below) and parameters of the robotic brain *should* be introduced in the `CreateBrain` function (see the examples at the end of Chapter 5). Your `BrainStep` function should contain an FSM, i.e. a sequence of `if-then-else`-rules (again, see the two examples in Chapter 5), with clear and descriptive variable names. You may introduce local variables in the `BrainStep` function, but keep in mind that their values will not be available when the function is called again.