Perception-Action paradigm: perception in embodied AI / robots

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Additional reading

- From textbooks (available at LRC; see reading list Module Guide):
  - From *Behavior-Based Robotics*: Chapter 7 (also chapter 5, which is about representations; these are not covered in the lectures in detail but they are relevant for those interested in robotics)
  - From *Understanding Intelligence*: Chapter 12

Paradigm shift: classical (symbolic) and embodied paradigms in perception

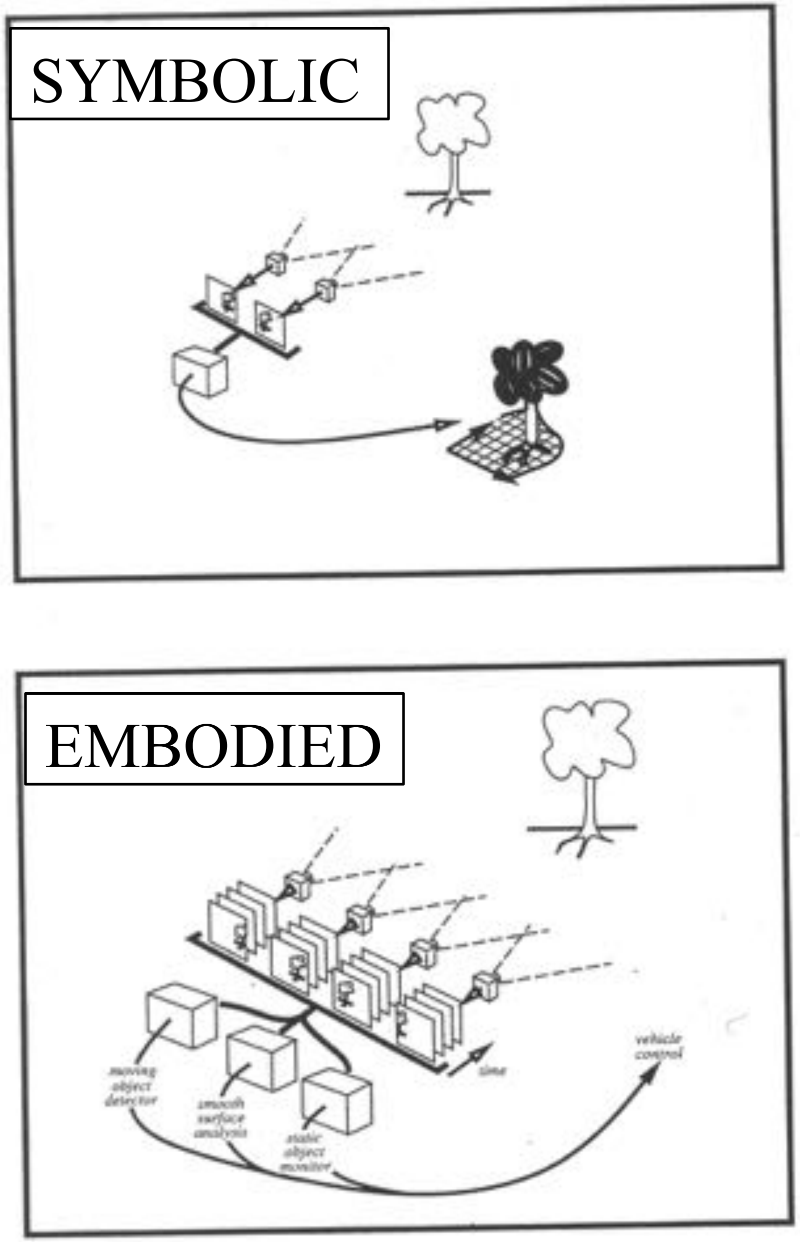


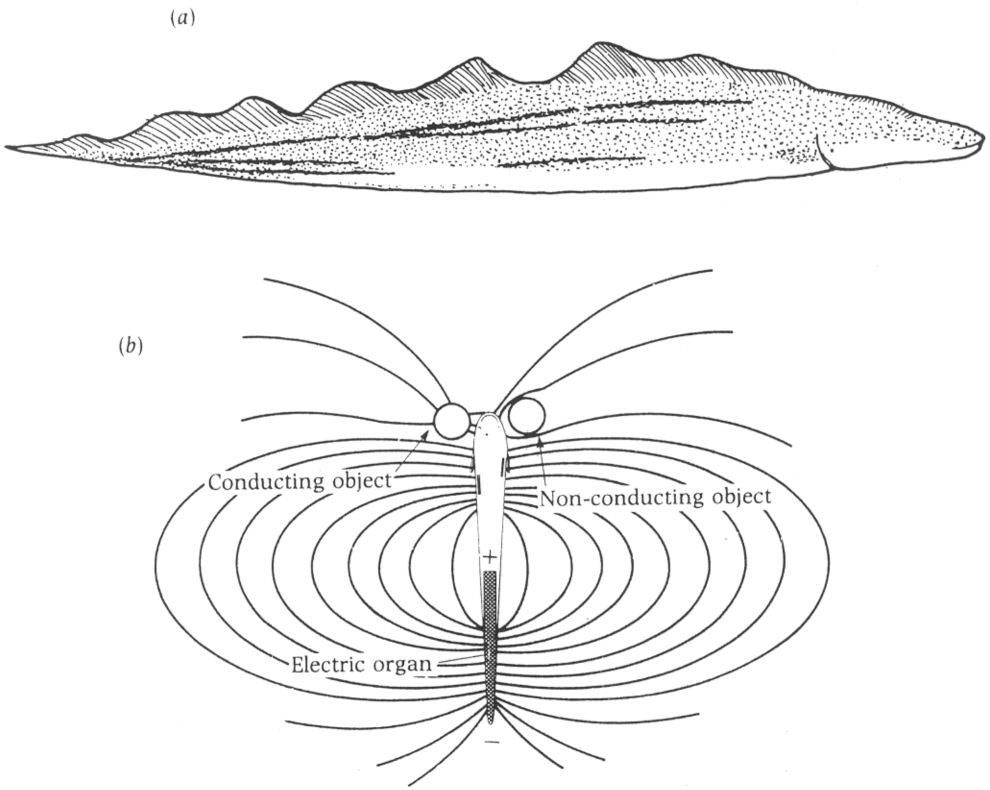
Figure 7.1
Approaches to perception. (Figure courtesy of Bob Bolles).

Perception in embodied AI/robotics

- **Paradigm shift with respect to symbolic / classical AI**:
  - ➢ perception is a partner process with action
- **Duality**:
  - The needs of motor control provide context for perception
  - Perceptual processing is simplified through the constraints of motor action
- Perception ***produces motor control outputs***, not representations
- **Very limited use of representations**:
  - Partial, "intermediate" representations
  - Deictic (indexical-functional) representations: relationship of creature to its environment (e.g. "the object I am pushing", "the resource I am consuming")
- Perception is conducted in a **need-to-know** basis
- A primary purpose of perceptual algorithms is to **support particular behavioral needs** (*dedicated, situated perception*)

Beyond the "five senses"

