LECTURE 12

Robot anatomy, Robot paradigms
Ola Ringdahl

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CONTENTS OF THIS LECTURE

- Robot anatomy (part 2)
- Sensor fusion
- Robot paradigms
  - Deliberative – Strips
- Biological Foundations of Robot Behavior

ROBOT ANATOMY
PART 2

“Anatomy is the study of the structure of the body and its parts”

ROBOT ANATOMY LAST LECTURE

- Effectors
  - E.g. wheels, tracks, grippers
- Actuators
  - E.g. electric motors, hydraulic/pneumatic cylinders
- Proximity sensors
  - IR, Laser scanner, Ultrasound (sonar), 3D cameras, bumpers, ...
- Physical entity vs. property of the environment
  - US: time of flight gives distance

Now some more sensors!

POSE SENSORS

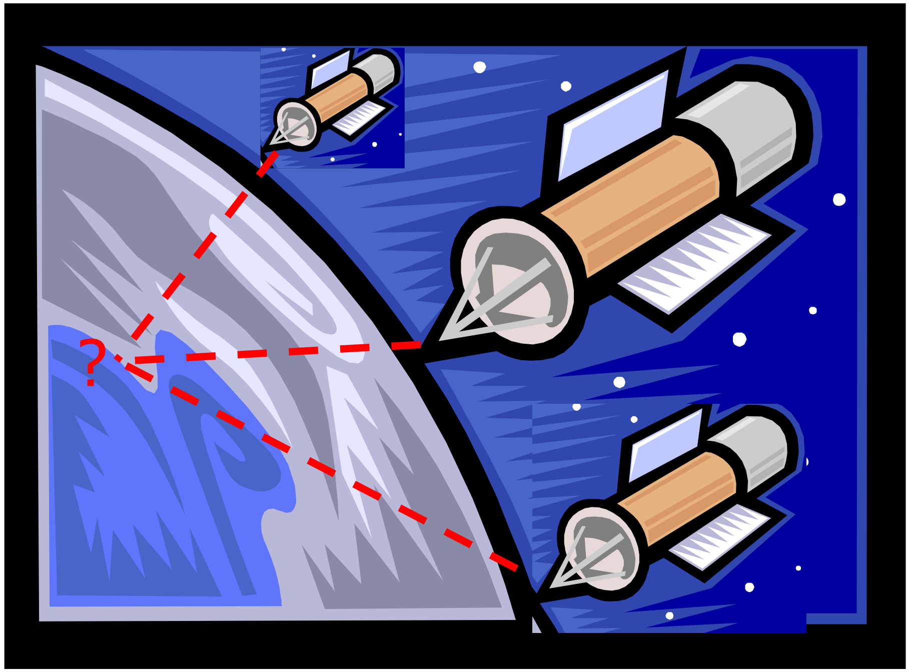
Absolute

Relative

ABSOLUTE POSE SENSORS

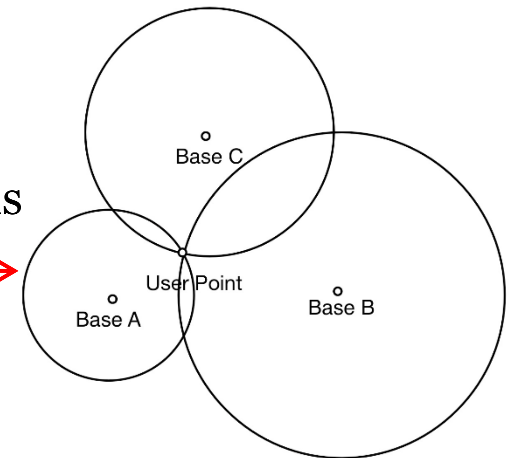
GPS:

- Radio signals are transmitted from the satellites to the receiver on ground
- The time-of-flight is estimated
- Trilateration gives the position (x,y,z)
- Multiple receiver antennas can provide full pose $(x, y, z, \phi, \theta, \psi)$



CELL PHONE POSES

- Uses radio signals between phone and base stations
  - Trilateration based on signal strength
  - Triangulation based on antenna patterns
  - Quality depends on the density of base stations
- Often combined with GPS
- Indoors: WiFi positioning systems combined with Crowdsourcing



