Autonomy Architectures

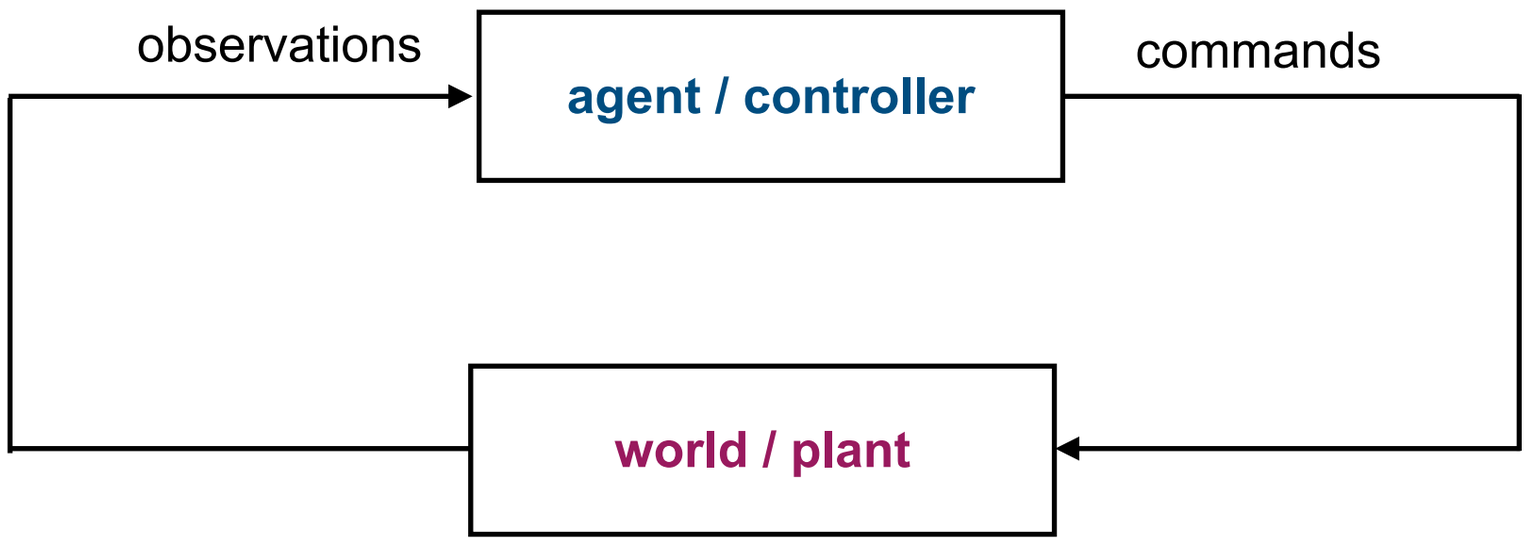
The design boundary

- Control theory nomenclature:

  controller/ **plant**

- Computer science nomenclature:

  agent / **world**



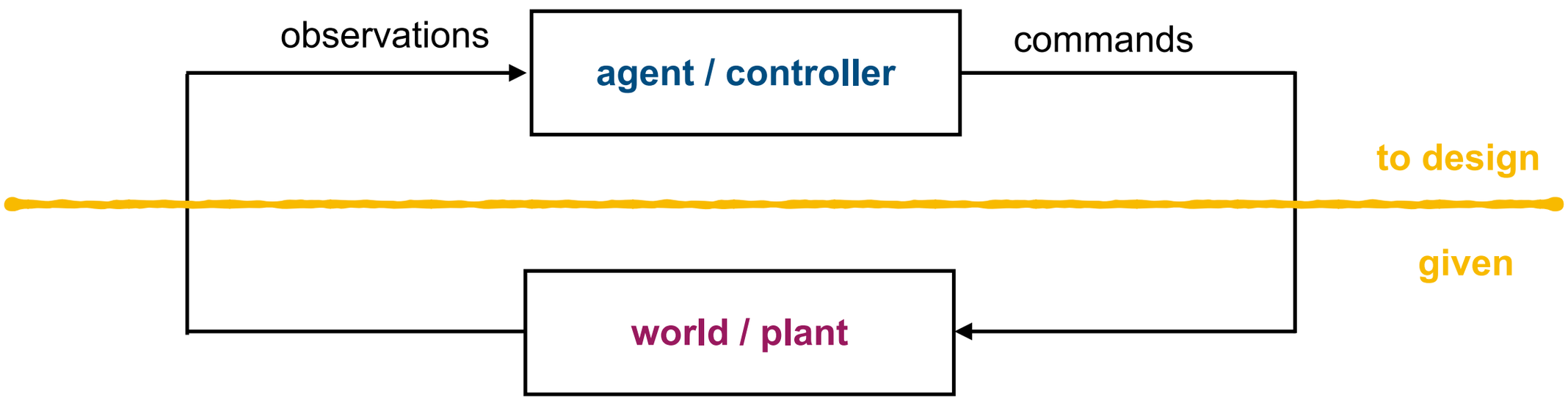
The design boundary

- **World** (**plant**):

  everything that is given to you.

- **Agent** (**controller**):

  what you can design arbitrarily.



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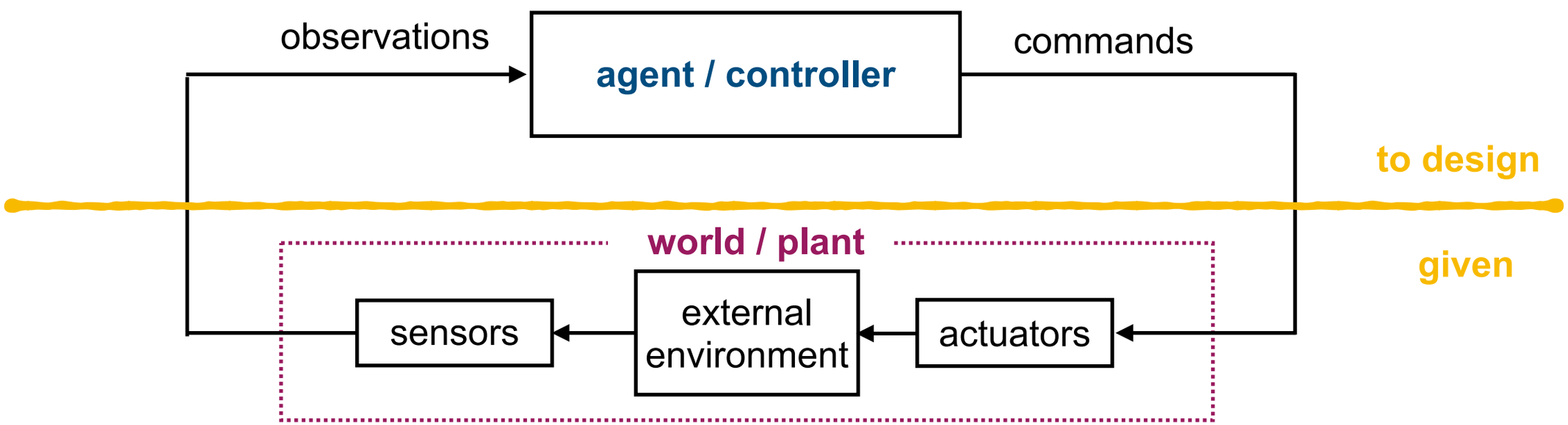


Finally… how to design this?

Architectures for autonomy

- Fundamentally, we **do not know** how to build good robotic architectures.

- Not a smooth evolution from previous practices

  from a industrial robot to self-driving car: a big gap

- There are **no easy answers**:
  - we know what is the “ideal” solution;
  - we know why the ideal solution doesn’t work.

- In 5 years the answers will be different…

Architectures for autonomy

- We can see at least 3 philosophies:

  - **Cybernetics / Control Theory** (1930s-)
    - Focus on signals, dynamics, simple representations.
  - **Artificial Intelligence** (1950s-)
    - Focus on building symbolic representations, symbolic planning.
  - **So-called "Artificial Intelligence" (deep learning)** (2013-)
    - Focus on utilizing data, machine learning, opaque representations.

