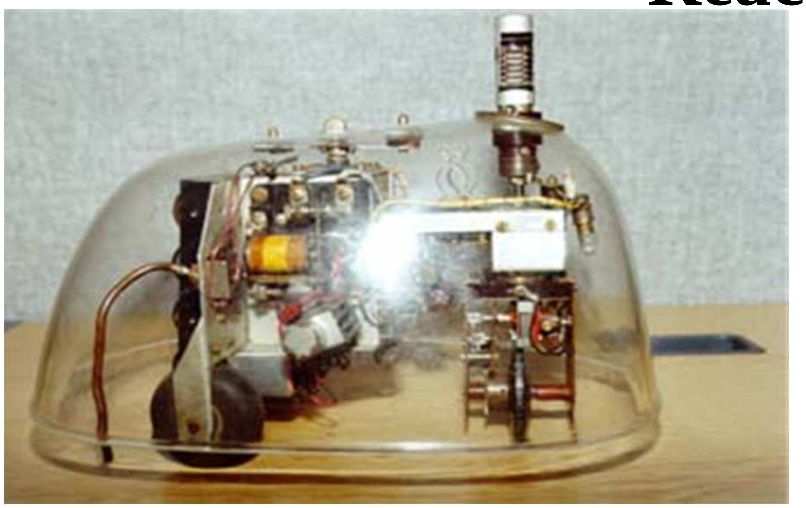
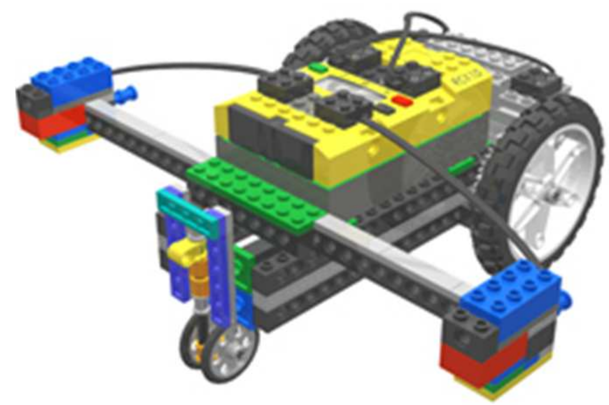
Robotics
Connect Sensors to motors:
Reactive Robotics





Martin Jagersand

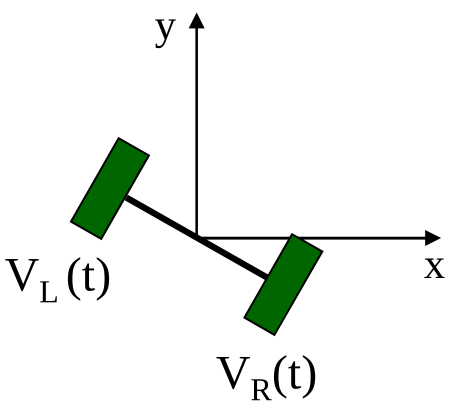
With slides from Zach Dodds, Robin Murphy, Amanda

Readings: Introduction to AI robotics, R. Murphy Ch 4 (and 3 cursorl

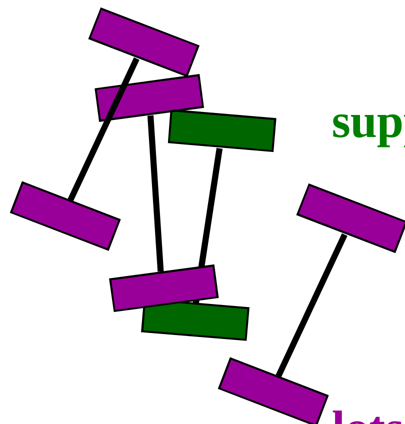
Previous lecture: *Probabilistic* Kinematics

Key question:

We may know where our robot is *supposed to be*, but in reality it might be somewhere else…



starting position



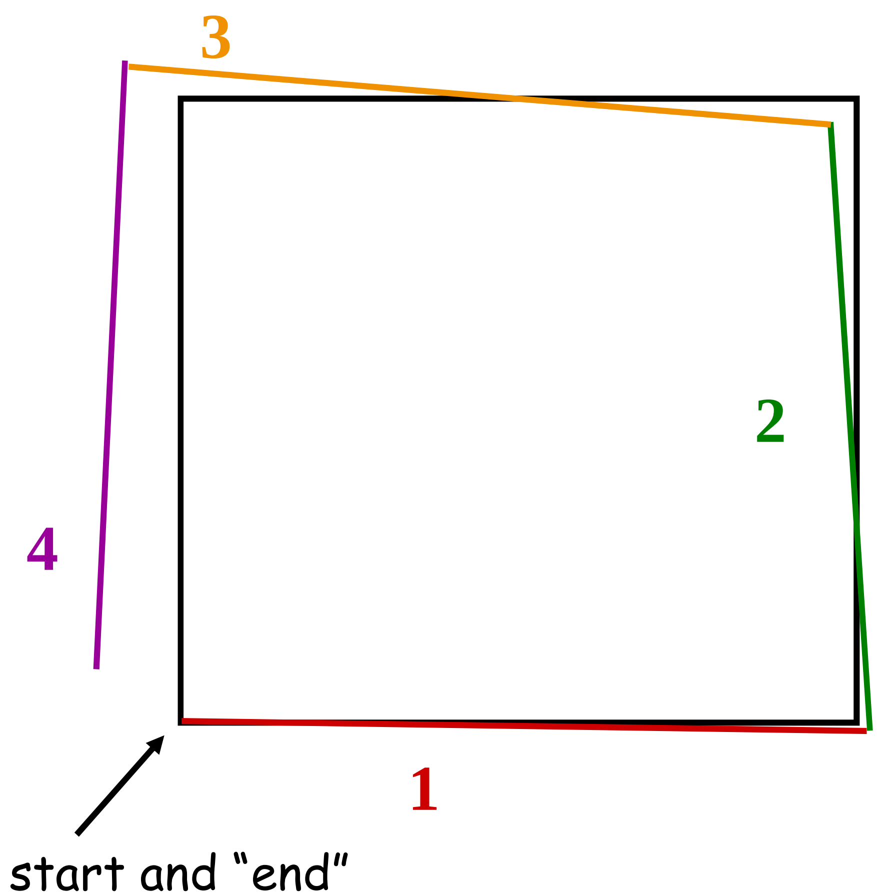
supposed final pose

lots of possibilities for the *actual* final pose

What should we do?

MODEL the error in order to reason about it!

Previous lecture: Running around in squares



- Create a program that will run your robot in a square (~2m to a side), pausing after each side before turning and proceeding.

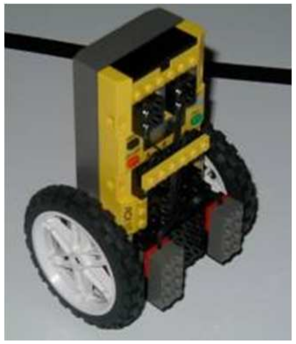
- For 10 runs, collect both the odometric estimates of where the robot thinks it is and where the robot ***actually is*** after each side.

- You should end up with two sets of 30 angle measurements and 40 length measurements: one set from odometry and one from "ground-truth."

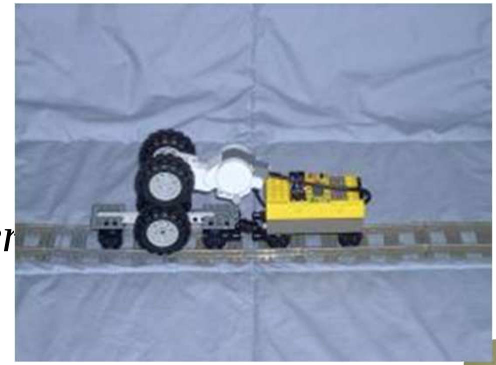
- Find the **mean** and the **standard deviation** of the ***differences*** between odometry and ground truth for the angles and for the lengths – this is the robot's ***motion uncertainty model***.

This provides a *probabilistic kinematic* model.

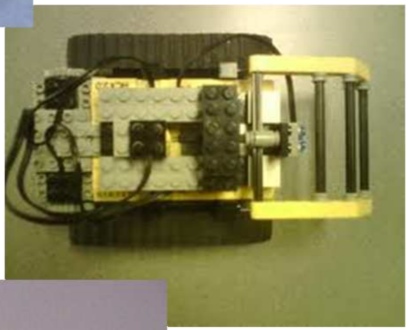
Now: How can we make movement (more) precise



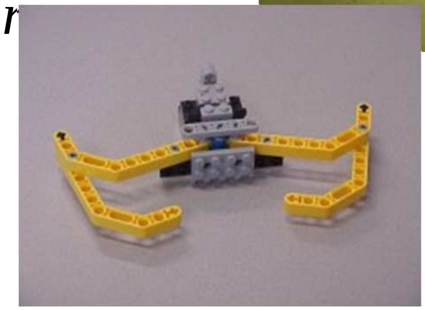
- Physical constraints
  - *Drive into wall*
    - *We will know the distance y*



  - *Follow a track/corridor*
    - *We know the transversal alignmen*



- Sensor imposed constraints
  - *Drive into wall, have stop switch*
  - *Drive along a wall using a whisker*
  - *Stop before a wall with a distance sensor*
  - *:*
  - *Navigate using GPS and a map*

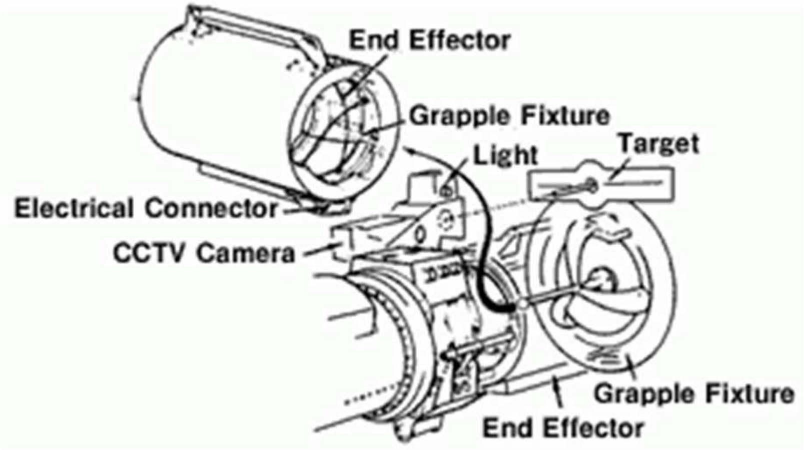


Physical constraints

- Railroad car coupler
  - *"Bullsnose"*
    - *Conical*

- In-air refuelling
  - *"Funnel"*

- Robot end effector
  - *Grapple fixture for docking in space(JAXA)*
  - *Guide pin, sliding surfaces*
  - *Start +-50mm, final pos +1mm*



Behavior Definition (graphical)

Types of Behaviors

- **Reflexive**
  - *stimulus-response, often abbreviated S-R*
- **Reactive**
  - *learned or "muscle memory"*
- **Conscious**
  - *deliberately stringing together*

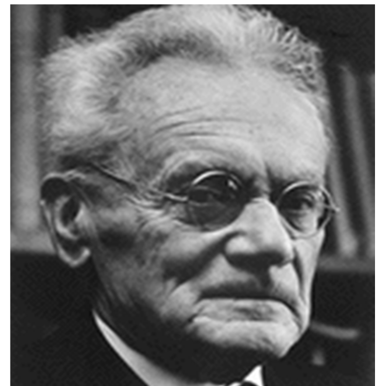
WARNING Overloaded terms:
Roboticists often use "reactive behavior" to mean purely reflexive,
And refer to reactive behaviors as "skills"

Reflexive behaviors

- Reflexes - lasts as long as the stimulus only,
- Taxes - moves in a particular direction (tropotaxis in baby turtles, chemotaxis in ants),
- Fixed-action patterns - continues for a longer duration than the stimulus.

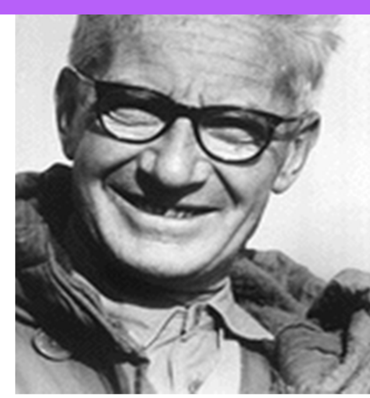
Ethology: Study of Animal Behaviors

Nobel 1973 in physiology or



INNATE RELEASING MECHANISMS

- Lorenz
- Tinbergen



www.nobel.se

Biological Inspiration

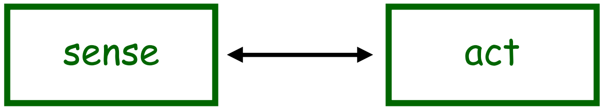
Ethology: describing animal behavior

Getting to the ocean?

Digger wasps' nest-building sequence

AI reasoning systems abstract too much away: *frame problem*

"The world is its own best model"



Decision-making is based only on current sensor inputs.