Figure 3.3. (*a*) The electric fish *Gymnarchus niloticus*, showing the position of its electric organ in strips spreading forward from the tail. The receptors are largely concentrated in the head. (*b*) The fields of force around *Gymnarchus* as altered by the presence of an object of high conductivity (*left*) and by one of low conductivity (*right*). (After H. W. Lissmann & K. E. Machin (1958), *J. exp. Biol.* **35**, 451–86.)



The nature of perceptual stimuli

- **Origin of the received stimuli**:
  - *Proprioception*:
    - The sense of the static position and movement of our fingers and limbs
    - Perception associated with stimuli arising from within the body, e.g. tendon or muscle tension from which limb position or the number of times an action has been repeated are computed
  - *Exteroception*:
    - Perception associated with external stimuli
    - The environment transmits this information via sensory modalities such as vision, touch, smell, audition and taste.
- **Example: orientation**
  - Path integration using *ideothetic information (proprioception),* e.g. stored traveled distance used by insects to return to homesite => supports *open-loop control* (greater error)
  - Orientation using *allothetic (exteroceptive) information*, such as landmarks, sun position, etc. => supports *closed-loop control*

Two types of control loops

- **Closed-loop control**:
  - Use of continuous feedback from external sources
  - A closed-loop control system uses feedback from the results of its output actions to compute the deviation between what it is “commanded” to do and what is actually accomplished
  - The feedback is used as one of the inputs to the controller
- **Open-loop control**:
  - An open-loop control system has no means to evaluate the difference between the commanded action and the actual result
  - No feedback is available as input to the controller
  - Greater error due to noise during locomotion