- Most successful applications will utilize a mix of approaches. To be a good roboticist **you need to know pros & cons** of all of them **and create your own mix / evolution.**

Sensorimotor architectures

Drawing inspiration from nature

- **The only example of intelligent systems we have are from biology**, and they work very differently from any of the techniques we use for robots.

- Animal perception/action is **robust**, **adaptable**, and **efficient.**

  Our robots are not!

- **Bio-inspired solutions:**

  - Focus on **tight sensorimotor loops.**

  - Co-design of **hardware and behavior.**

Good readings:

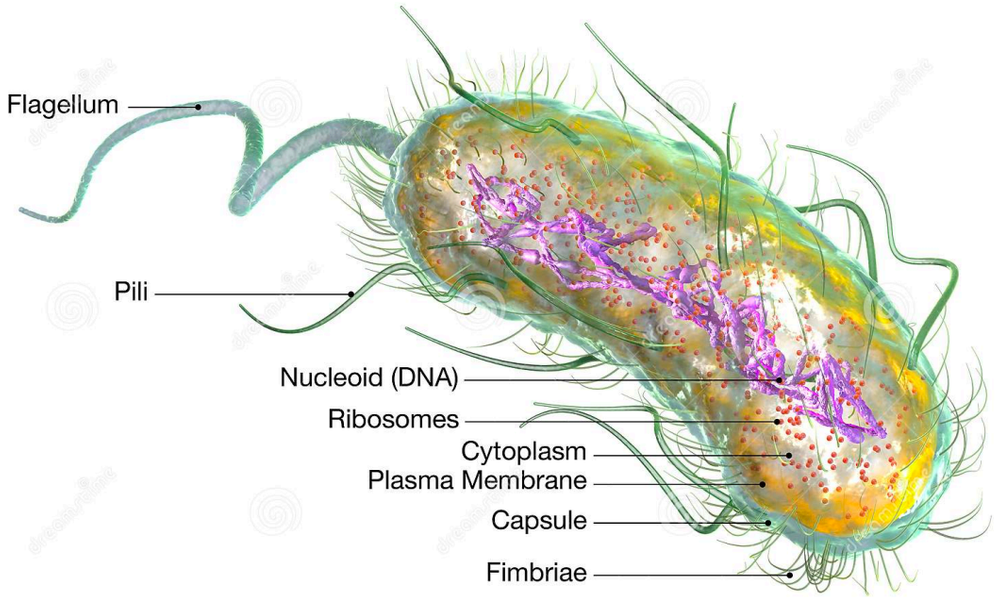
Josh Bongard and Rolf Pfeifer. *How the body shapes the way we think. 2006*

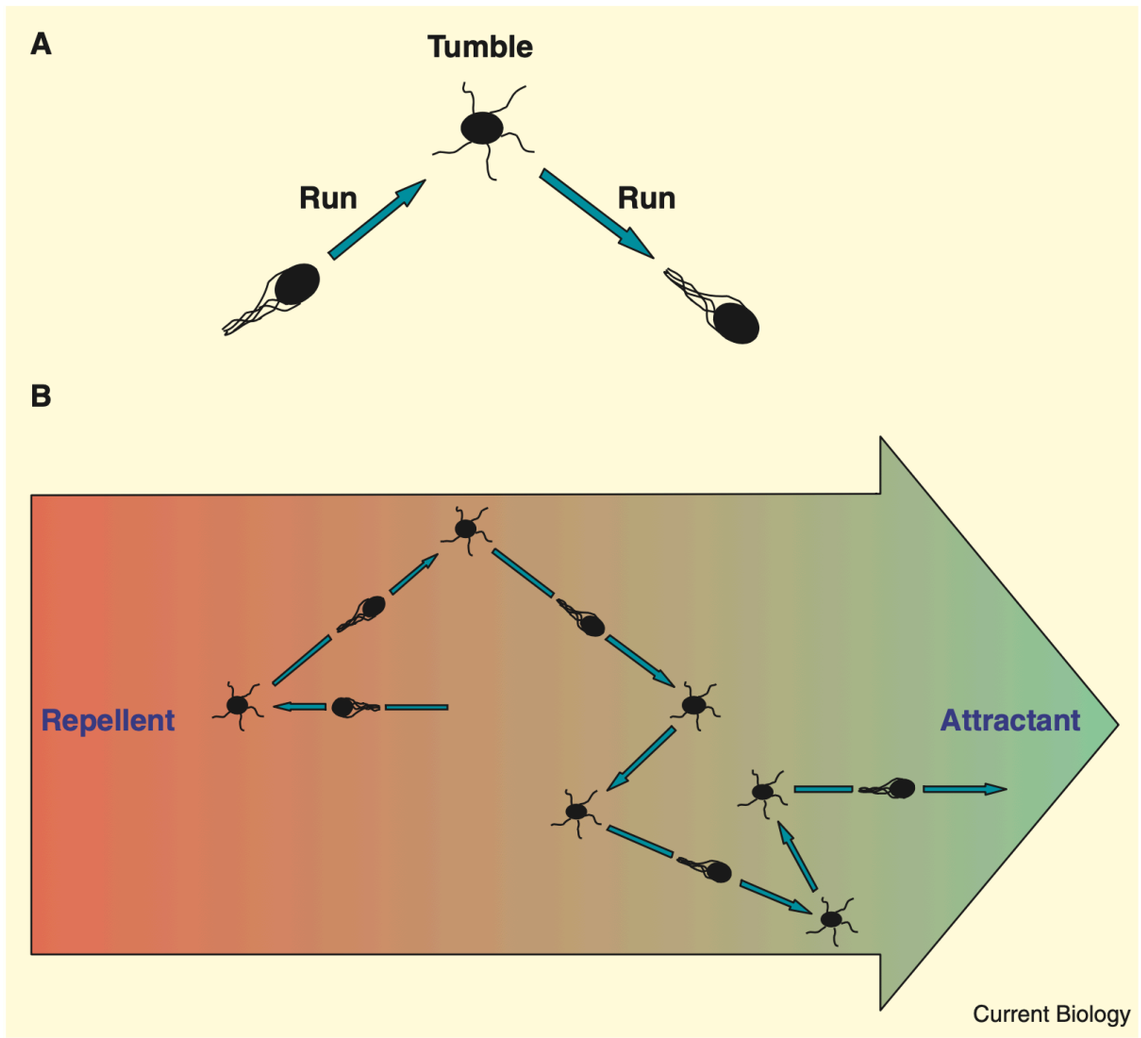
Rodney Brooks. 🔗 *Intelligence without representation*

Bacteria chemotaxis

- **Chemotaxis** is the directed motion of an organism toward environmental conditions it deems attractive and/or away from surroundings it finds repellent.