Arctic Terns

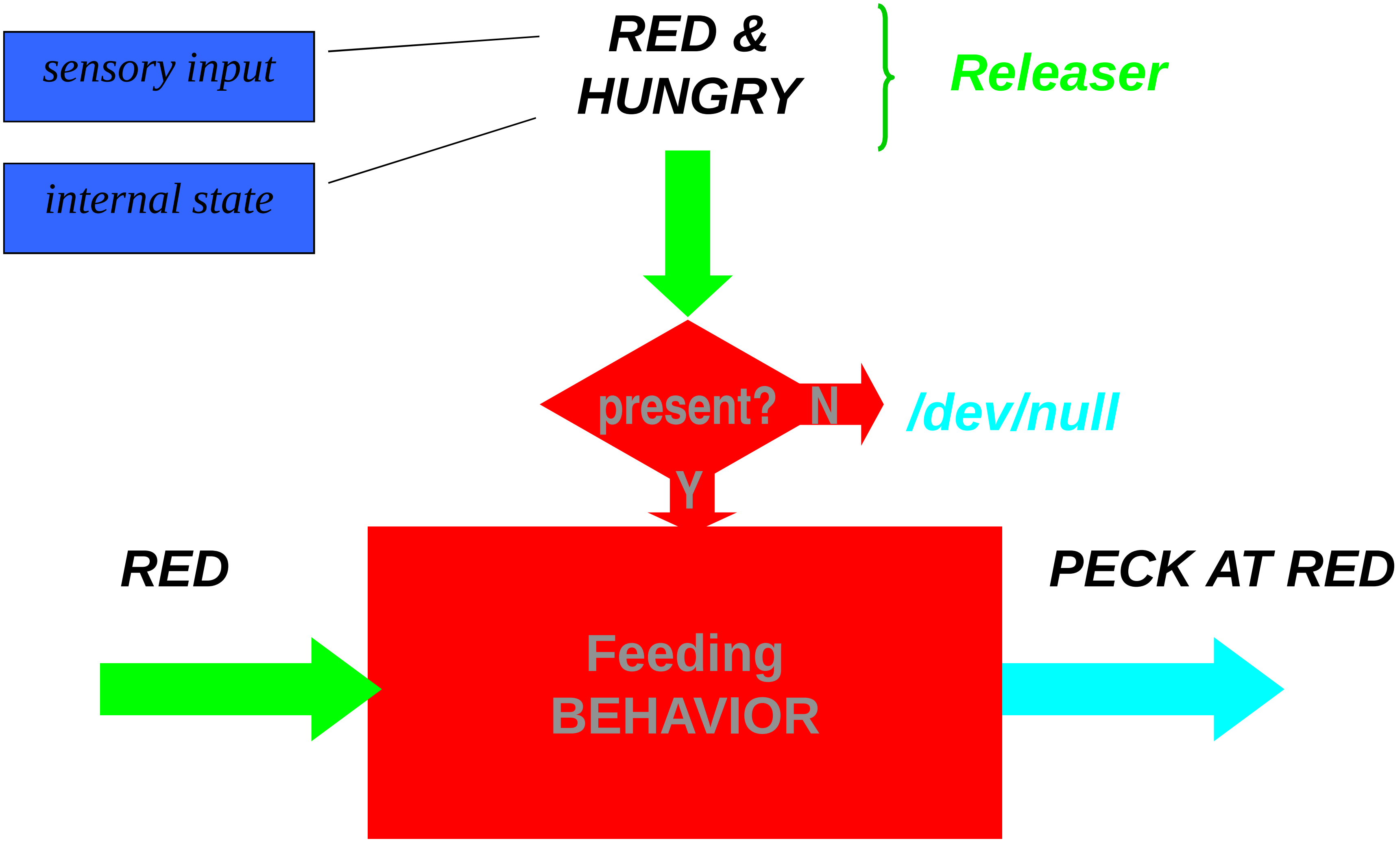
- Arctic terns live in the Arctic (a black & white world w/some grass), but adults have a red spot on beak (?)

- When hungry, a baby pecks at parent's beak, who regurgitates food for the baby to eat.

- How does it know its parent?
  - ***It doesn't***, it just goes for the largest red spot in its field of view (e.g., ethology grad student with construction paper)
  - **Only red thing should be an adult tern**
  - **Closer = larger red area**

1973 Nobel in physiology / medicine

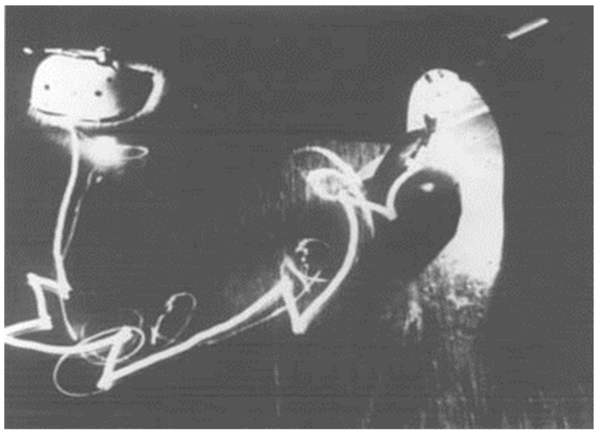
Arctic Tern: the feeding releaser

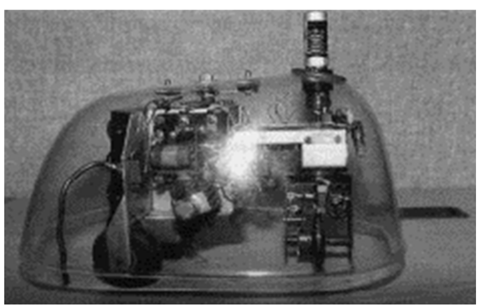


Analog reactive robots

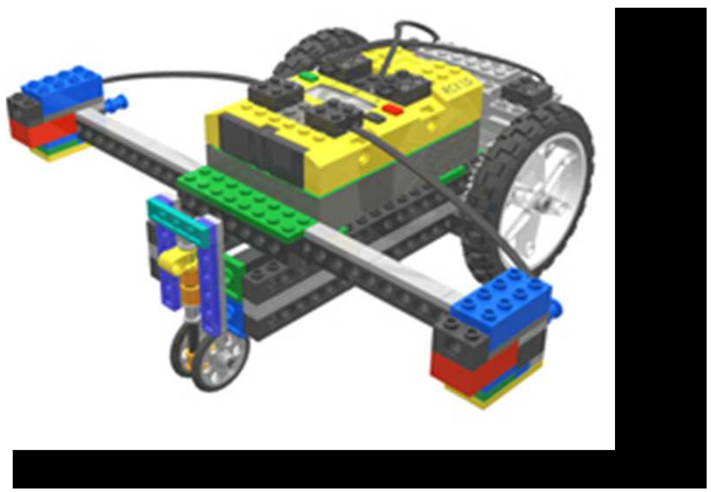
“Tortoise” Gray Walter Valentino Braitenberg Mark Tilden “BEAM”

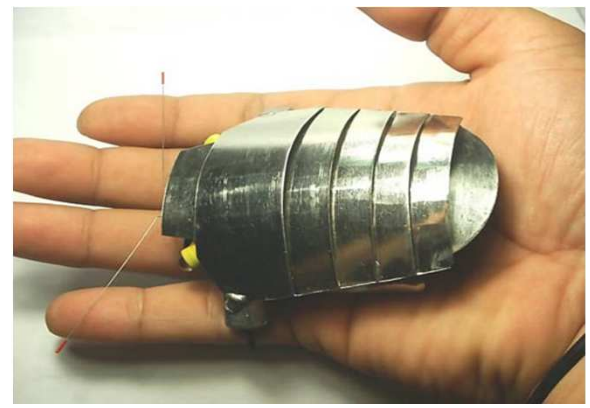
commercial products…





“light-headed” behavior





http://haroldsbeambugs.solarbotics.net/mercury.htm

robot made from Playstation pieces…!

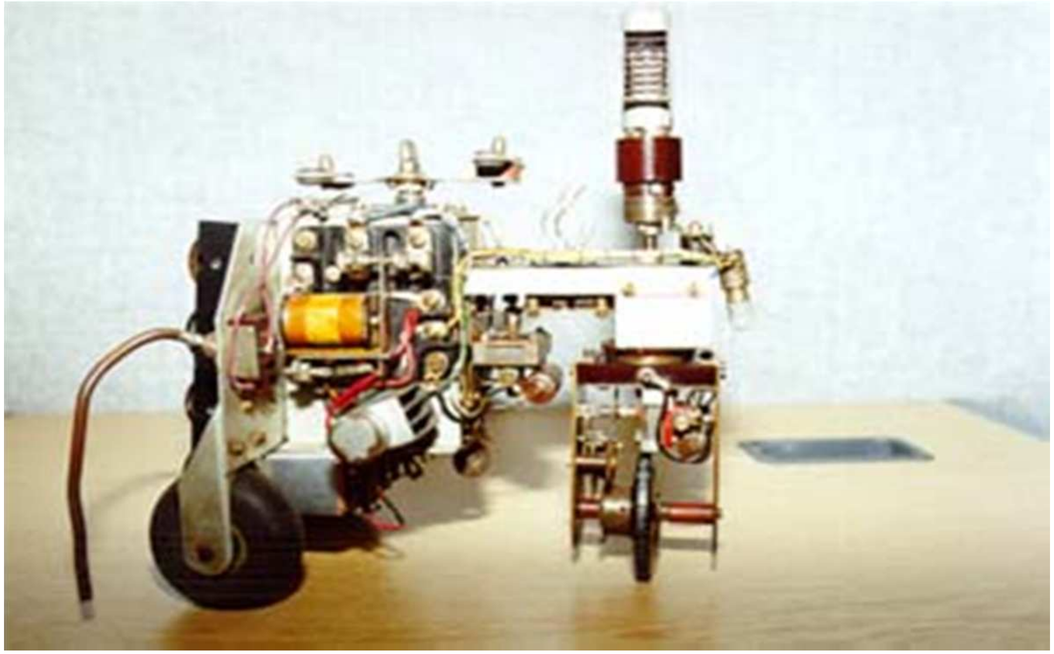
http://people.cs.uchicago.edu/~wiseman/vehicles/

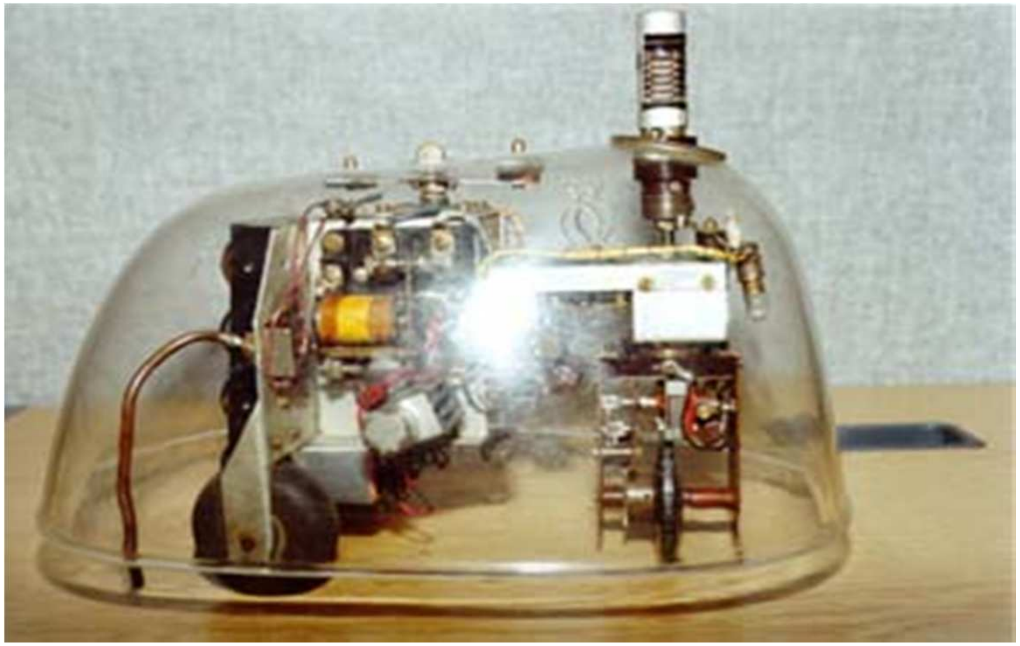
http://www.youtube.com/watch?v=NJo5HEdq6y0

1951 1984 1989- …

stateless…

Phototropism (*photo taxis*)