Action-oriented perception

- *How can perception provide information needed for behavior?*
- Perception is performed **within the context of a behavior** (selective, dedicated, purposive, situated perception)
- Perception is conducted in a "**top-down**" manner and on a **as-needed** basis:
  - Perceptual control and resources are determined by behavioral needs
  - The world is viewed differently based upon the creature's needs & goals
- **The task (behavior) determines**:
  - The specifications for a perceptual process: what must be discerned from the environment & constraints on its location
  - the perceptual strategy and processing required (many are possible)
- Use of **focus-of-attention** mechanisms

Active perception

- *How can motor behaviors support perceptual activity?*
- Perceptual requirements dictate the creature's actions (behavior)
- Motor action is performed to acquire specific (missing) perceptual information necessary to execute a behavior/task.
  - E.g. moving to discriminate among objects to find food
- It enables the perceptual process to control supporting behaviors
- E.g. an active (animate) vision system:
  - Has control over its cameras (search, move in, change focus, etc)
  - Can move the camera in stereotypical ways, if needed
  - Image features can be isolated and extracted without the use of models
  - Object-centered coordinate systems guarantee invariance with respect to observer motion; alternate coordinate systems possible

Action-oriented and active perception

- These notions are deeply related
- **Differences**:
  - Action-oriented perception focuses primarily on the needs of action
  - Active perception focuses primarily on the needs of perception
- **In both cases**:
  - Perception performed within the context of a particular behavior/task (selective, dedicated perception)
  - What the agent needs to know to accomplish its task dictates perceptual requirements
- **But …**
  - Active perception provides the perceptual process with the *ability to control the motor system* as well (to make its task easier)

Coordinating perceptual modules

➢ *Behavior-based systems can organize perceptual information in three general ways (combinations also possible):*

a) **Sensor fission** (perceptual channeling):

- A behavior requires a specific stimulus to produce a response
- Multiple independent behaviors, each with its own perceptual module

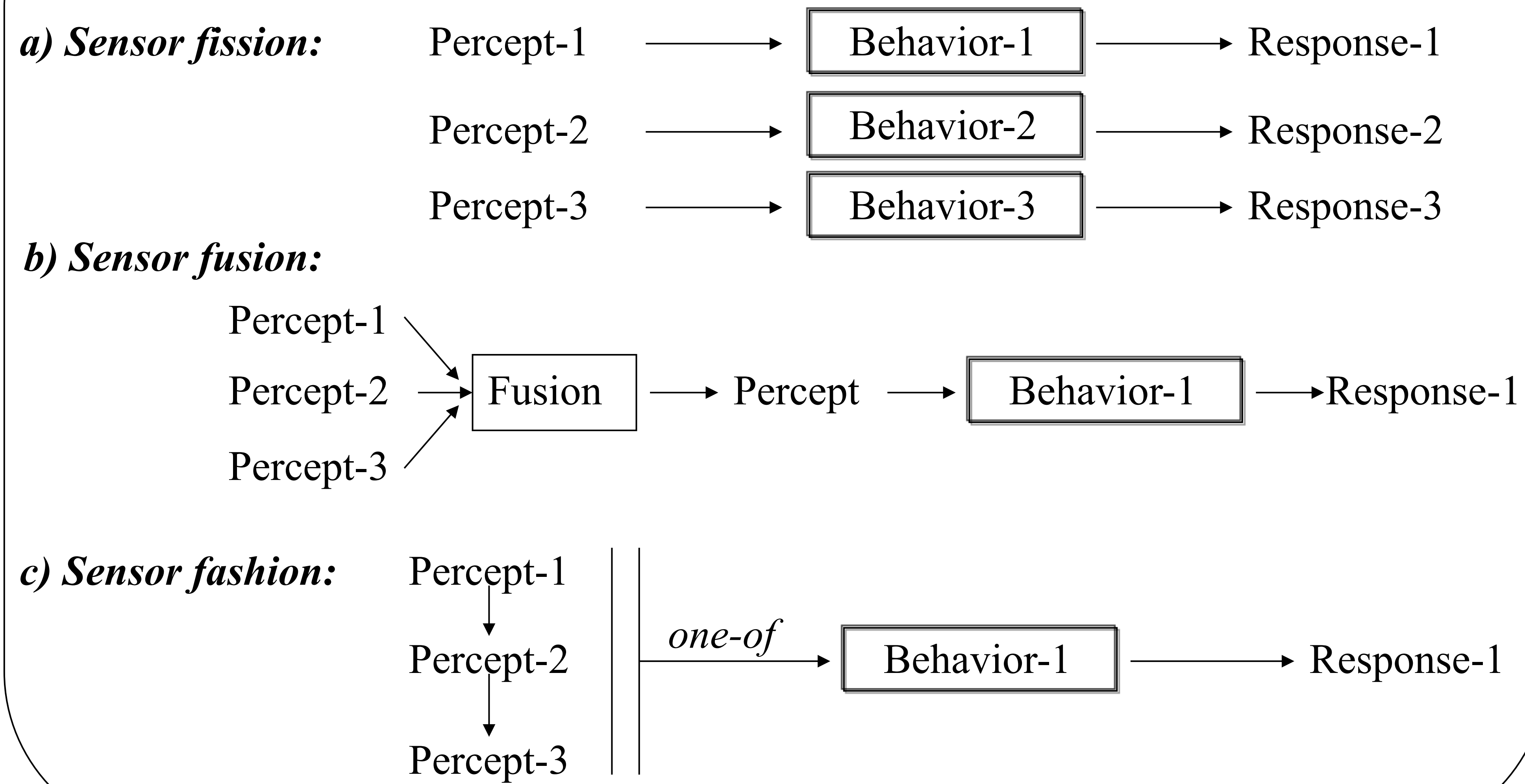
b) **Sensor fusion**:

- Multiple perceptual submodules support a single perceptual module within the context of a single behavior
- Construction of transitory representations (percepts) local to individual behaviors (local perception + reactivity + increased robustness)

c) **Sensor fashion** (perceptual sequencing):

- Complex behaviors might require varying stimuli over space and time (e.g., use different sensors to perceive stimulus at different distances)
- Multiple perceptual modules are sequenced within the context of a single behavior

Coordinating perceptual modules



Sensor fusion

➢ *Sensor reports are fused only within the context of motor action, not into some abstract, all-purpose global representation*

- **Differences in incoming evidence**:
  - Complementary vs. competitive
  - Synchronous vs. asynchronous
  - Qualitative distinctions (e.g. color yields presence information, tact yields texture, laser yields shape, etc.)
  - Widely separated viewpoints

  ➢ *What to believe? How to provide a simple coherent percept?* (complex task!)
- **Various possibilities**:
  - Complete sensor fusion
  - Fusion with possibility of discordance and recalibration of suspect sensors
  - Fusion with possibility of discordance and suppression of discordant sources

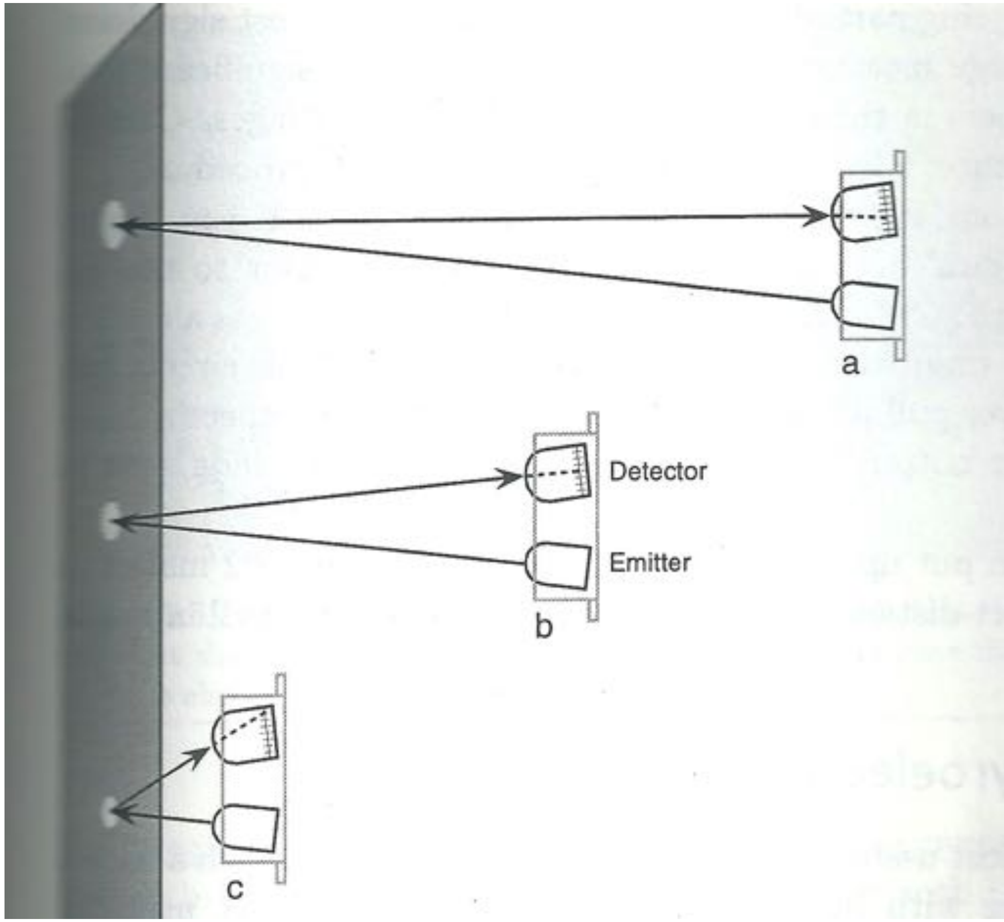
Robotic sensors: some generalities

- **Sensor**:
  - *Transducer* that converts some physical phenomenon into electrical signals that the microprocessor can read
  - Typically, some *interface electronics* needed between sensor and microprocessor to condition or amplify the signal
  - Hardware-software interface: Software drivers (assembly code) connect sensors to microprocessor (programming the microprocessor to read the sensor)
- **Two important notions**:
  - *Sensitivity*: measure of the degree to which the output signal changes as the measured quantity changes.
  - *Range*: mapping of the quantity measured by the sensor into the range of digital values available to the microprocessor (e.g. linear, logarithmic).