- Movement of flagellated bacteria such as **Escherichia coli** can be characterized as a sequence of **smooth-swimming** runs punctuated by **intermittent tumbles.**

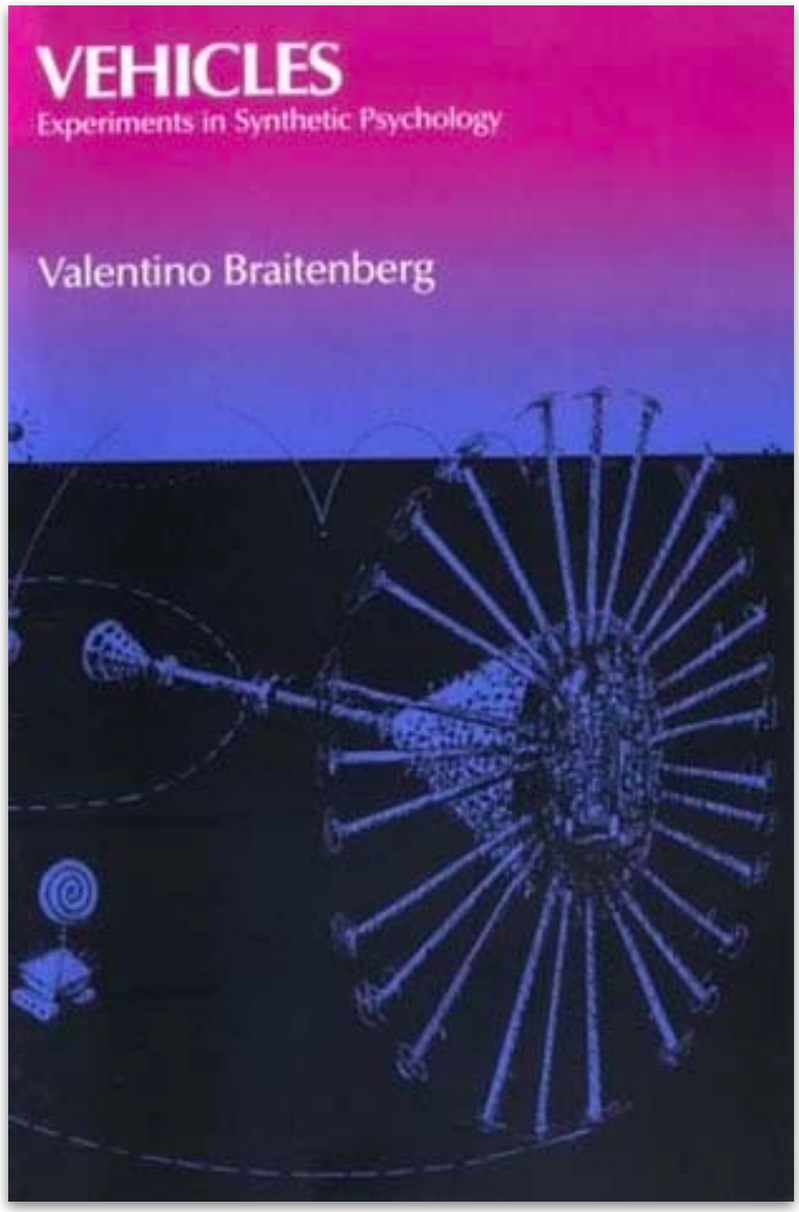


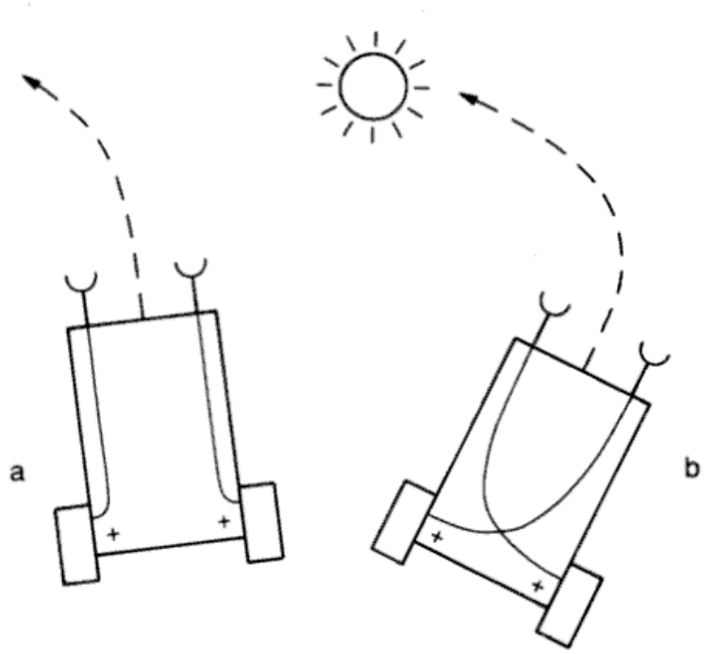


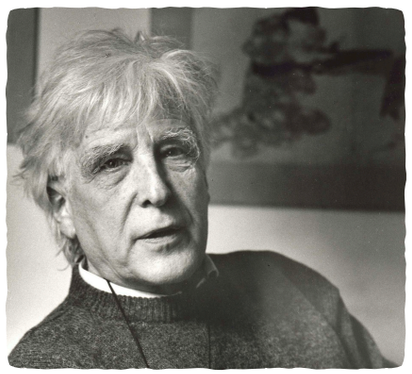
Ref: Bacterial Chemotaxis, Current Biology Vol 13 No 2

Braitenberg's Vehicles

- Influential cybernetics book.
- Shows how **complex behavior can arise from simple sensorimotor connections.**





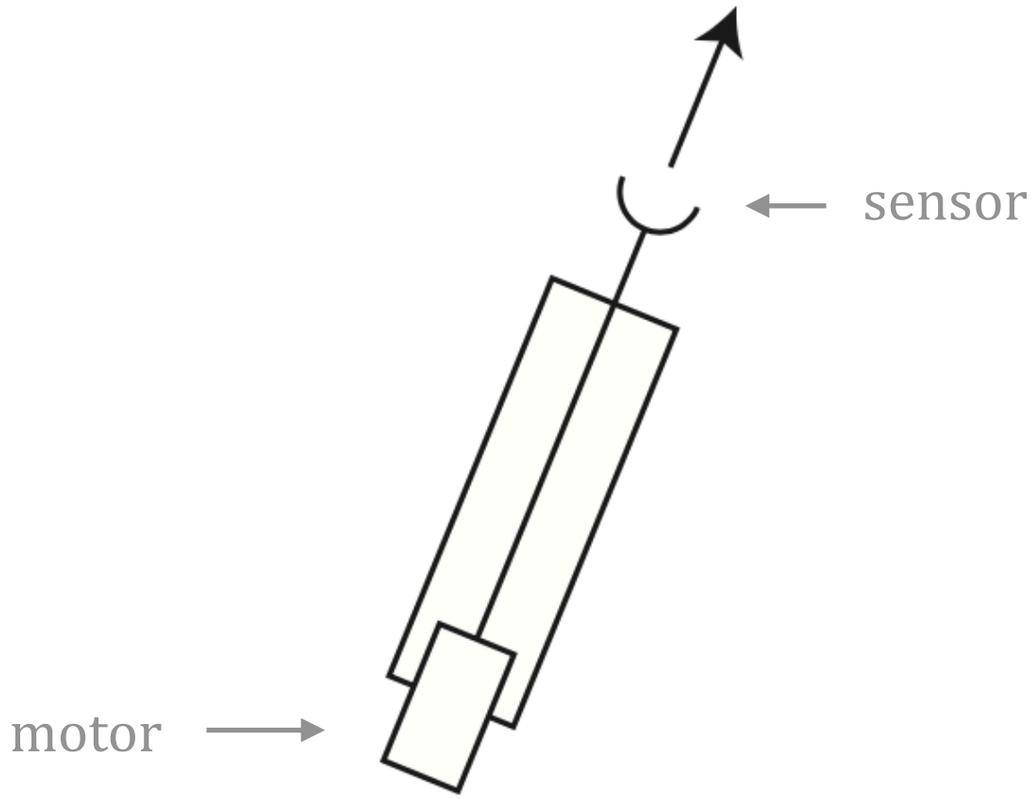


Valentino Braitenberg
1926-2011

Vehicle 1: The simplest vehicle

- The speed of the **motor** (rectangular box at the tail end) is **controlled by a sensor** (half circle on a stalk, at the front end).