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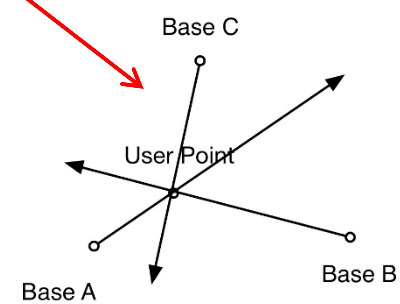
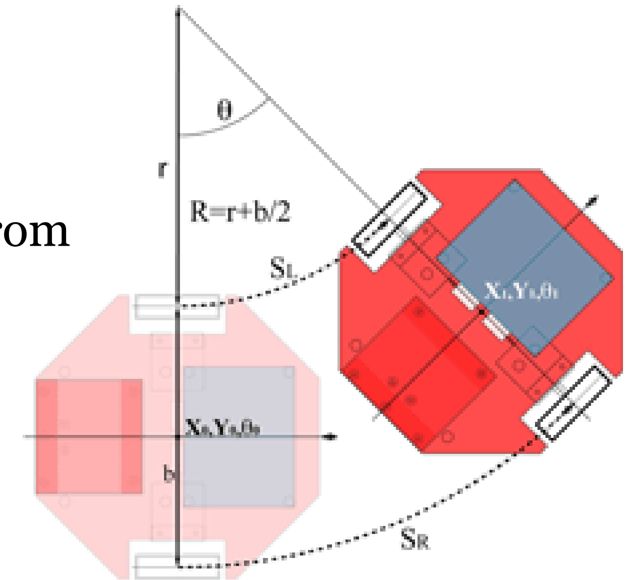


(b)

RELATIVE POSE SENSORS

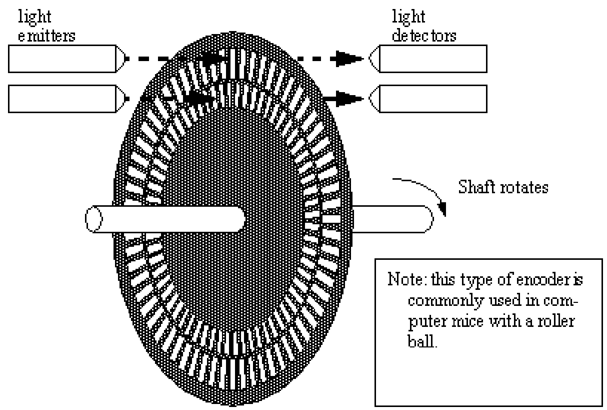
- Give relative motion (change in pose)
- Can give absolute pose by ”Dead reckoning”: accumulating relative motion
- Examples of sensors using dead reckoning:
  - Wheel odometry
  - Accelerometers and gyroscopes

WHEEL ODOMETRY



- Compute relative motion by estimating motion from shaft encoders, speedometer, steering angle, …
- Example:
  ”We have moved for 1 second at 35 cm/sec while turning 0.6 rad/sec.
  This results in a pose change of …”

- Wheel encoders outputs ”ticks” as the wheel rotates
- Number of ticks and wheel diameter gives the moved distance



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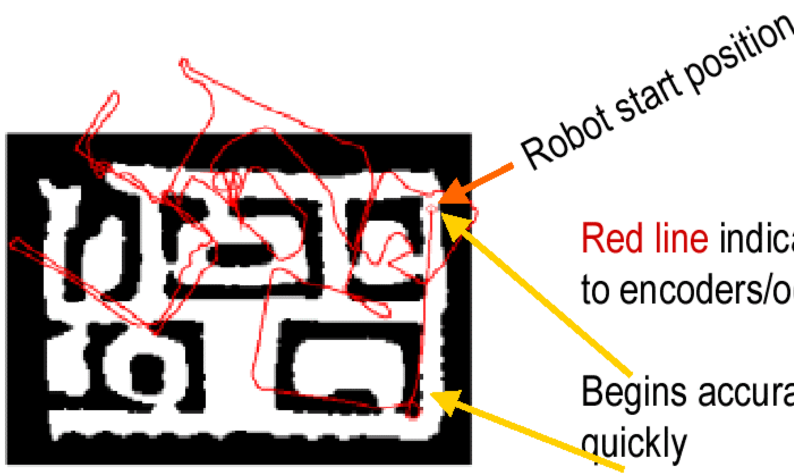
WHEEL ODOMETRY PROBLEMS