Machina speculatrix
Elsie and Elmer

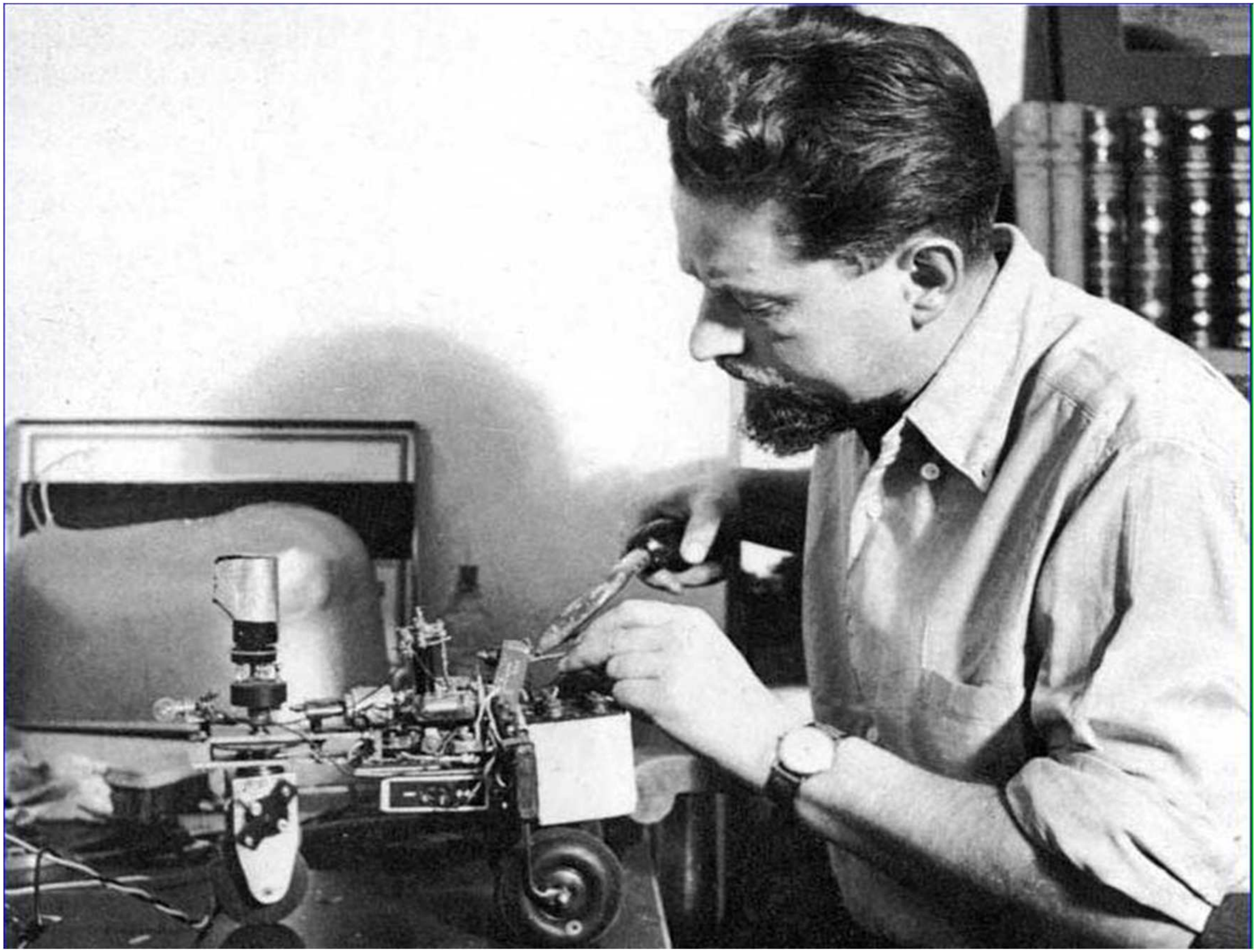
–Two receptors, two nerve cells, two effectors

–Receptors: photo-electric cell, and touch sensor

–Effectors: drive motor for front wheel, and motor for control of steering. (both full or half speed).

–Nerve cells – interlinked amplifiers that controlled motors

Grey Walter Soldering Elsie



Fancy names for behaviours

- Parsimony – simple reflexes as basis for behaviour
- Attraction (positive tropism) – moves towards moderate light
- Aversion (negative tropism) moves away from e.g. obstacles and slopes

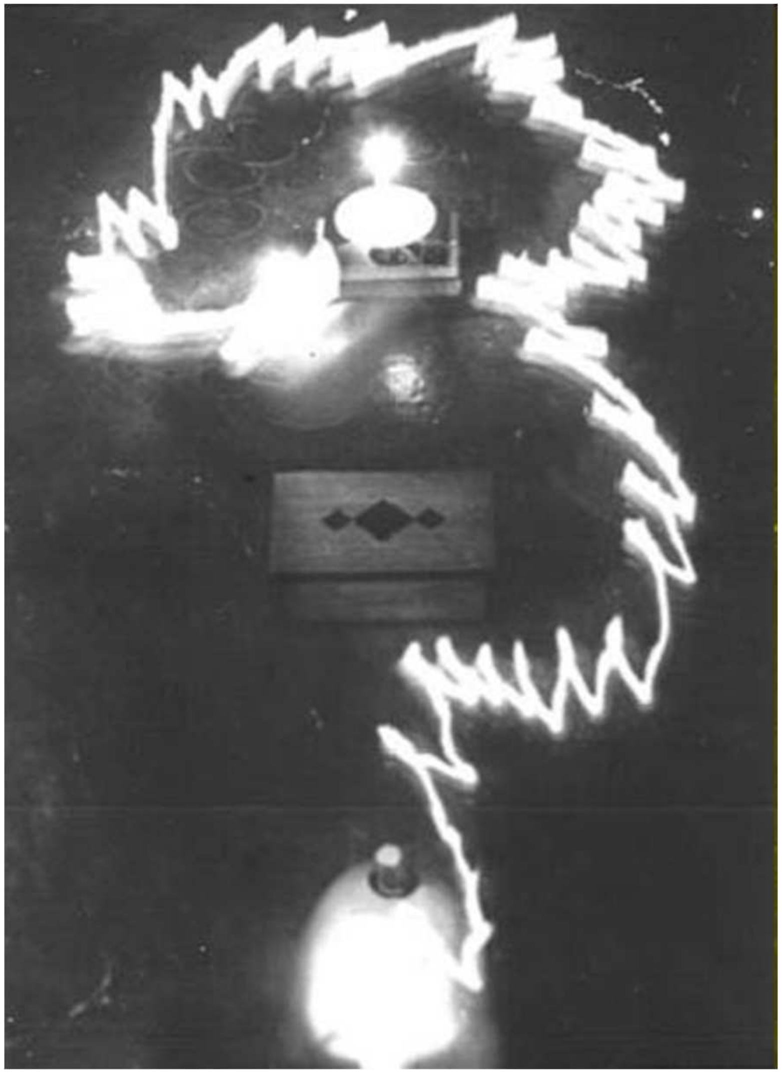
Behaviours of electronic tortoise

- Seeking light: sensor rotated until weak light detected
- Head towards weak light
- Back away from bright light
- Turn and push (to avoid obstacles)
- Recharge battery – when power low, strong light became attractive.
- Tortoise returned to recharge – when recharged bright light repelling.

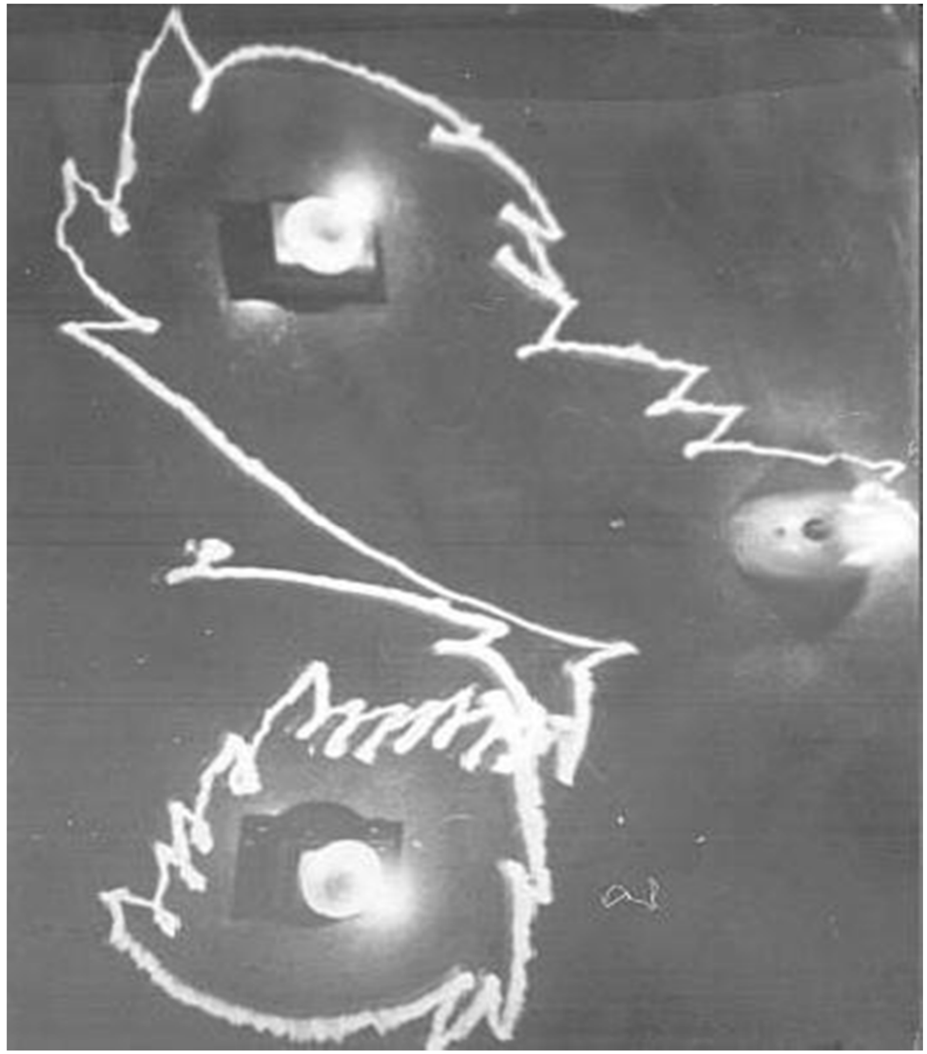
Tortoise behaviours

- Dark: steering motor rotated, drive motor half speed.
  - *Wandering round in series of arcs*
- Moderate light detected:no scanning or steering
  - *Drive towards source of light*
- Bright light: steering motor half speed, drive motor full speed
  - *Turn away from light*

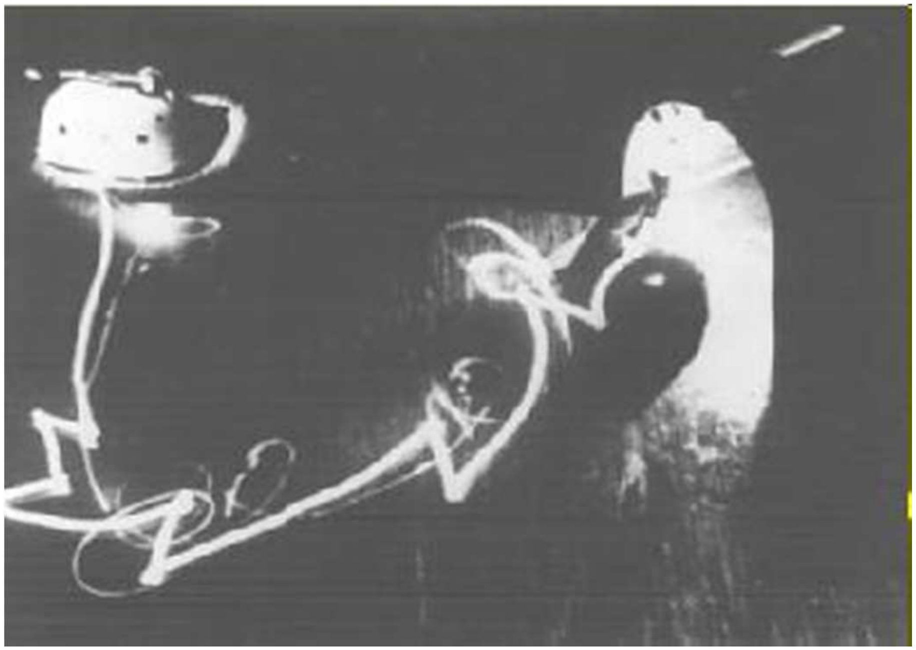
Avoids the stool and approaches the light



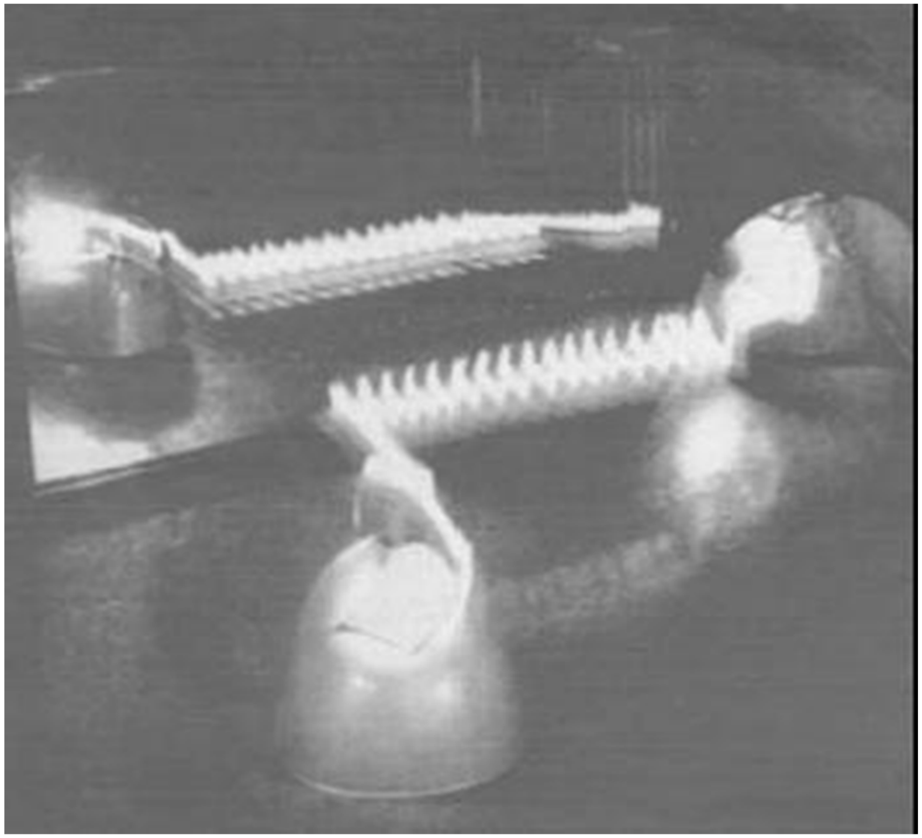
Circling two lights (choosing between alternatives)