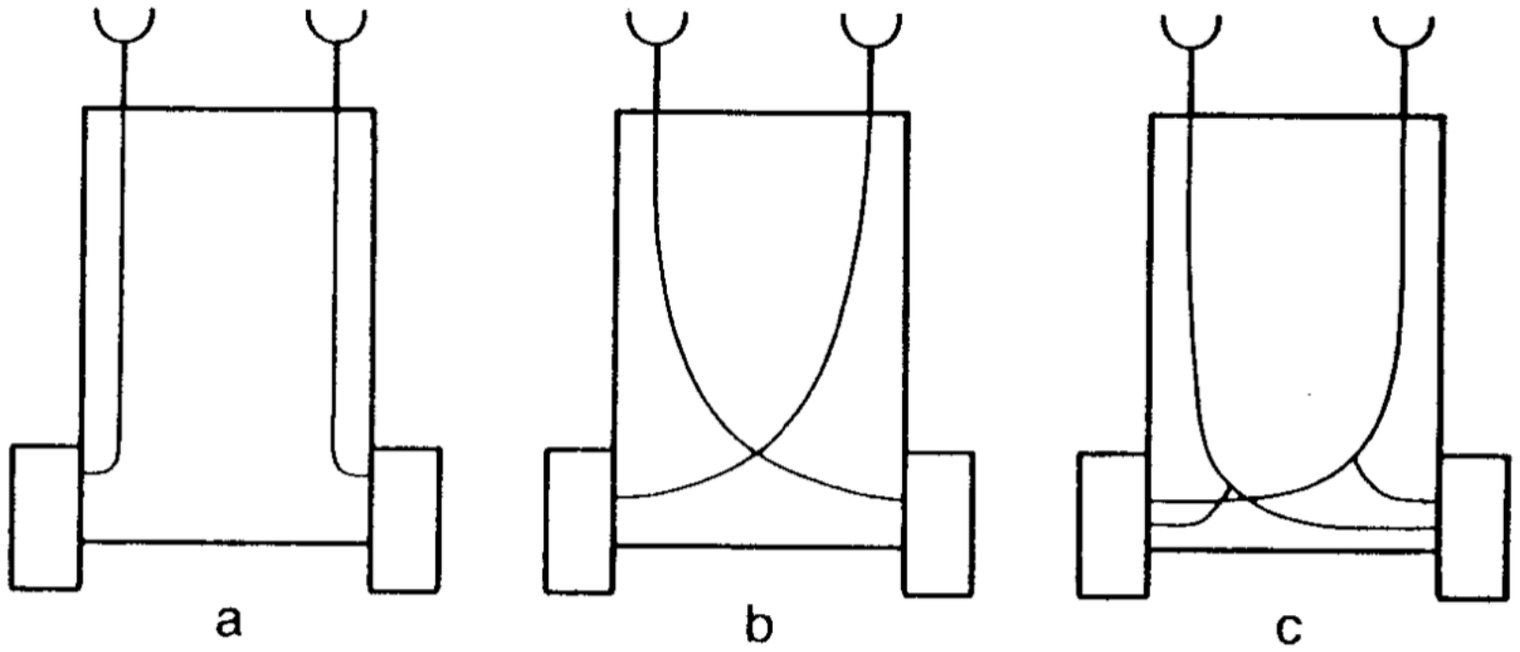
- **Motion is always forward**, in the direction of the arrow, except for random perturbations.



Vehicle 1

Vehicle 2

- We now have **2 sensors** and **2 motors**.
- The **wiring / weights** between sensors and motors will create different behaviors.

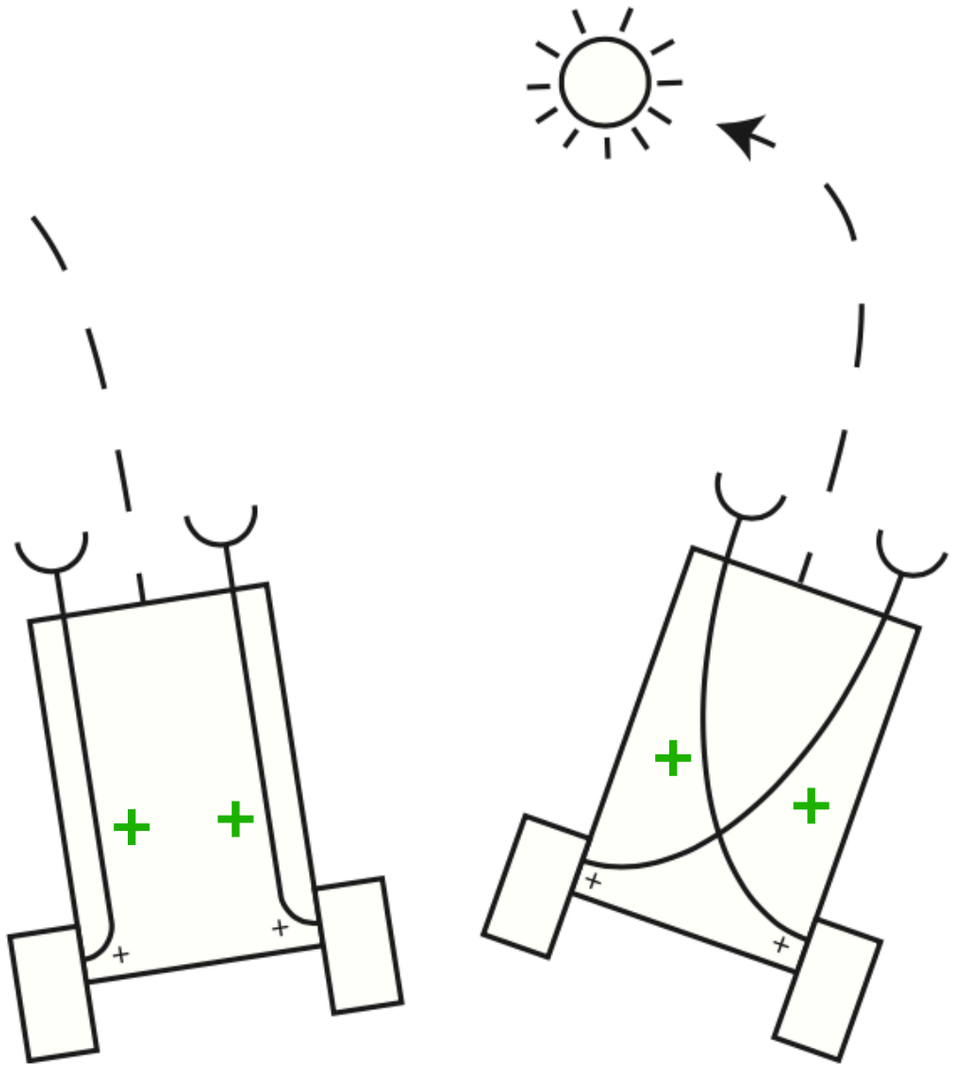


Vehicle 2

Fear and aggression

fear

aggression



Vehicle 2a

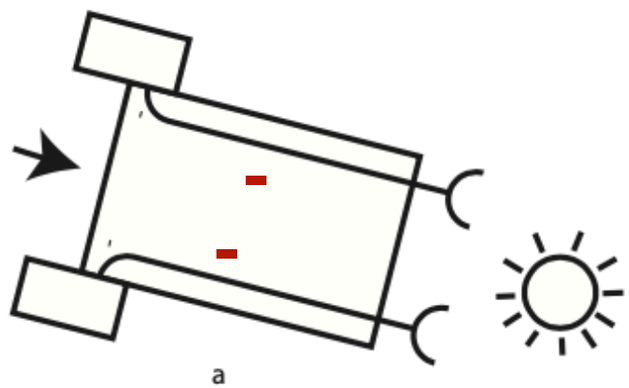
Vehicle 2b

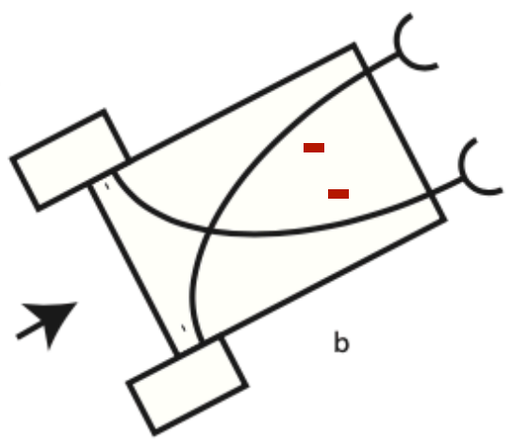
"Let Vehicles 2a and 2b move around in their world for a while and watch them. Their characters are quite opposite. Both DISLIKE sources. But 2a becomes restless in their vicinity and tends to avoid them, escaping until it safely reaches a place where the influence of the source is scarcely felt. Vehicle 2a is a COWARD, you would say. Not so Vehicle 2b. It, too, is excited by the presence of sources, but resolutely turns toward them and hits them with high velocity, as if it wanted to destroy them. Vehicle 2b is AGGRESSIVE, obviously. "