- The wheels move but not the robot (spinning)
- The robot moves but not the wheels (slipping,sliding)
- The ground is not flat

- All this causes drift when accumulating pose changes (same problem with all kinds of dead reckoning)



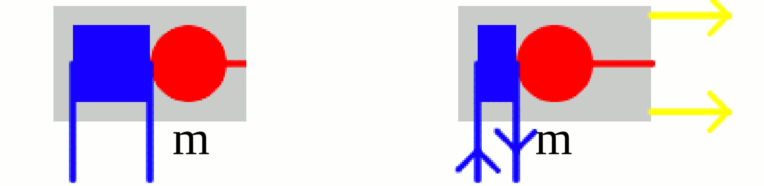
Red line indicates estimated robot position due to encoders/odometry/dead reckoning.

Begins accurately, but errors accumulate quickly

Odometry Data

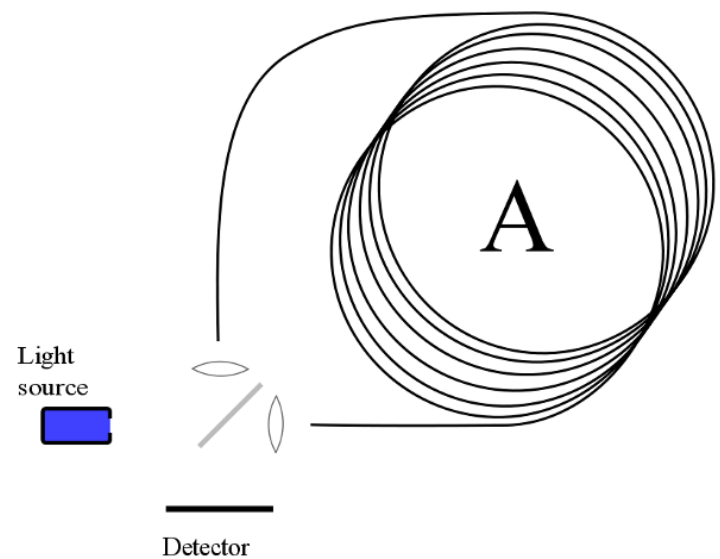
ACCELEROMETERS

- Used for estimation of change in position (x,y,z)
- Common in air planes, missiles and sub-marines since the 50´s
- Now common in game controls and phones
- How they work:
  1. F is measured with some device
  2. F = m a ➔ a = F/m
  3. Distance is computed by integrating a twice
- One accelerometer per axis gives (x,y,z)
- Often implemented in silicon



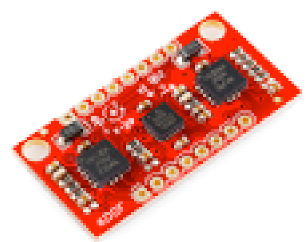
GYROSCOPES

- Measure rotation with one, two or three DOF
- Mechanical gyroscopes
  - Orientation remains fixed, regardless of any motion of the platform
  - Based on the physical propery conservation of angular momentum
- Fiber optical gyroscopes
  - Estimate angular velocity
  - Based on the Sagnac effect
- Often implemented in silicon
- One gyro per axis gives (ϕ, θ, ψ)



INS (INERTIAL NAVIGATION SYSTEMS)

- Combine 3 accelerometers with 3 gyroscopes
- Relative pose sensor:
  Measure changes in the pose $(x, y, z, \phi, \theta, \psi)$
- Extensively used in submarines, cruise missiles, robots