Entering the hutch – the thin light is the pilot light

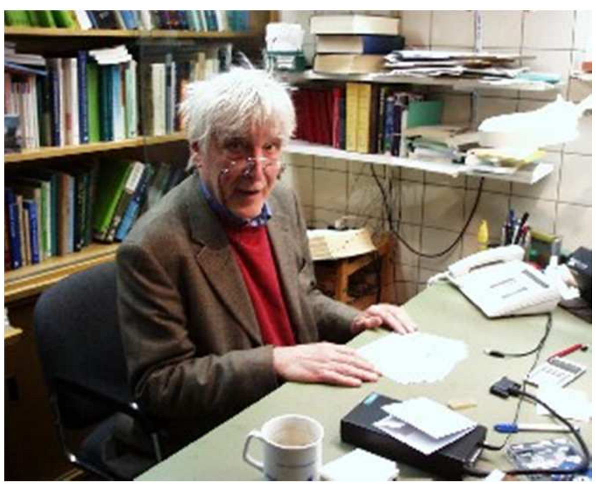


Elsie performing the famous mirror dance



Braitenberg vehicles

- Valentino Braitenberg (1984)
- "*Vehicles: experiments in synthetic psychology*"
- Vehicles with simple internal structure that generate behaviours that appear complex.
- Like Grey Walter's tortoise – systems fixed, and not reprogrammable
- Vehicles used inhibitory and excitatory influences, directly coupling sensors to motors



Vehicle 1

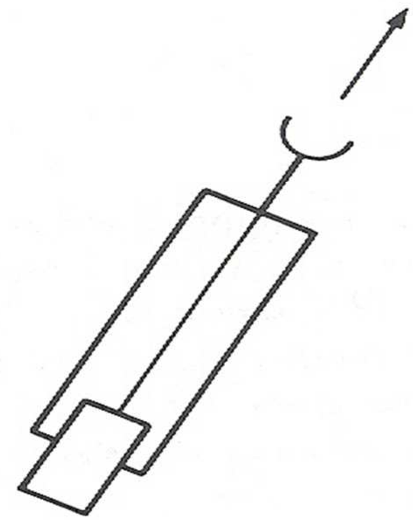


Figure 1
Vehicle 1, the simplest vehicle. The speed of the motor (rectangular box at the tail end) is controlled by a sensor (half circle on a stalk, at the front end). Motion is always forward, in the direction of the arrow, except for perturbations.

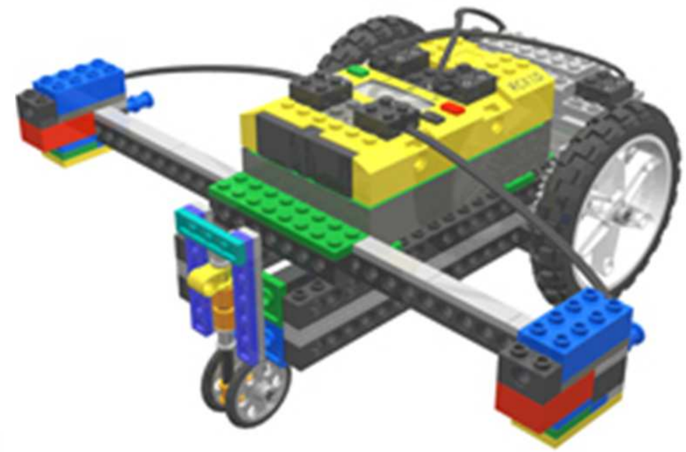
Vehicle 1

- His innovation with this vehicle: the propulsion of the motor is directly proportional to the signal being detected by the sensor; so, the stronger the sensed signal, the faster the motor.

Other simple options to control speed behaviour

- E.g. moving in water, with temperature sensor.
- Will slow down in cold and speed up in warm
- Appears to dislike warm water
- Underlying idea – the observer of the system may infer a more complex mechanism than the one that actually underlies the system.

Vehicle 2: Fear and aggression



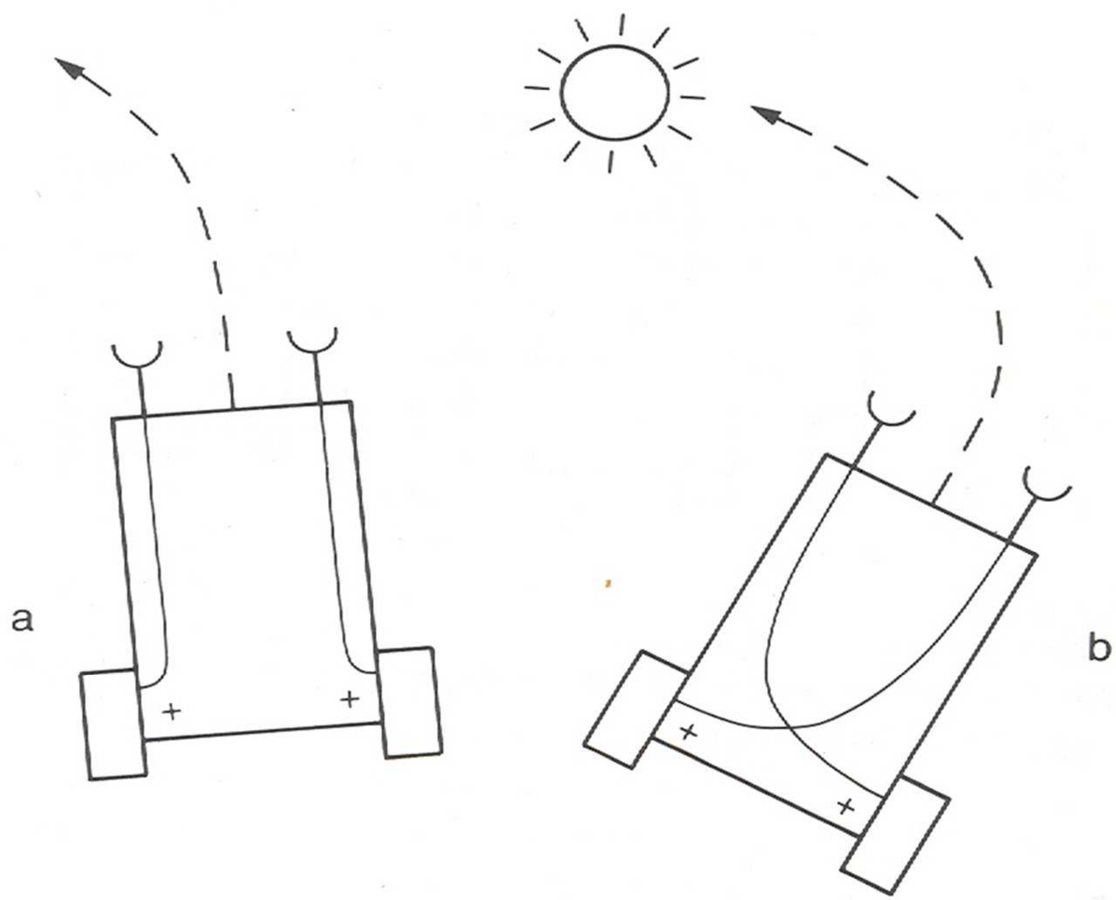


Figure 3
Vehicles 2a and 2b in the vicinity of a source (circle with rays emanating from it). Vehicle 2b orients toward the source, 2a away from it.

Vehicle 2a and 2b

- 2a: if sources directly ahead, vehicle will charge at it. Otherwise will turn away from it ("coward")
- 2b: if source to the side, will charge at it ("aggressive").

Vehicle 3: Love

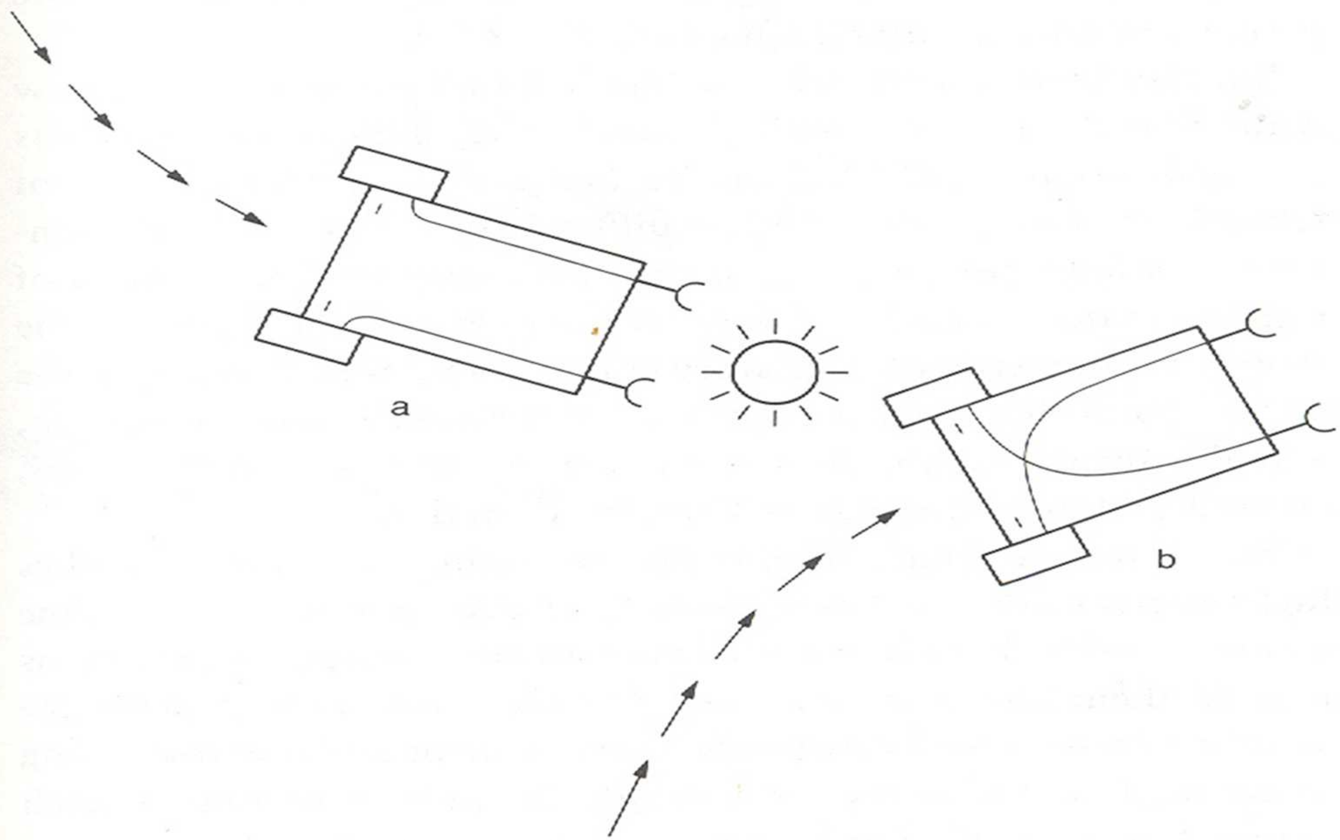


Figure 4
Vehicle 3, with inhibitory influence of the sensors on the motors.

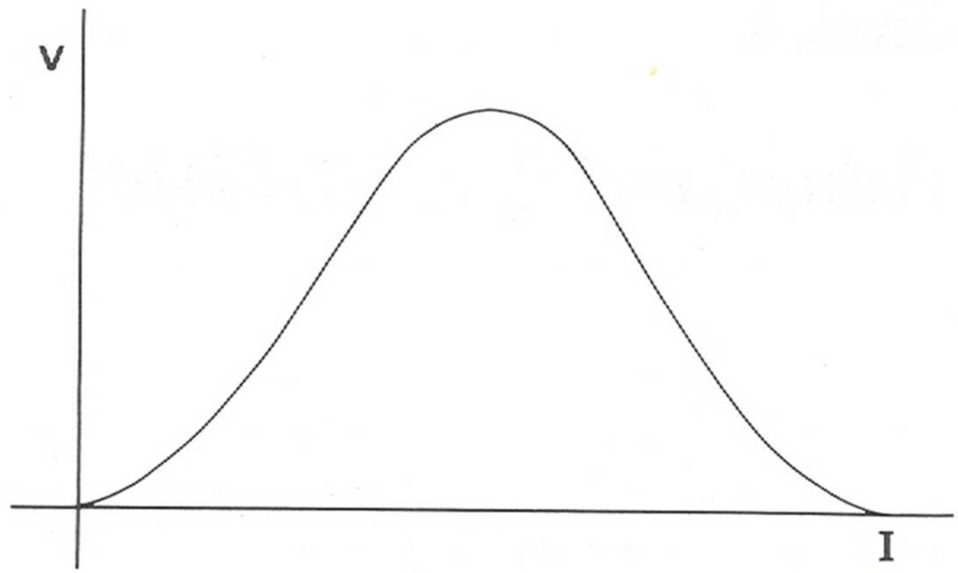
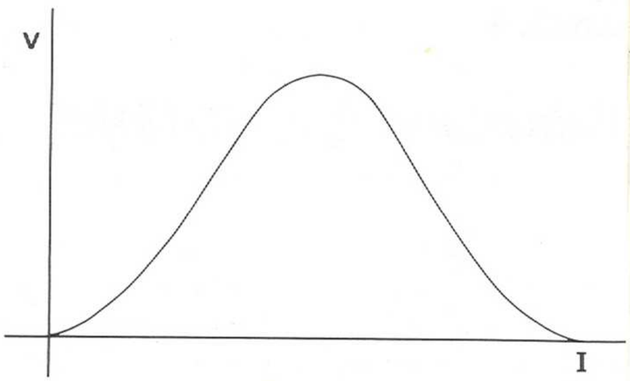


Figure 6

A nonlinear dependence of the speed of the motor V on the intensity of stimulation I, with a maximum for a certain intensity.