Lover and explorer

Vehicle 3a

lover





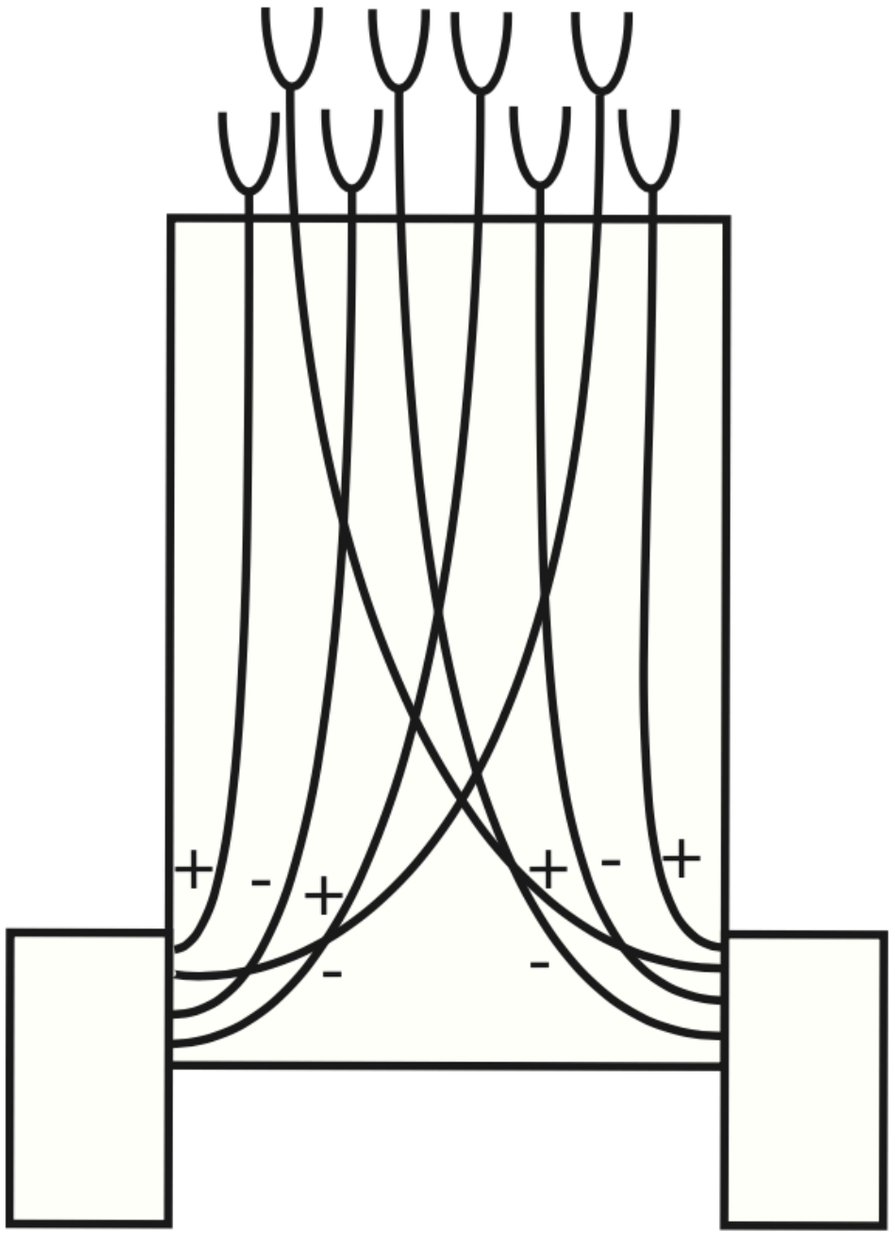
Vehicle 3b

explorer

"Approaching the stimulation, Vehicle 3a will orient towards it and come to rest facing it. Vehicle 3b on the other hand will come to rest facing away from the stimulation.

You will have no difficulty giving names to this sort of behavior. These vehicles LIKE the source, you will say, but in different ways. Vehicle 3a LOVES it in a permanent way, staying close by in quiet admiration from the time it spots the source to all future time. Vehicle 3b, on the other hand, is an EXPLORER. It likes the nearby source all right, but keeps an eye open for other, perhaps stronger sources, which it will sail to, given a chance, in order to find a more permanent and gratifying appeasement. "