    - Physical quantity is transformed into a digital value accessible to the microprocessor (values between 0 and 255).

Light sensors

- Visible light sensors, infrared sensors, video cameras; broad complexity spectrum
- **Common types of light sensors**:
  - *Photoresistor (photocell)*: a change in light produces a resistance change.
    - Allow robot behaviors such as hiding in the dark or moving toward a beacon
  - *Infrared (IR) sensors: active sensors (emit a signal); can be used as passive*
    - *Infrared proximity detector*: signal whether or not something is present within the cone of detection. Typically do not return distance (only presence). Sensitive to color and texture
      - Good for: following behaviors, obstacle avoidance, (coarse) reactivity to color.
    - *Infrared range sensor*: IR emitter + position sensitive detector. It computes an actual range to an object based on triangulation.
  - *Pyroelectric sensor*: its output changes when small changes in the temperature of the sensor occur over time
    - Good for interaction with humans (used in motion-detecting burglar alarms)
  - *Ultraviolet sensor*: reactive to UV light (e.g. flame), insensitive to visible light
  - *Video camera*: usually require transmission to off-board workstation. Vision.

Infrared (IR) sensor: actively emitting and receiving IR signals



Force sensors

- The most reliable, lowest noise, most easily interpreted signal, cheap
- Can be used to **detect contact** with another object and where the contact takes place
- **Different types**:
  - *Microswitches* (*bumpers*): momentary switches that signal when an obstacle is hit; can detect contact
  - *Bend sensors* (conductive ink between two electrodes): gives variable resistance dependent on the degree of bending
  - *Force-sensing resistors* (conductive ink technology): measure force
  - *Rubbery ruler*: measures changes in its own length