Vehicle 4



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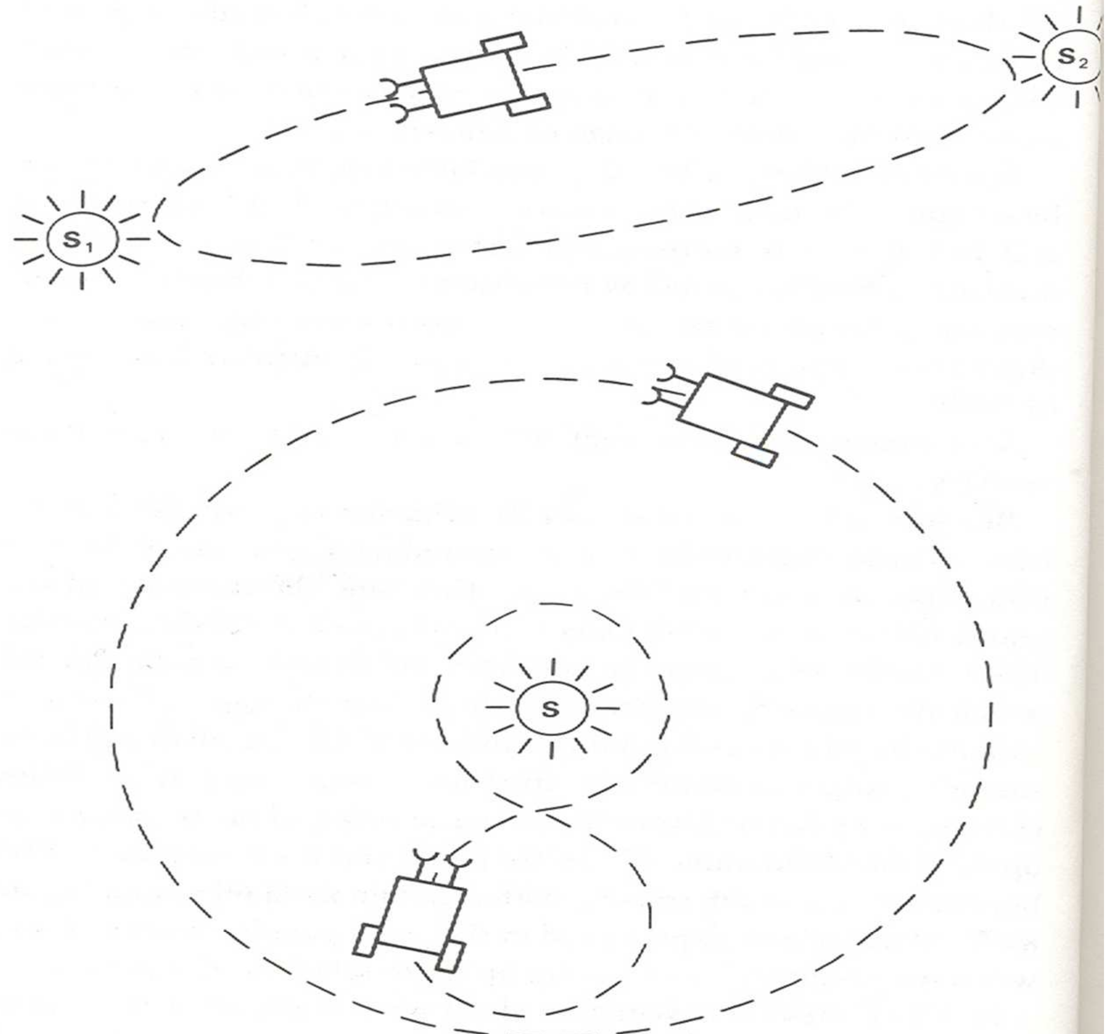


Figure 7

Trajectories of vehicles of brand 4a around or between sources.

Summary: Braitenberg vehicles

- Vehicles appear more complex than they are –
- Easy to overestimate complexity, and assume they have knowledge, are deciding what to do, etc.

UA Lego Breitenberg:
http://www.youtube.com/watch?v=NJo5HEdq6y0

The behavioural response of the coastal snail

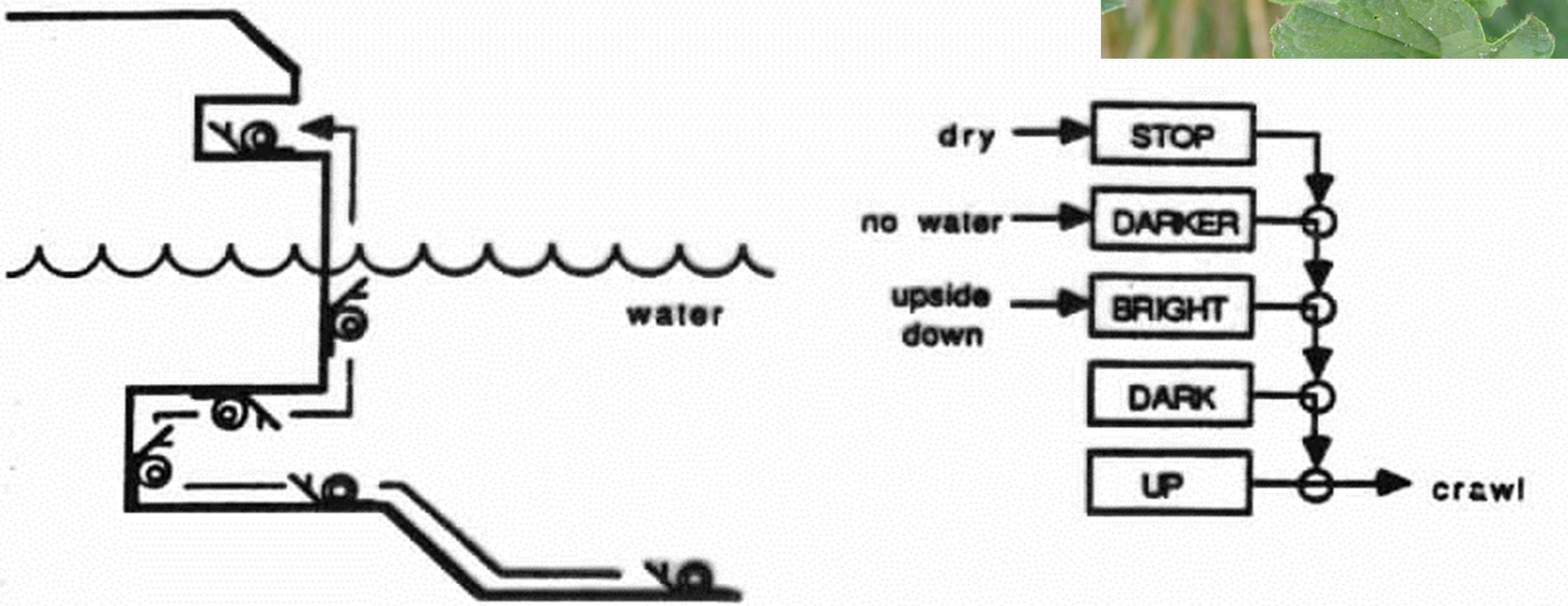


Figure 1-3. The coastal snail may be controlled by a fixed hierarchy of behaviors. The combined effects of these behaviors enables the snail to navigate to its feeding area.

Behavior-based control

Behavior a direct mapping of sensory inputs to a pattern of task-specific motor actions

sense ⟷ act

extinguish
approach
wander →

“Vertical” task decomposition

little explicit deliberation except through system state

SENSING

→ planning and reasoning →
→ identify objects →
→ build maps →
→ explore →
→ wander →
avoid objects

ACTING

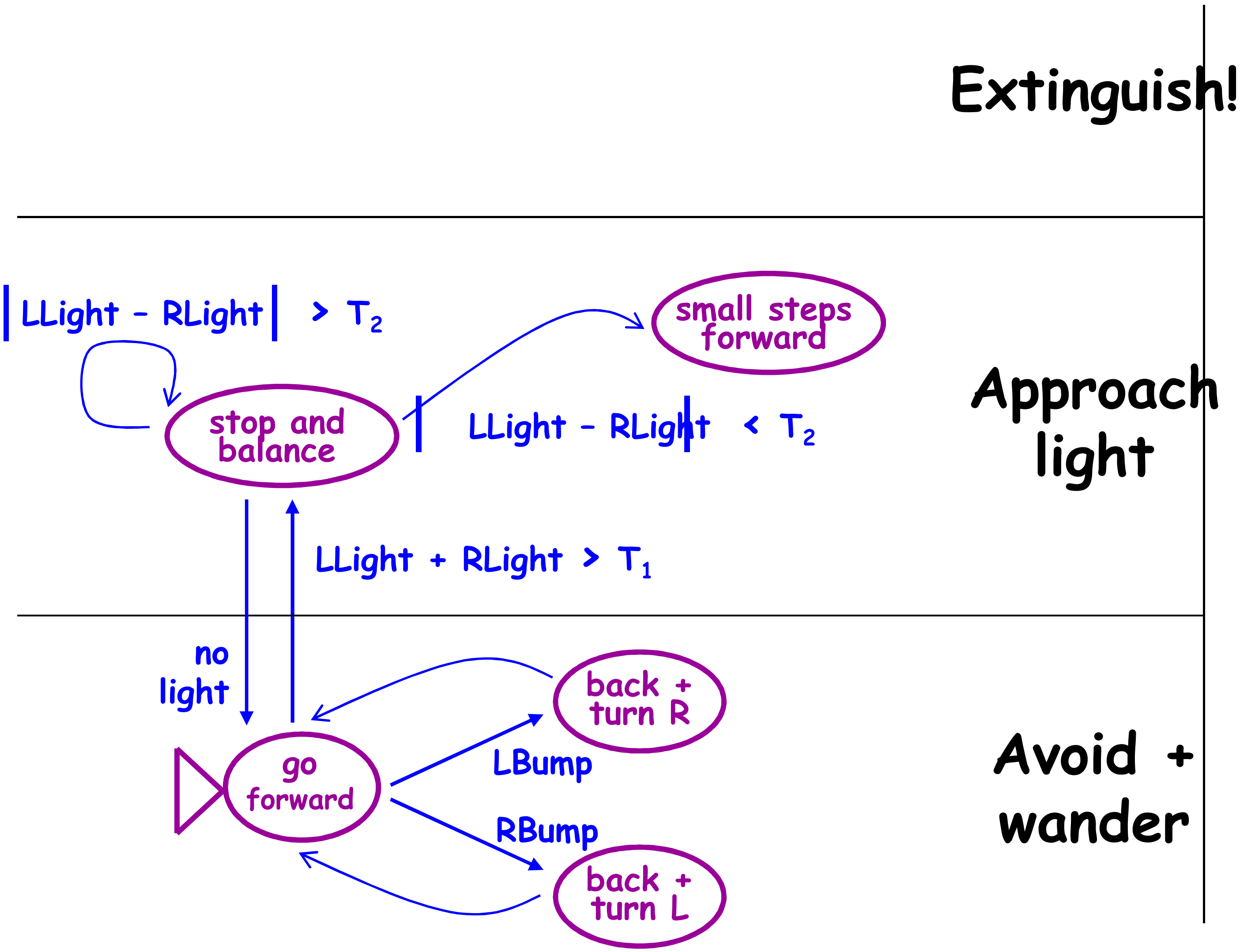
Genghis

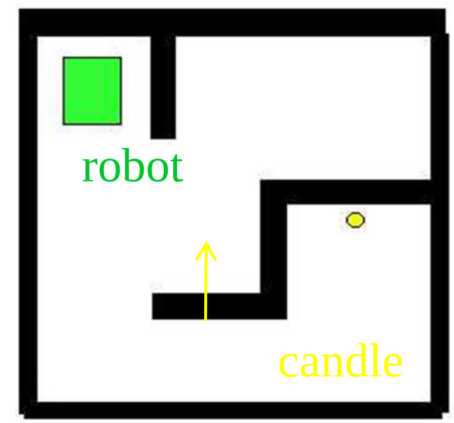
• • • 1985 • • •

“*Quiz*”: A fire-extinguishing state machine

Complete this finite state machine that is controlling the robot…

then find the bug in the bottom layer!