Vehicle 3c - a system of values

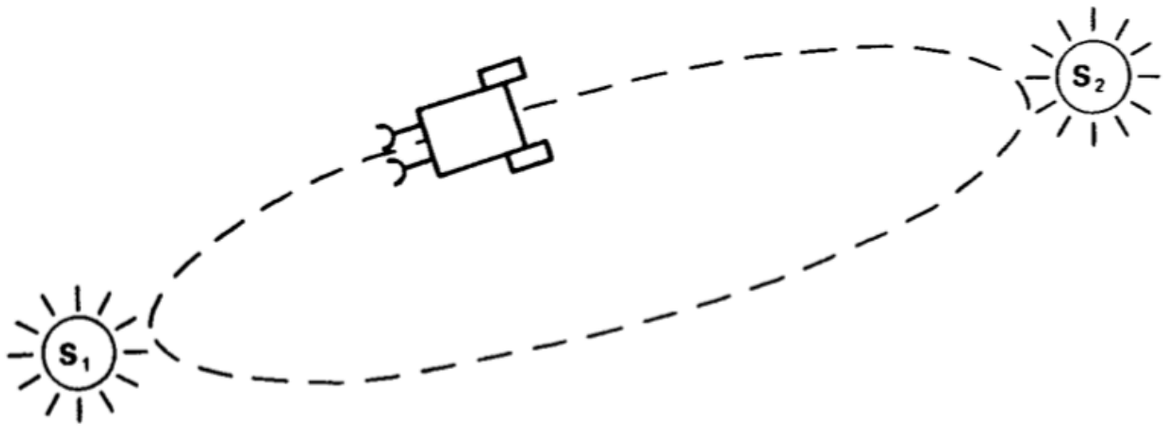


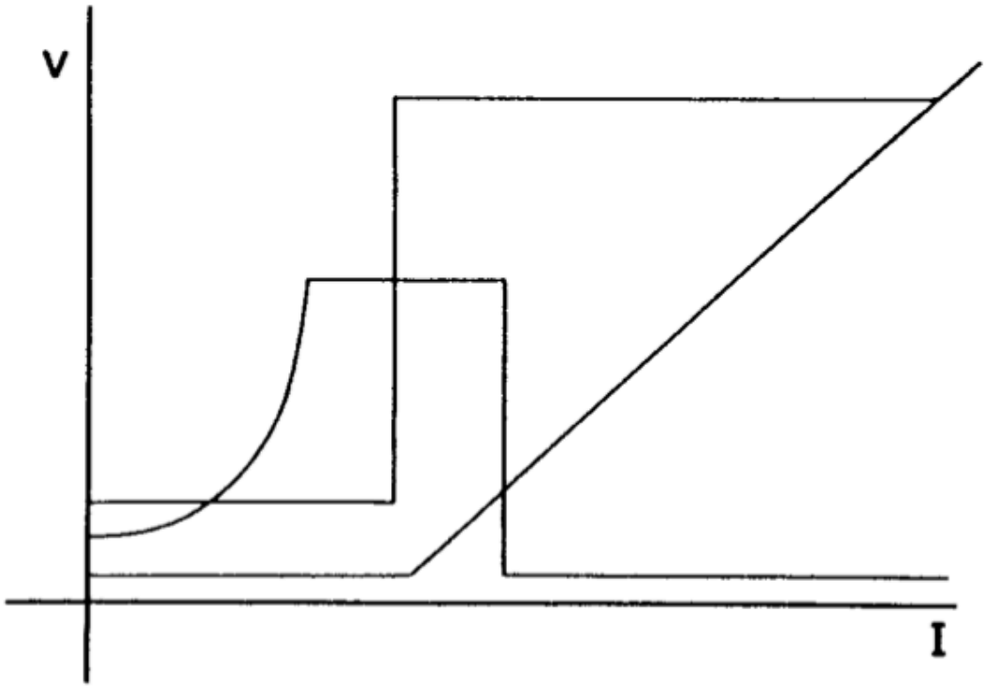
" …not just one pair of sensors but four pairs, turned to different qualities fo the environment, say light, temperature, oxygen, concentration, and amount of organic matter.

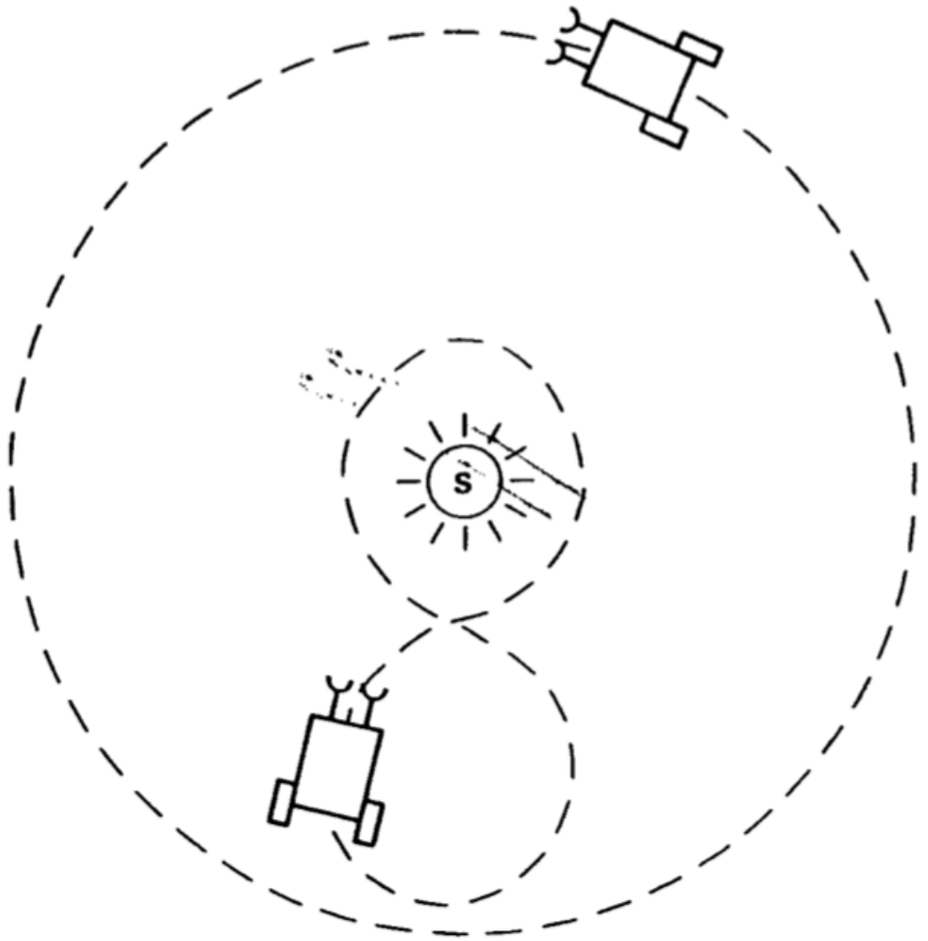
.. This is a vehicle with really interesting behavior. It dislikes high temperature, turns away from hot places, and at the same time seems to dislike light bulbs with even greater passion, since it turns towards them and destroys them... You cannot help admitting that Vehicle 3c has a system of VALUES, and, come to think of it, KNOWLEDGE."

More complex behavior

- By **changing the activation function** from light intensity I to velocity of the motor V, many more behaviors can be obtained.

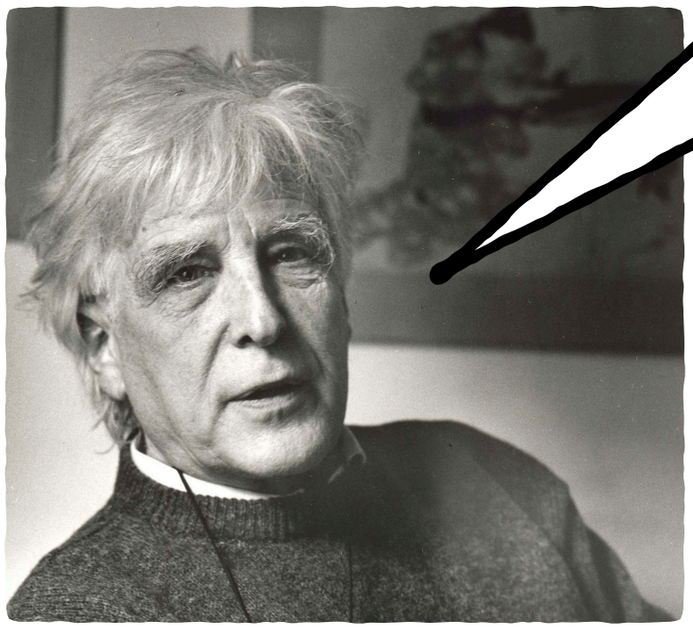






KiSS

KEEP IT SIMPLE
FROM THE START

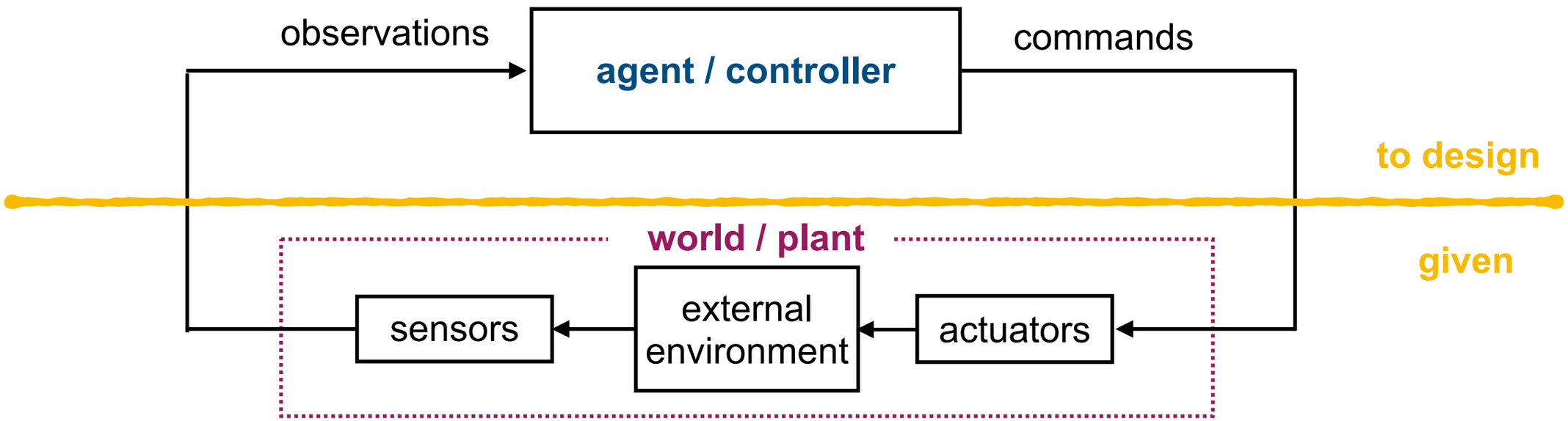


Il semble que la perfection soit atteinte non
quand il n'y a plus rien à ajouter, mais
quand il n'y a plus rien à retrancher.