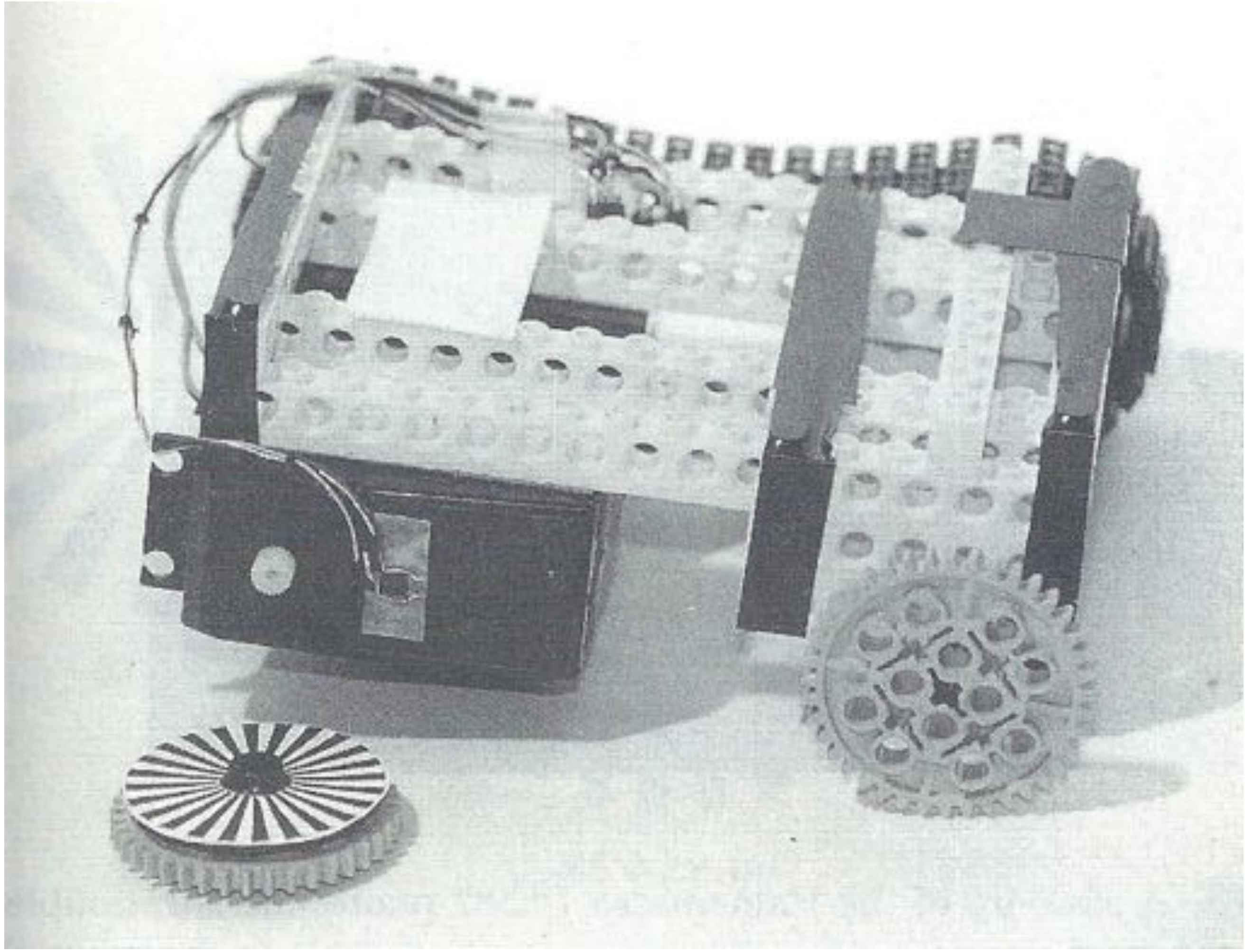
Sound sensors

- Sound in the **audible range**: interaction with operator
- **Ultrasonic**: help the robot detect and avoid obstacles
- **Some types**:
  - *Microphones*
    - Problem: need to sample the signal very frequently (e.g. to detect a hand clap or whistle). Dedicated microprocessor might be necessary.
  - *Piezoelectric film sensors*: detect changes. A voltage is produced only when change in the sensed quality occurs (constant contact not detected)
    - The same material can be used to detect vibrations, changes in applied force, changes in temperature, or far-infrared radiation. Inexpensive sensor.
  - *Sonar*: produces sound (active sensor) and measures the time of flight between initiation of a ping and the return of its echo.
    - Can provide distance information (time of flight and speed of sound in air must be known)

Position and orientation

- Measurements needed for a robot to find its way about in the world
  - Information such as: direction of gravity, local compass heading, how far it has moved or turned since it was in some known position
- **Some common types**:
  - *Shaft encoder*: measures the position or rotation rate of a shaft. Typically mounted on the output shaft of a drive motor or on an axle.
  - *Rate gyroscope (gyro)*: determines either how rapidly the robot is rotating or how far is has rotated, relative to a fixed coordinate system
  - *Tilt sensor*: determines whether the robot is level or tilted. Similar to vestibular system. Mercury switch is the simplest type.
  - *Compass*: provides a way for the robot to acquire absolute information about its orientation (very useful for navigation)
    - Very reliable outdoors, problematic indoors (steel in building, magnetic fields, etc.)

Shaft encoders



Proprioceptive sensors

- Used to **measure the internal state** of the robot
- Monitoring these sensors can **tell us things such as**:
  – It's time to recharge batteries (or error in the level of internal variables in homeostasis-based models)
  – When a motor is overheating
  – When a component has malfunctioned
- **Commonly used sensors**:
  – *Battery-level indicator*
  – *Stall current sensing*: the current used to drive the motors is monitored to detect when the robot is stuck, as wheels are stopped but current is provided to motors (collision detector of last resort, all other collision sensors failing)
  – *Over-temperature* sensors