Sensing

LBump - left bump

RBump - right bump

LLight - left light

RLight - right light

Actuation

Go - go forward

Fan - turn fan on

TurnL - turn left

TurnR - turn right

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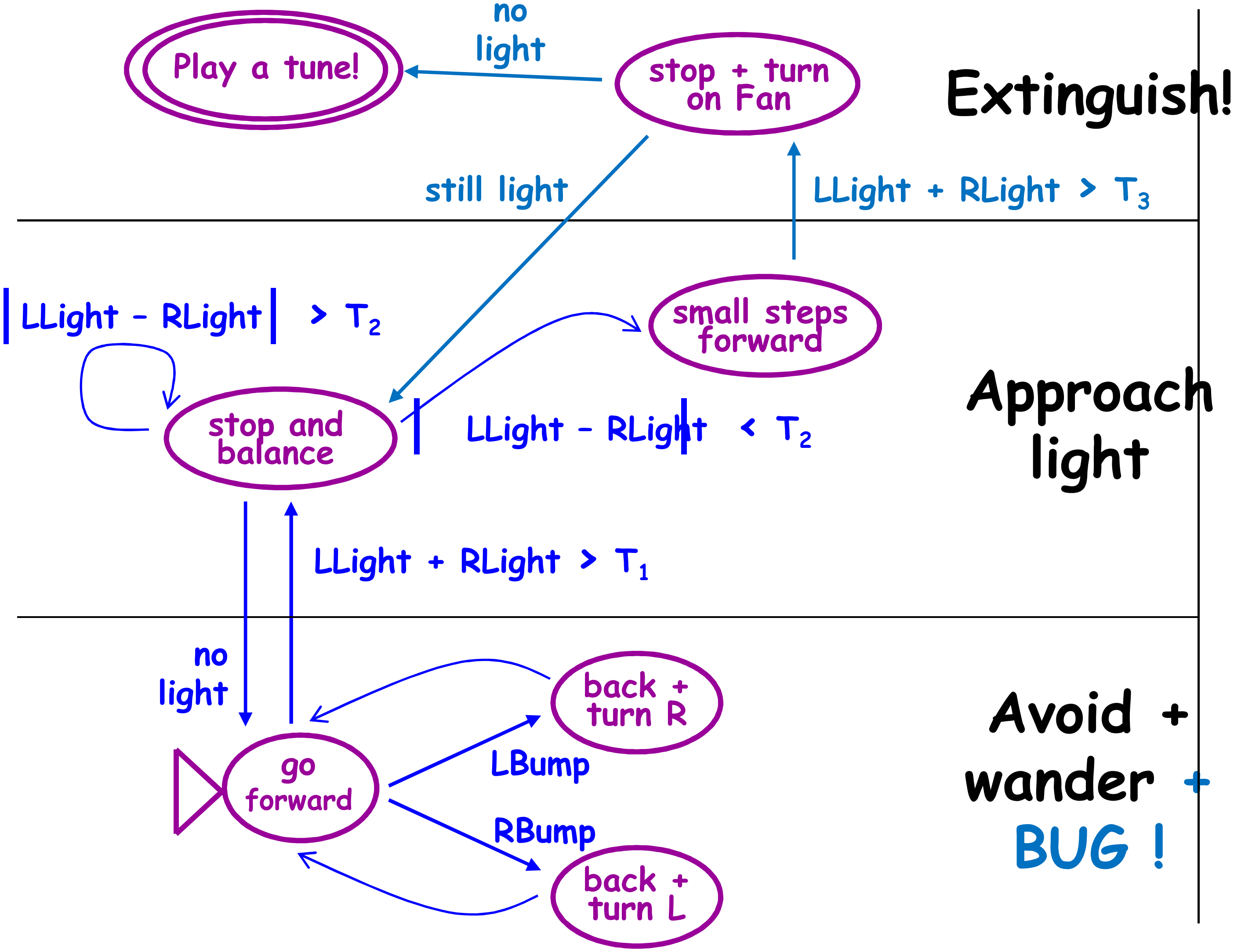

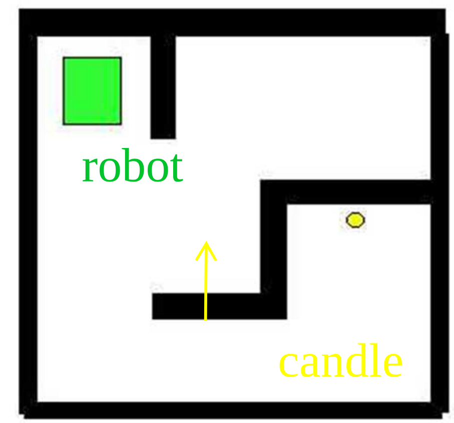

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…nguish
…roach
…nder

…e explicit deliberation except through system state

"Subsumption architecture"

planning and re…

id…

…aps

explore

wander

avoid objects

SENSING

ACTING

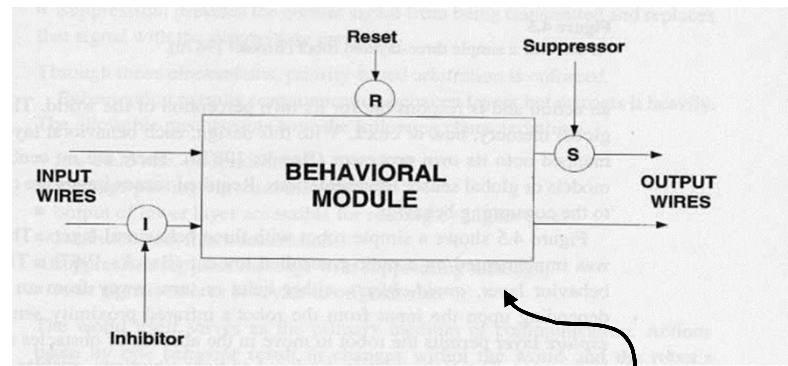
Genghis

… 1985 …

Subsumption

• **Subsumption** composes simple reactions (behaviors) by letting *one* take control at an appropriate time.

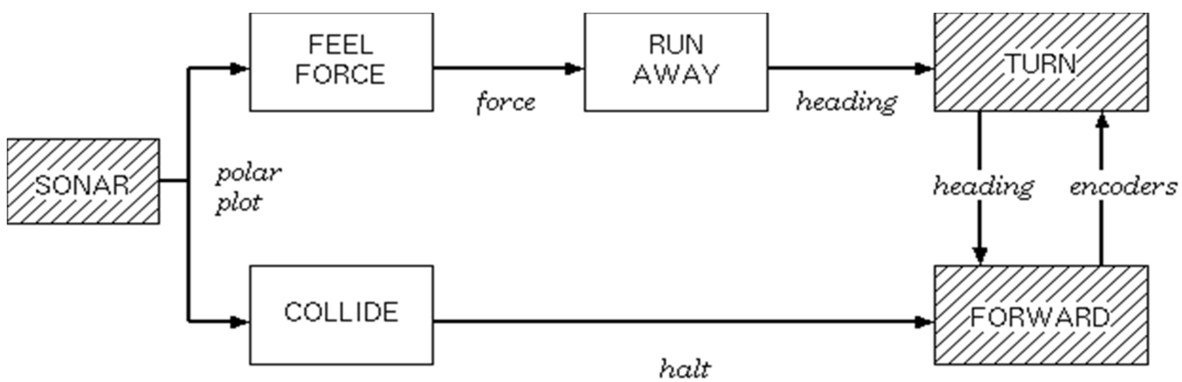
• State is maintained in a task-specific manner, and internal mechanisms may also be used as input (timers)



behavioral module

Behavioral stimulus-response modules can

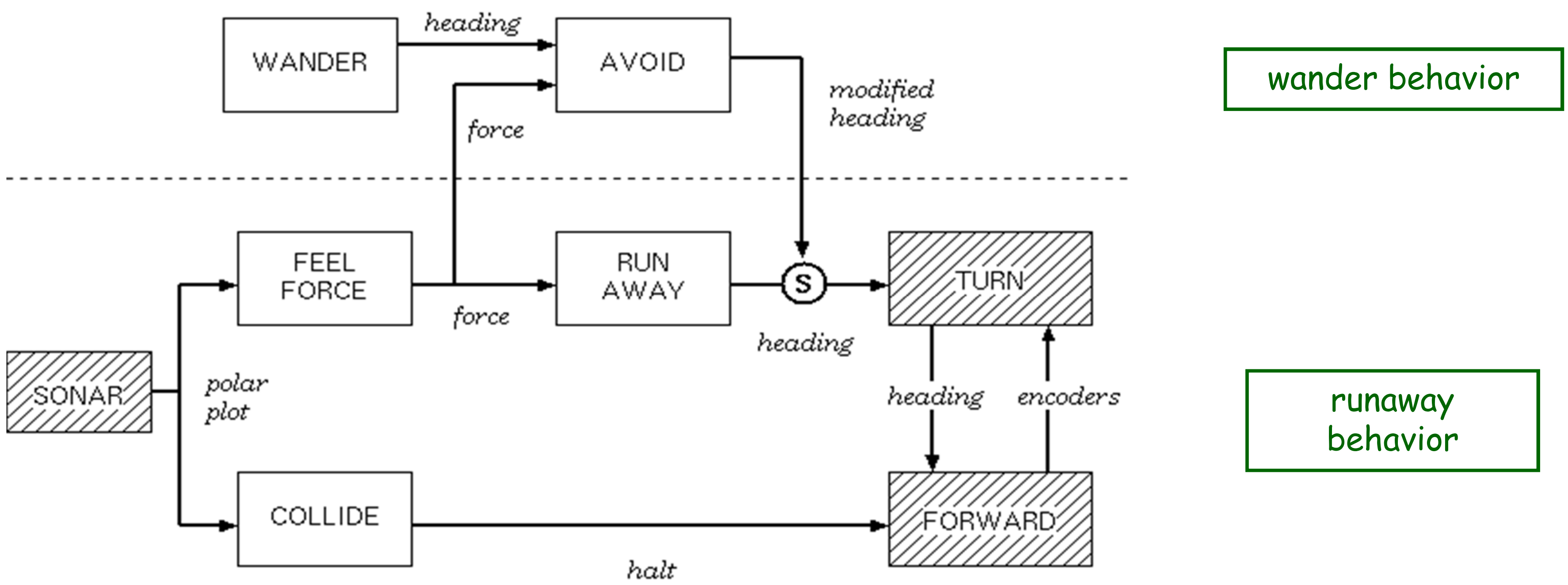
- inhibit (I) other modules
- reset (R) other modules
- suppress/subsume (S) others