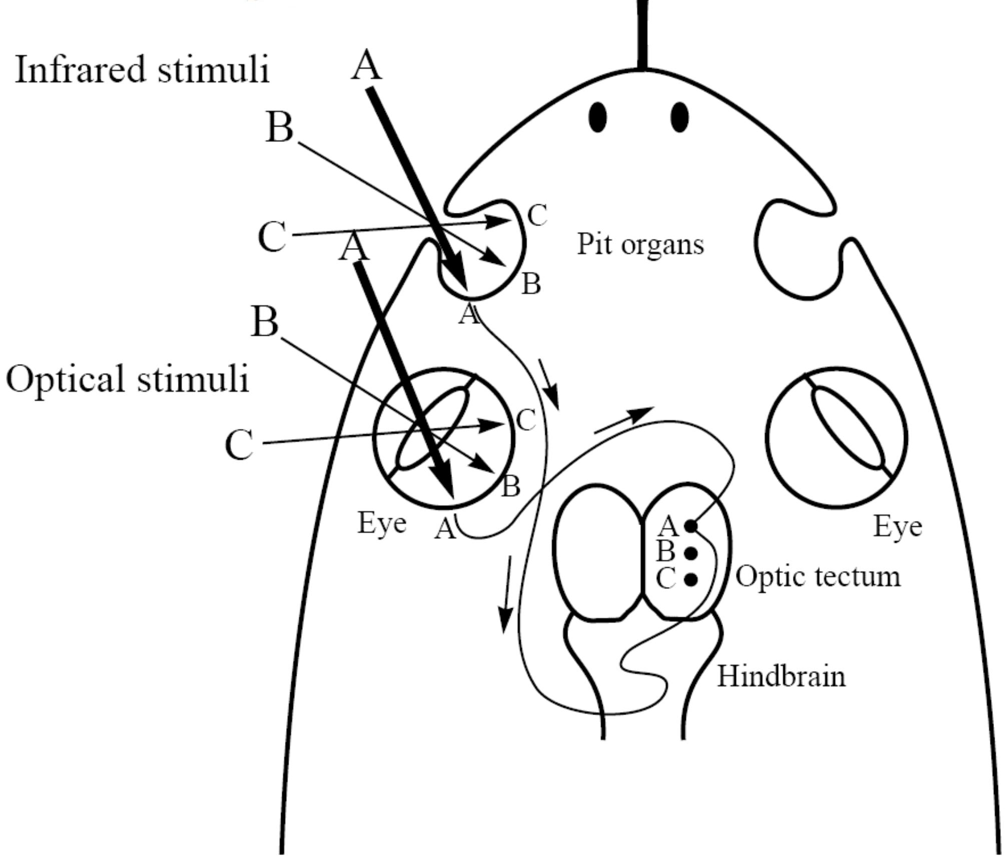
SENSOR FUSION

SENSOR FUSION

Combining information from multiple readouts into a single percept.

- Multiple readouts from the same sensor
- Multiple readouts from different sensor

SENSOR FUSION IN A PIT VIPER



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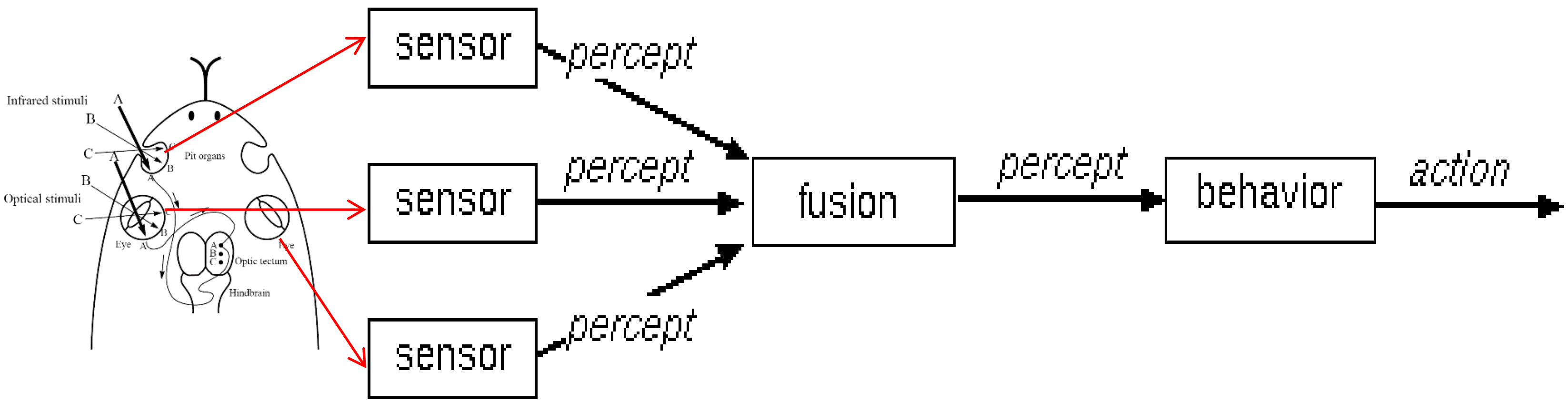
RELATIONS BETWEEN SENSORS