Antoine de Saint Exupéry

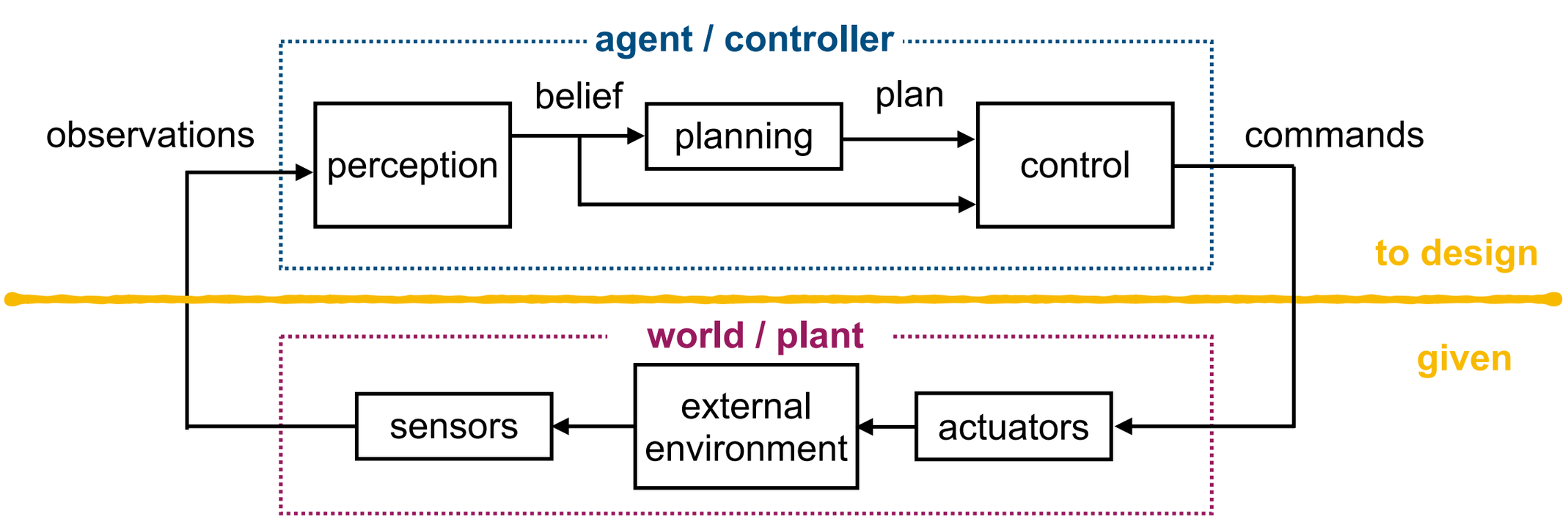
Stateful architectures

Stateful approach



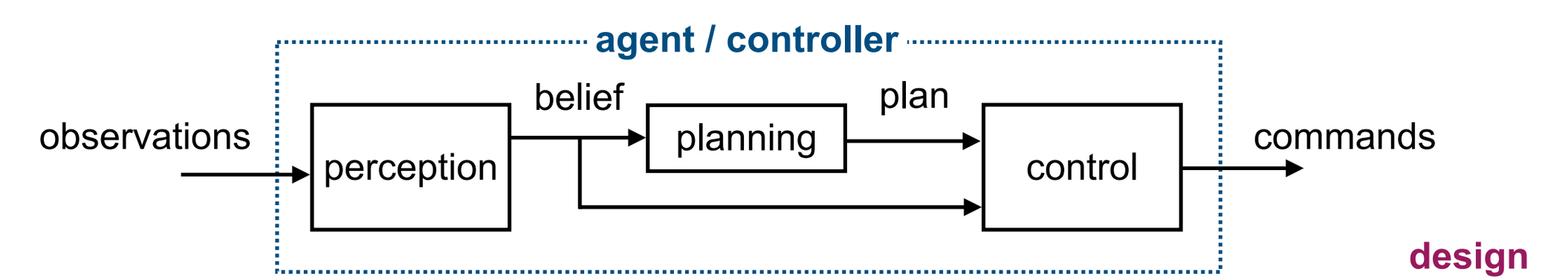
Stateful approach

- **OODA loop:** Observe, Orient, Decide, and Act [Boyd, 1940s]
- common current nomenclature: “Perception, planning, control”



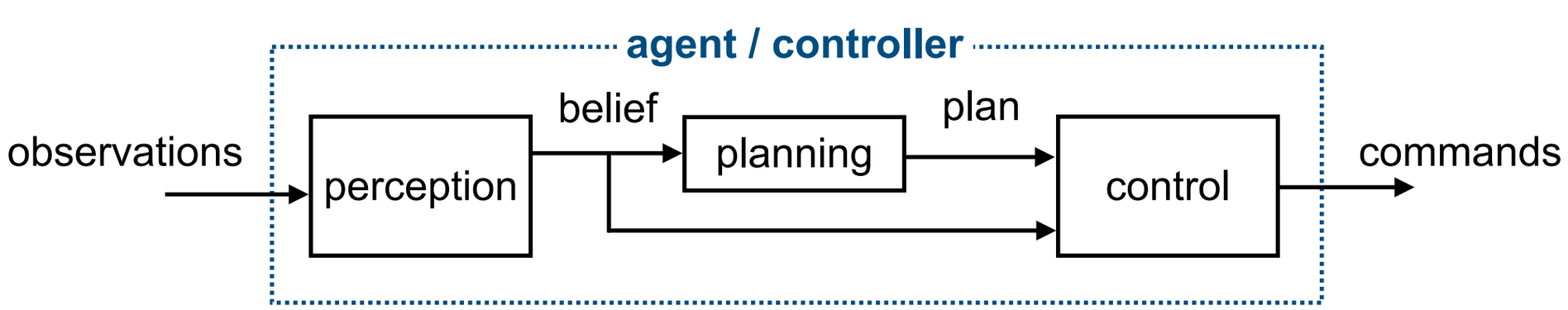
The social process of design

Conway's law:
"Organizations that design systems are constrained to produce designs which are copies of the communication structures of those organizations."



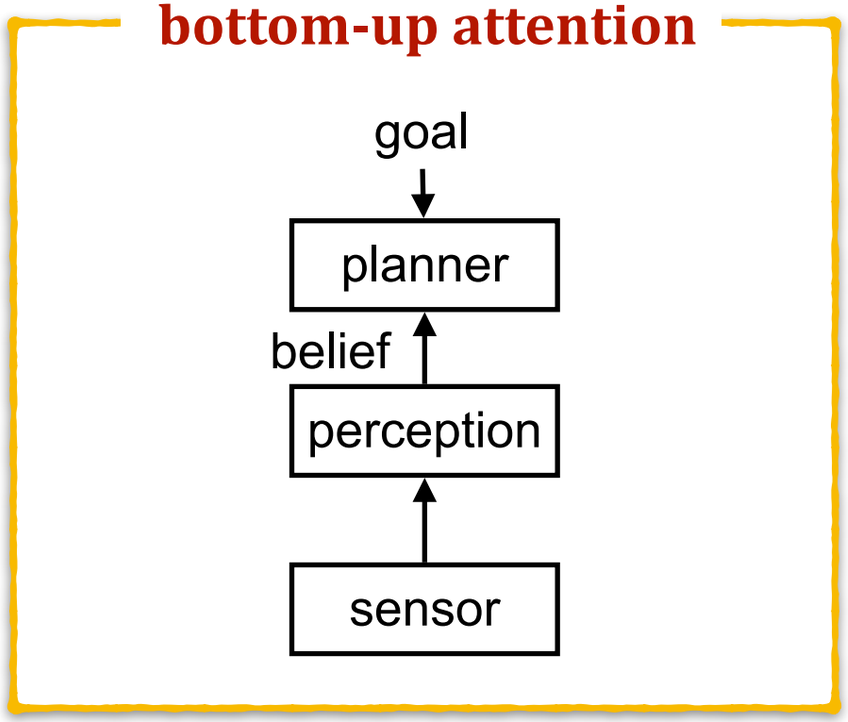
Simple critique of the simple decomposition