run behavior

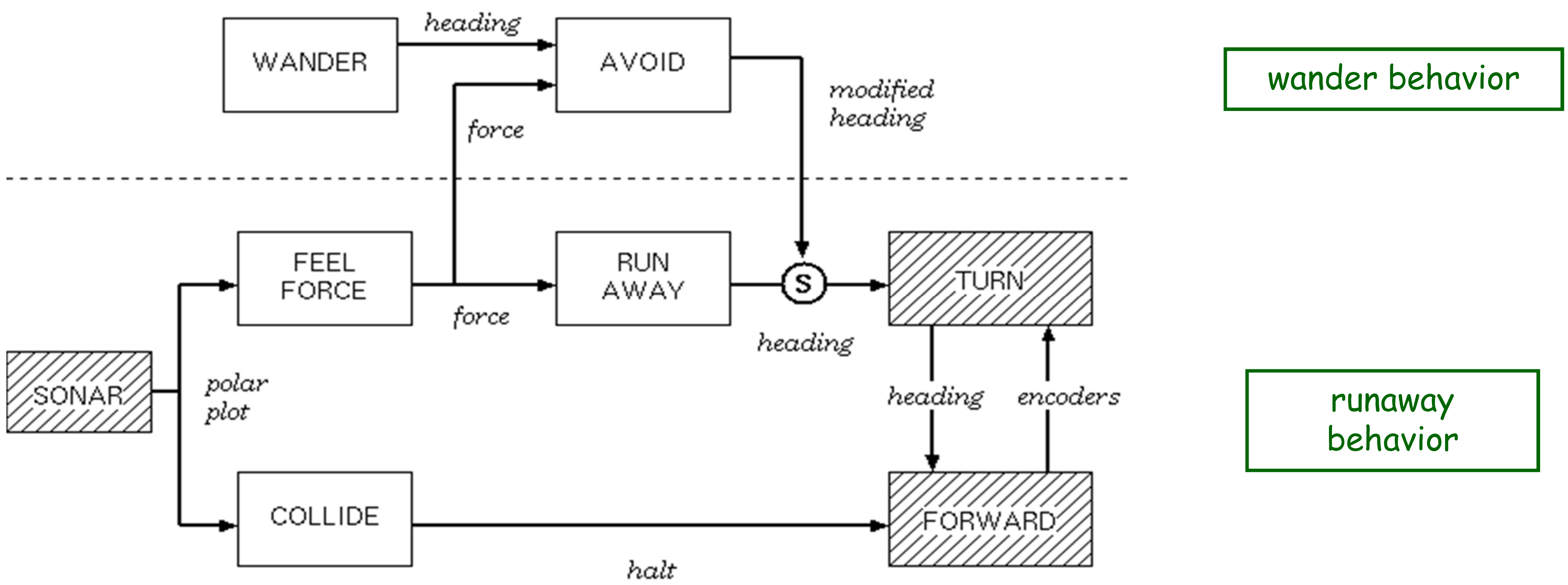
Subsumption

- **Subsumption** builds intelligence incrementally in layers



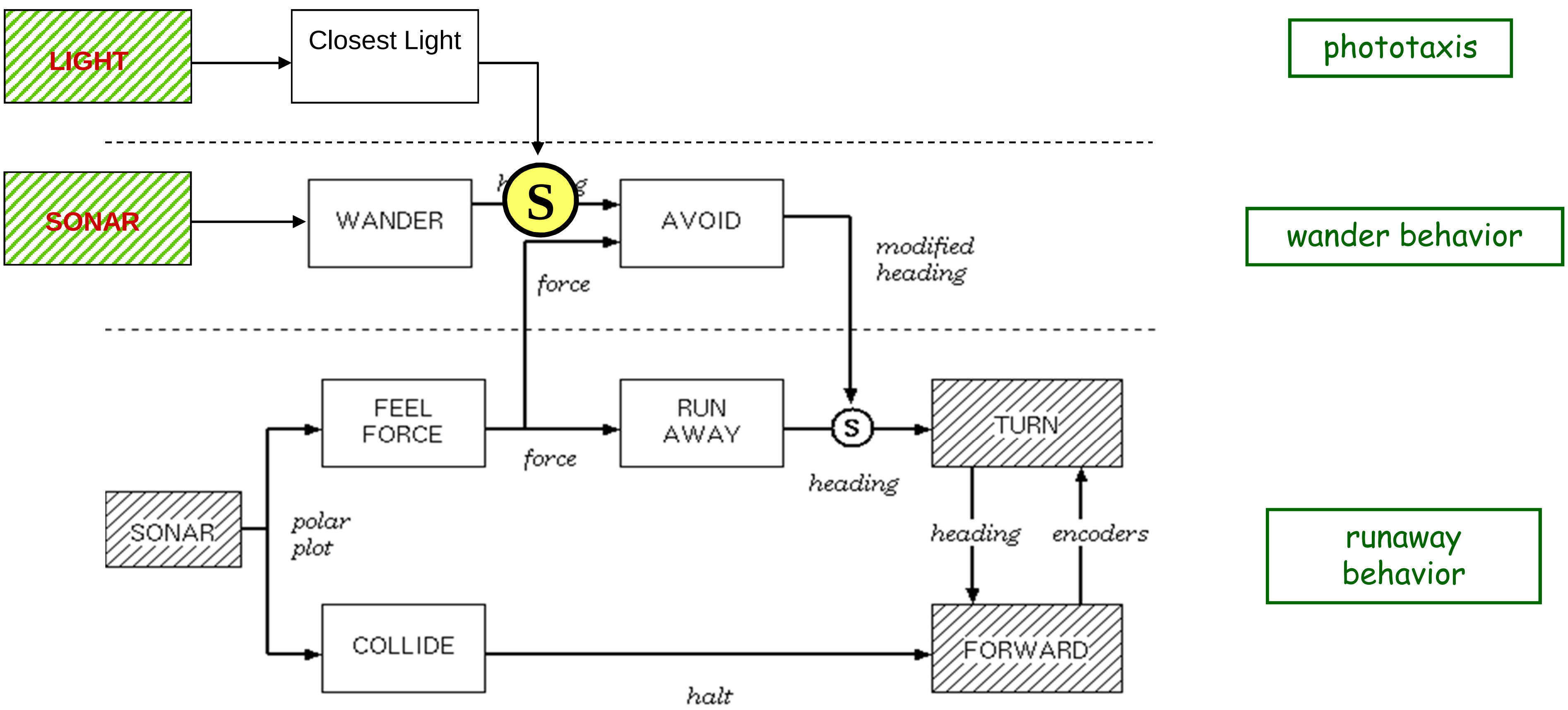
Subsumption

• Where would a light-seeking behavior/layer connect?



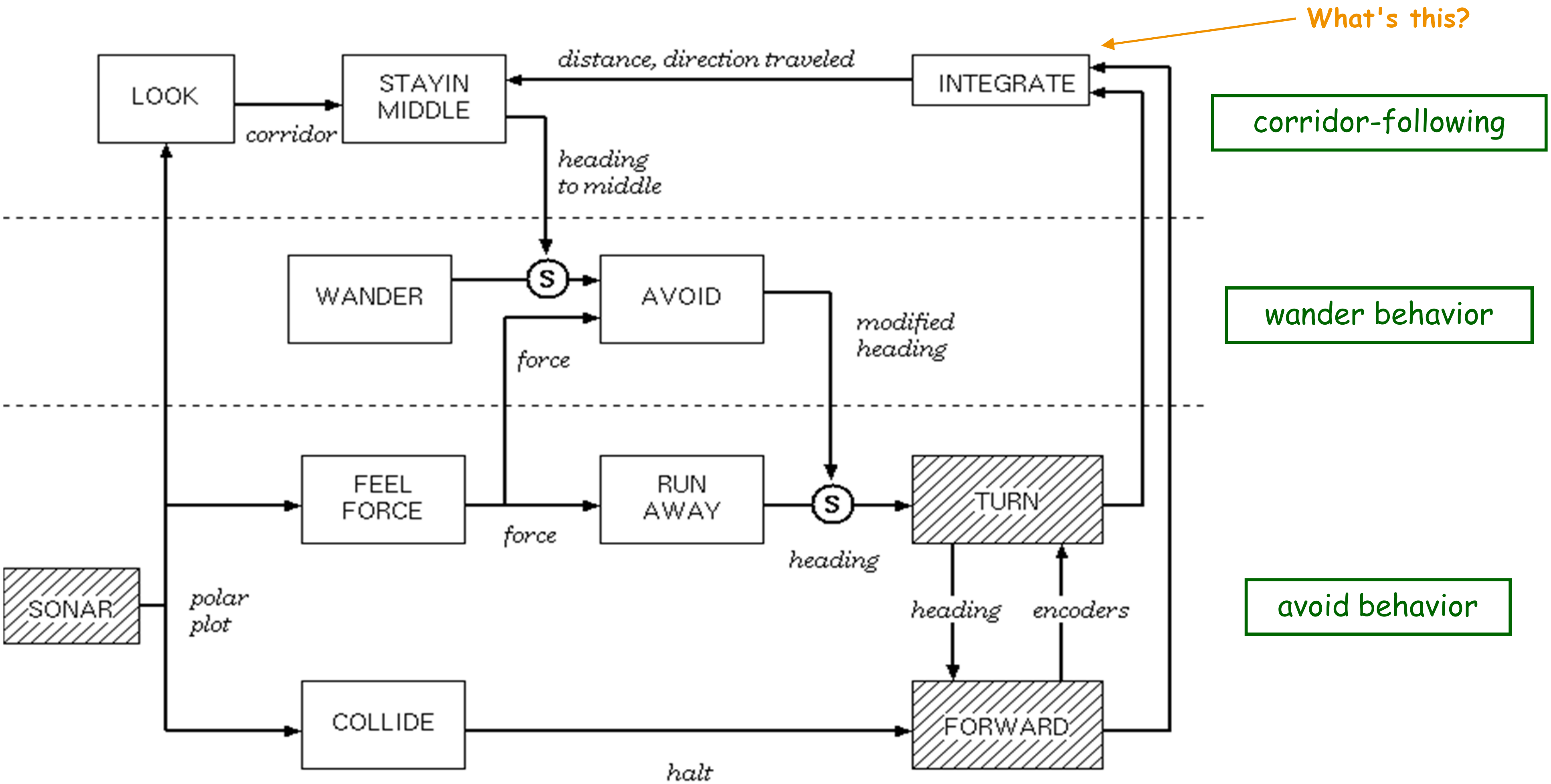
Subsumption

- Where would a light-seeking behavior/layer connect?

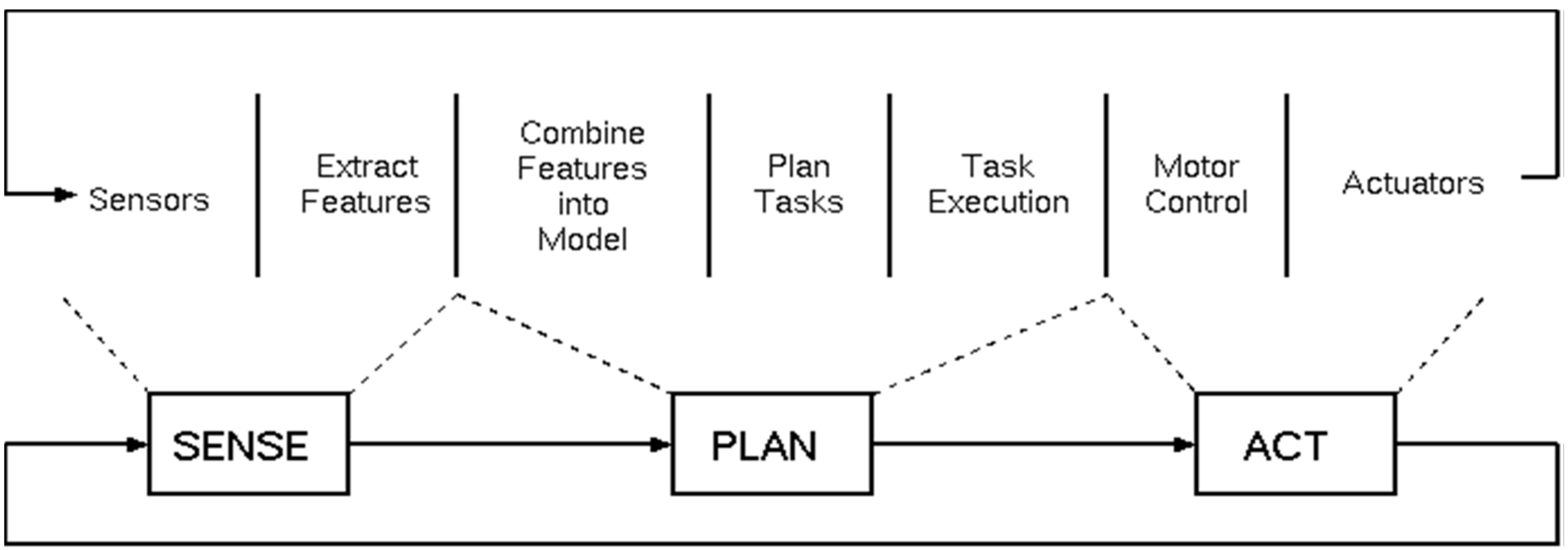


Another subsumption example

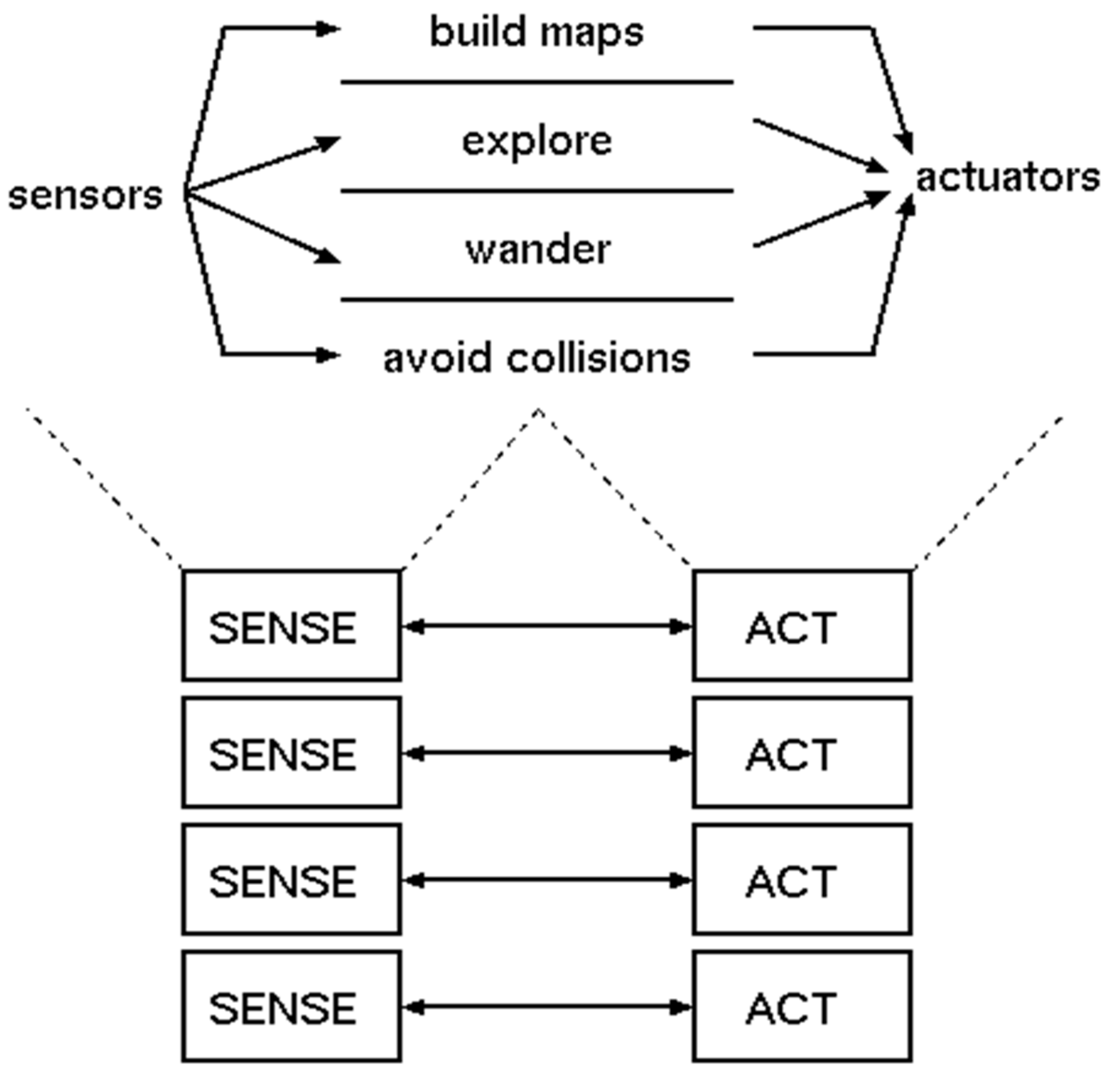
- Or, corridor-following was implemented on several robots:



Hierarchical Organization is "Horizontal"