- **Complementary sensors**
  - All sensors are needed for the task
  - Provide disjoint types of information
  - E.g.: An infrared sensor and an ordinary eye to create a percept that can distinguish a mouse form a frog
- **Redundant (Competing) sensors**
  - The task can be solved with anyone of them
  - Physically redundant: returns the same signals
  - Logically redundant: returns the same percept but with different modalities, e.g. IR reflex sensors and an ultrasonic sensor
- **Coordinated sensors**
  - Used for the same percept but in different situations

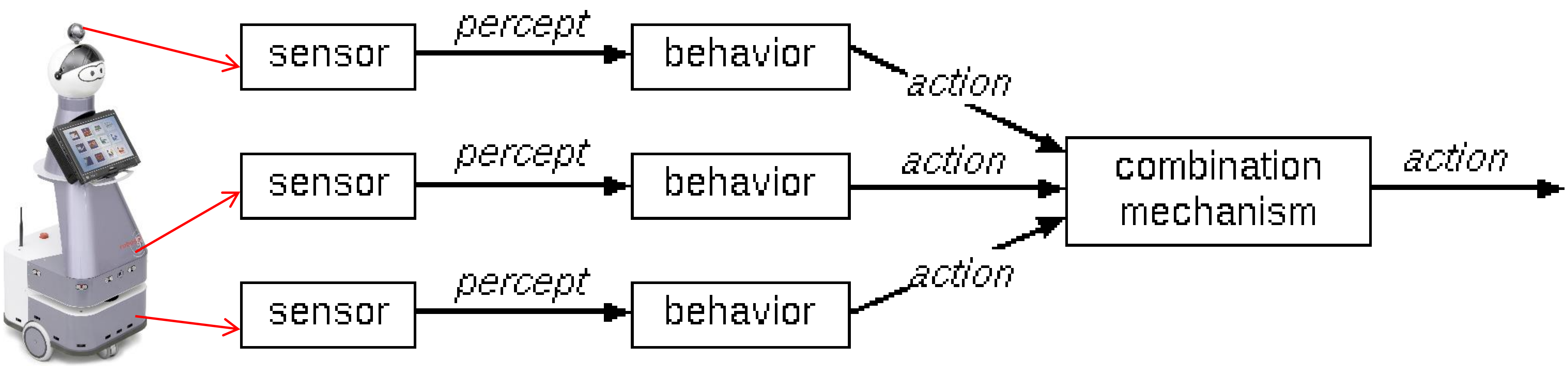
(ACTION-ORIENTED) SENSOR FUSION

For competing or complementary sensors



SENSOR FISSION

For competing sensors



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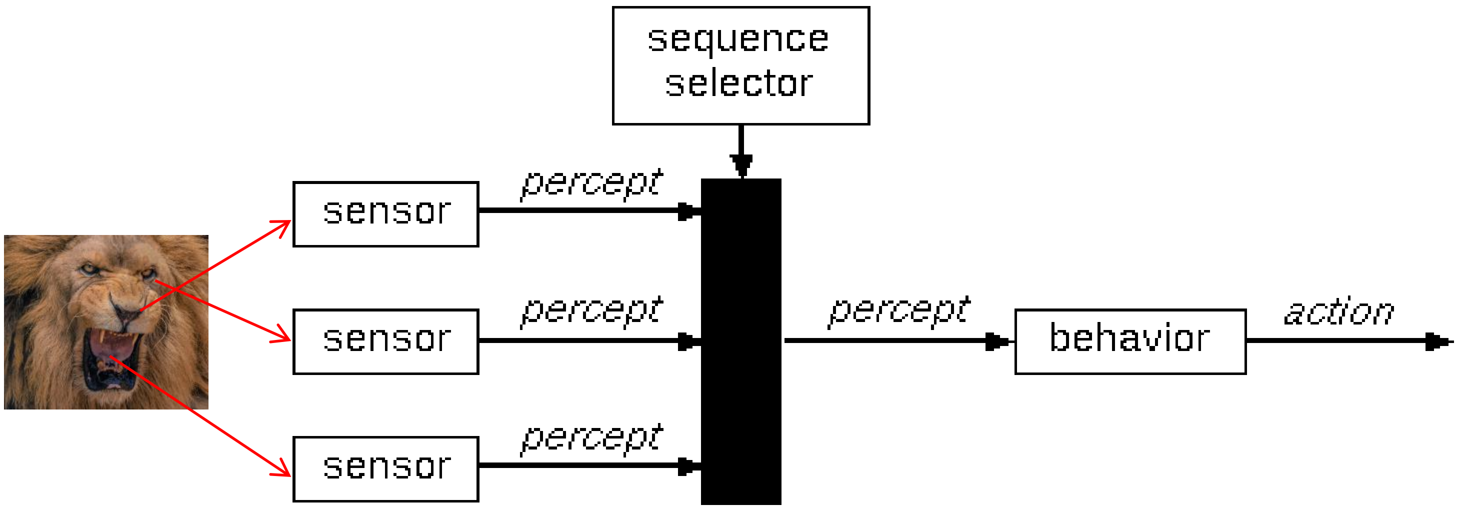
SENSOR FASHION

For coordinated sensors



SENSOR FUSION IN ROBOTS

Examples

Sensor fashion

- GPS + INS
  - GPS is used when good reception from satellites
  - INS is used otherwise
- GPS + Wheel odometry
  - GPS is used when good reception from satellites
  - Odometry is used otherwise
- Regular camera + IR camera
  - Use IR in darkness

(Action-oriented) Sensor Fusion

- Ultrasonic + Laser scanner
  - Ultrasonic: Noisy, large coverage, low spatial resolution
  - Laser: Low noise, small coverage, high spatial resolution
- Regular camera + Laser scanner
  - Laser distances may be fused with corresponding points in the camera image. The combined data can be used for object detection

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ROBOT SOFTWARE

“blows life into otherwise dead matter”

Several levels

- The application program
    - Solves a specific task (e.g. A program for a robot vacuum cleaner)
- Architectural framework
    - Coordinates all operations (e.g. A deliberative architecture)
- Robotics middleware
    - Manages process communication and synchronization (examples on next slide)

ROBOTICS MIDDLEWARE

- A software package to simplify development of robots
- Provides things like
  - Data structures
  - Communication functionality
  - Multi-tasking
  - Hardware interfaces
- Often also contains high-level functionality
  - Path-tracking and obstacle avoidance
  - Map-making
  - Sensor logging and display
  - GUI
  - Support for system development (simulators, data logging, etc.)
- Examples: ROS, MRDS, Player, Orca, CARMEN, Nav2000

ROBOTIC PARADIGMS

Bekey - Architectures (p.97-109).pdf

Murphy - STRIPS (p.44-53).pdf

PARADIGM

A framework containing the basic assumptions, ways of thinking, and methodology that are commonly accepted by members of a scientific community.