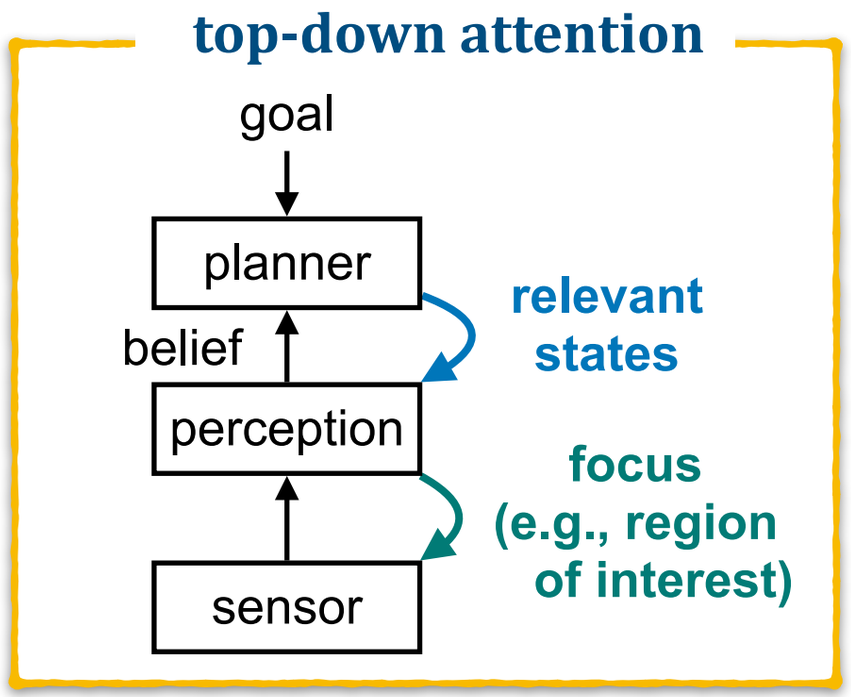
- Computational constraints: the state is huge, the belief over the state even larger.
- Do you really know the model of the system?
- Is the world probabilistic anyway?



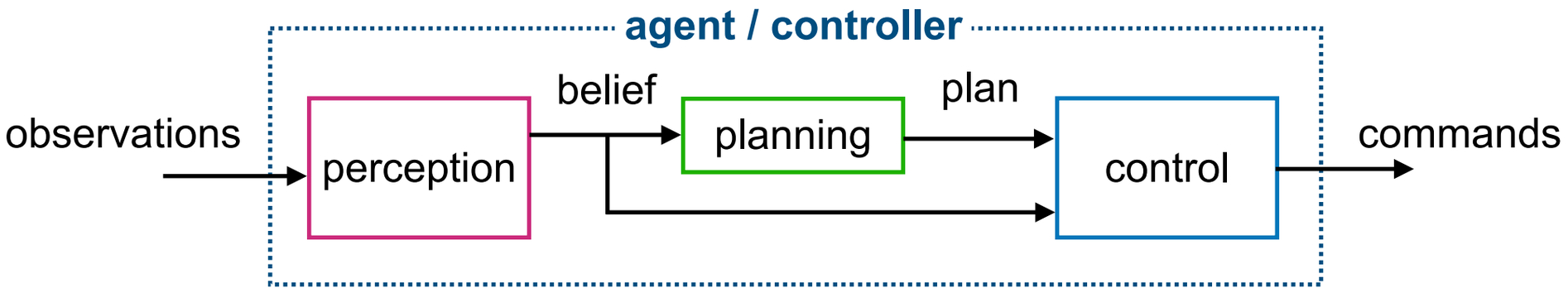
Bottom-up vs top-down attention

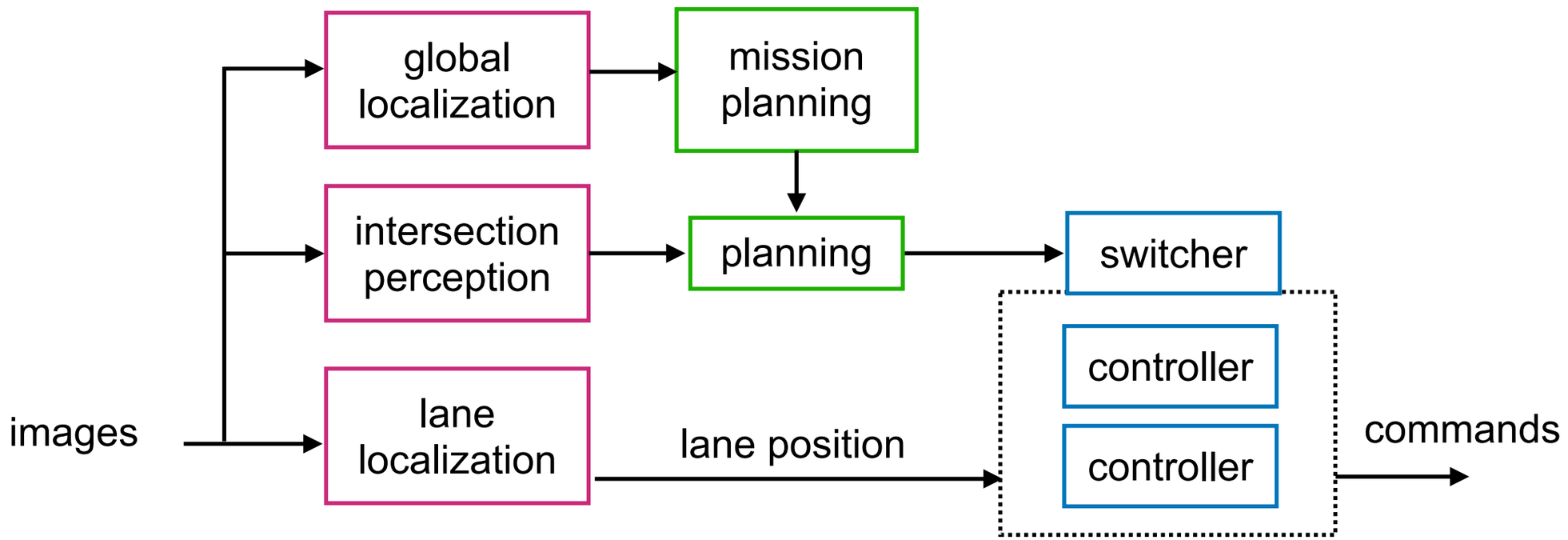
- **Bottom-up attention:**
  - The sensor “sees” something;
  - The belief is updated;
  - The plan is recalculated.
- **Top-down attention**
  - The goal establishes what is relevant;
  - The planner tells the sensor what to look for;
  - The sensor only “looks” for something relevant.





(Part of) Duckietown architecture





Conclusions

- There are many ways to design a robot architecture.
- There is value in understanding the “ideal” architecture:
  - perception, planning, control
  - hierarchical organization of processes and representations, in time and space
  - bottom-up and top-down attention
- … but keep in mind that all examples of real autonomous systems that we know (bio life) work fundamentally differently, and are really messy.

"~~Humor~~ can be dissected, as a frog can, but the thing dies in the process."

Autonomy