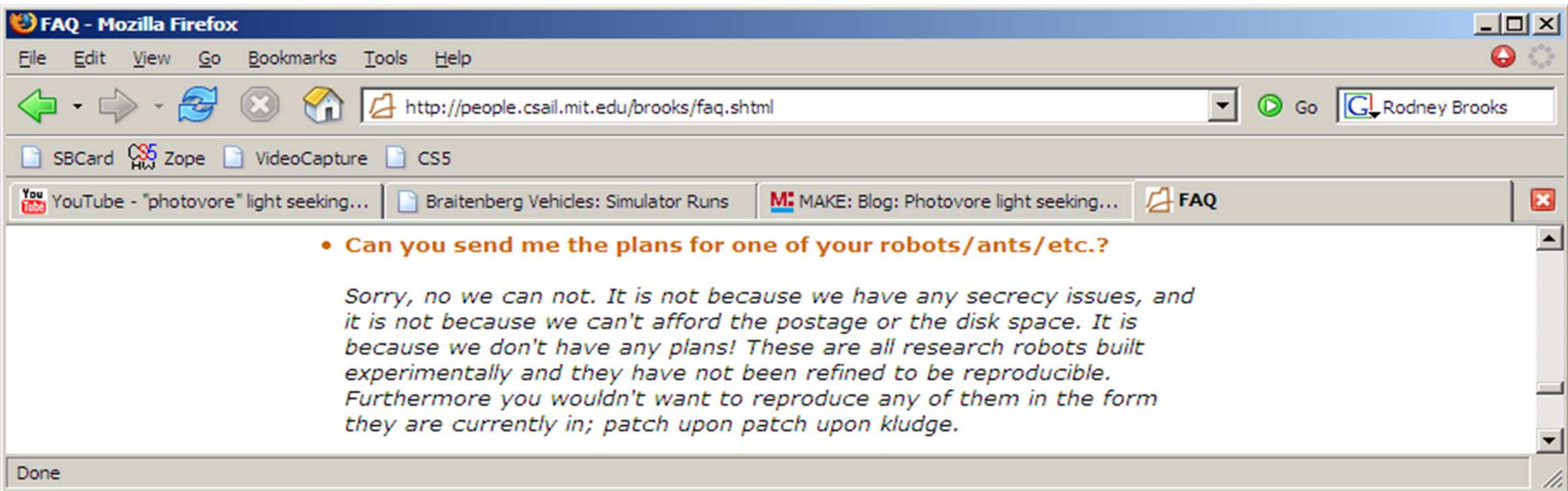
More Biological is "Vertical"



Subsumption - Limits

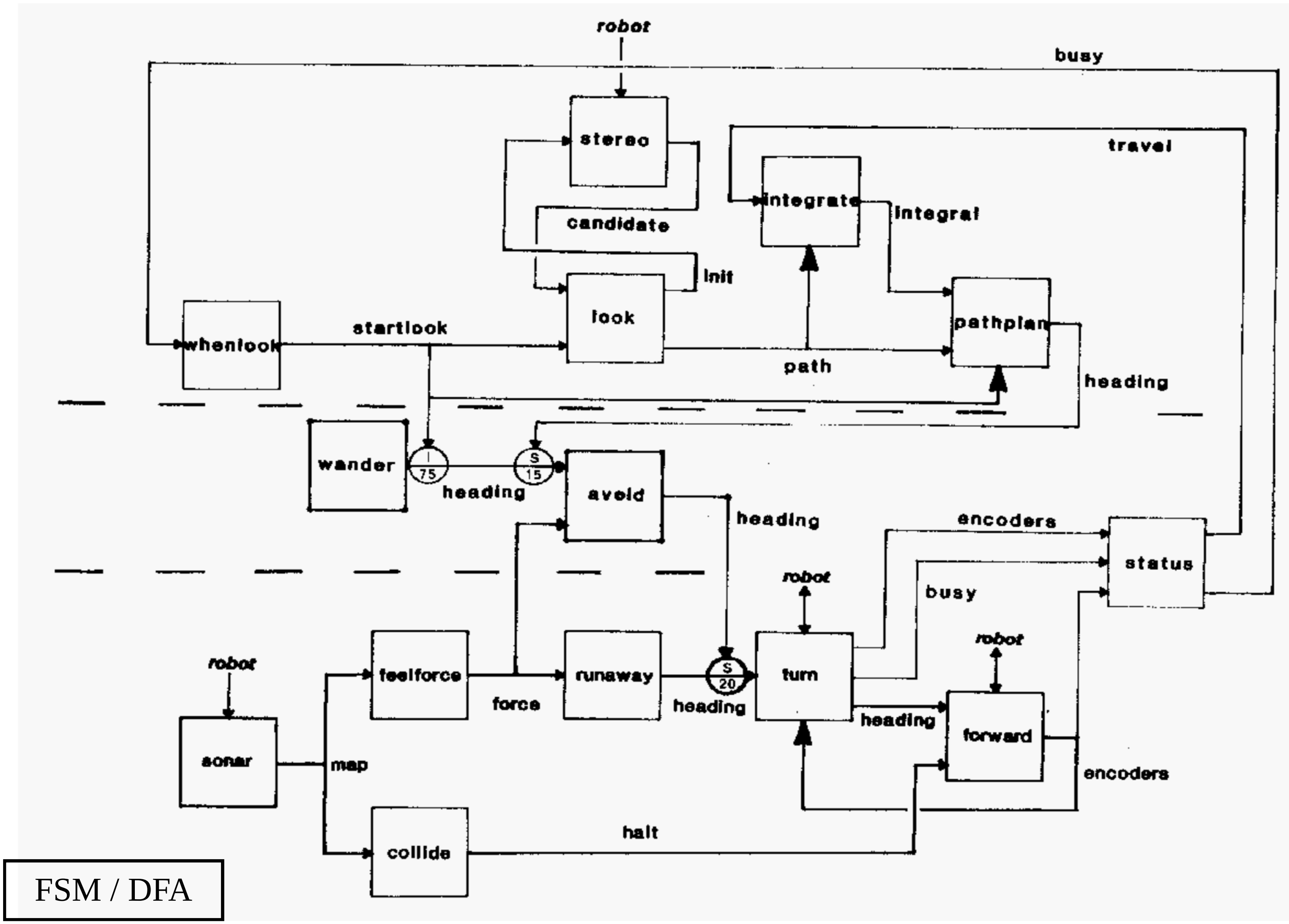
Reaching the end of the subsumption architecture and purely reactive approaches.

Herbert, a soda-can-collecting robot



Success of behavior-based systems depends on how well-tuned they are to their environment. This is a huge strength, but it's also a weakness …

Subsumption ***limits***: Genghis



navigate behavior

wander behavior

runaway behavior

FSM / DFA

Unwieldy!

Larger example -- Genghis

1) *Standing* by tuning the parameters of two behaviors:
the leg “swing” and the leg “lift”

2) *Simple walking*: one leg at a time

3) *Force Balancing*: via incorporated force sensors on the legs

4) *Obstacle traversal*: the legs should lift much higher if need be

5) *Anticipation*: uses touch sensors (whiskers) to detect obstacles

6) *Pitch stabilization*: uses an inclinometer to stabilize fore/aft pitch

7) *Prowling*: uses infrared sensors to start walking when a human approaches

8) *Steering*: uses the difference in two IR/range sensors to follow

57 modules wired together !

Maximizing capability and autonomy

how much of the world do we need to represent internally ?

Robot Architecture

how should we internalize the world ?

what outputs can we effect ?

what inputs do we have ?

what algorithms connect the two ?

how do we use this “internal world” effectively ?

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little explicit deliberation except through system state

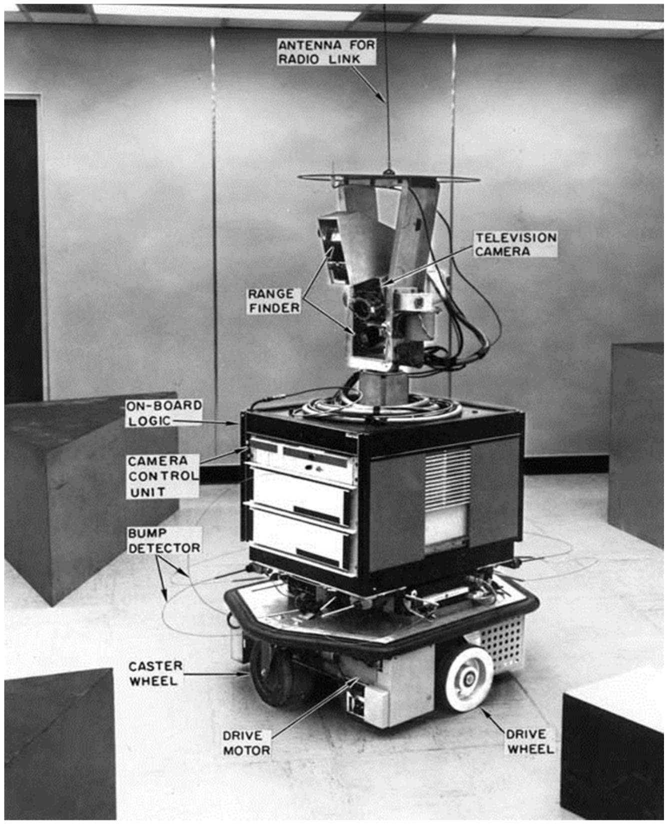
SENSING → planning and reasoning → ACTING
identify objects
build maps
explore
wander
avoid objects

Genghis

• • • 1985 • • •

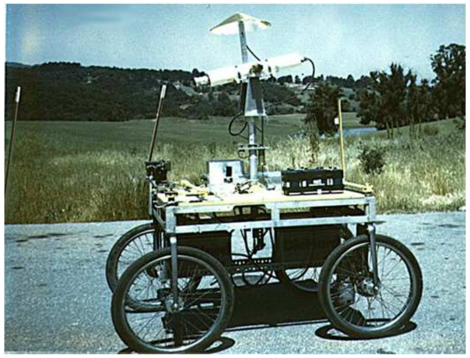
Sense - Plan - Act

Shakey

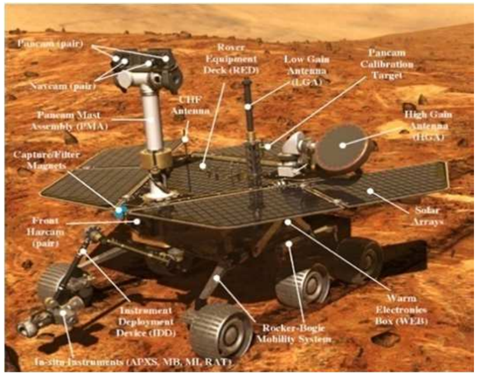


SENSING | perception | world modeling | planning | task execution | motor control | ACTING

sense → plan → act



Stanford Cart



MERs

• • • 1968 — 1976 — … - 2009 • • •

Robot Plot

World Modeling

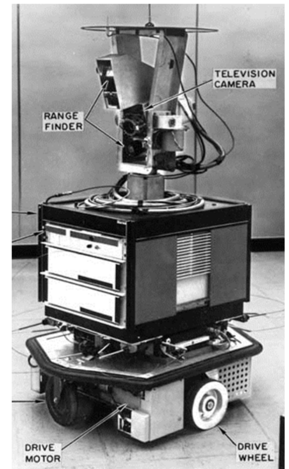
more

less

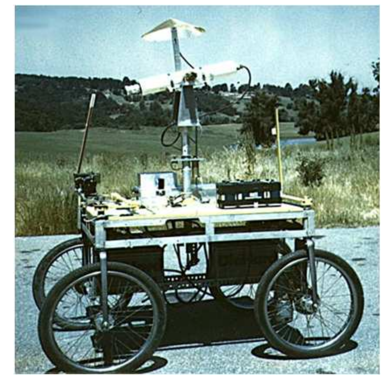
Capability (0-10)

Al Gore (11)

Sims (5)



Shakey (3)



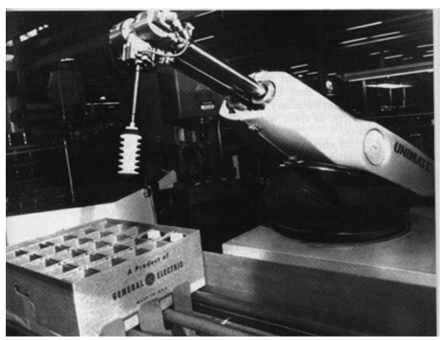
Stanford Cart (3)

Bar Monkey (9)

MERs (8)

Stanley/Boss (9)

da Vinci (2)



Unimate (4)

Roomba (7)

Genghis (3)

human-controlled

Autonomy

CS 154: algorithms for capable, autonomous robots

Robot Architecture

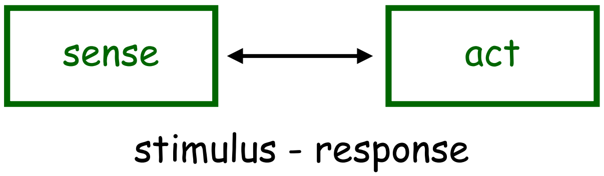
how much / how do we represent the world internally ?

As much as possible!

SPA paradigm

Not at all

Reactive paradigm



Task-specific

Behavior-based architecture

As much as *needed, obtainable, possible.*

Hybrid approaches

Robot Architecture

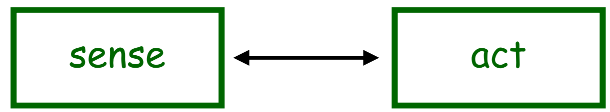
how much / **how** do we represent the world internally ?

As much as possible!

SPA paradigm

Not at all

Reactive paradigm



stimulus - response == "behavior"

Task-specific

Behavior-based architecture
- **Subsumption paradigm**
- Potential Fields (later)

} different ways of composing behaviors

Choice: As much as *needed, obtainable, possible.*

Hybrid approaches