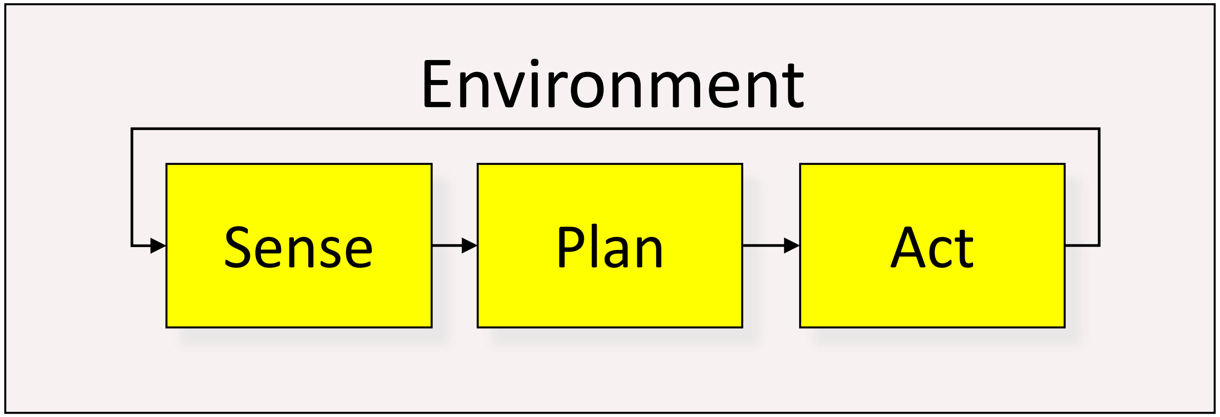
<u>Robot paradigms:</u>

- Deliberative (1967 – 1990)
  - AI inspired
- Reactive (1988 – 1992)
  - Inspired by animals' behavior
- Hybrid deliberative/reactive (1992-Present)
  - Combination of above two approaches

a.k.a "architectures"

THE DELIBERATIVE PARADIGM

”THE HIERARCHICAL PARADIGM” OR ”THE CLASSICAL AI APPROACH”



Method: “Sense-Plan-Act” (a.k.a. ”Sense-Think-Act”)

- Read and interpret sensors & Model the world
- Plan
- Execute the plan

A la Minsky!

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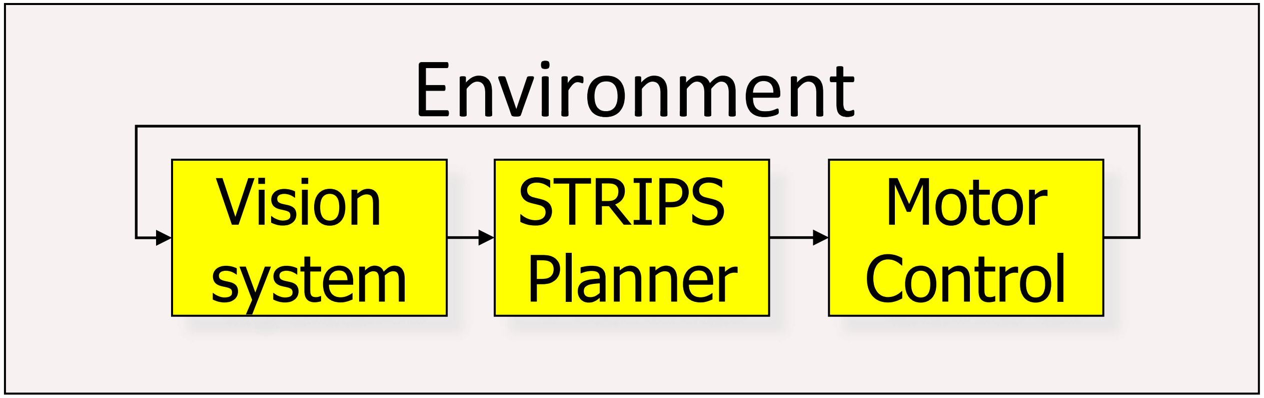
THE WORLD MODEL

1. An a priori representation of the environment
   - Everything knowable about the world is explicitly coded. E.g. a map.
2. Additional cognitive knowledge
   - E.g. "the kitchen is often crowded around noon".
3. Sensing information
   - All sensory input is explicitly modeled. E.g. robot position and object properties.

SHAKEY'S ARCHITECTURE



The a priori model descibes what the world looks like, how it works and how it is affected by robot actions

<u>Sense-Plan-Act:</u>

- Interpret the video stream & update the model
- Create a plan using STRIPS planner
- Send commands to the motors, based on the plan

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HOW TO DEVELOP A PLAN IN STRIPS?

Running Strips:

1. Sense the world ⇨ initial state
2. If robot is not at goal, then measure the distance (or difference) between robot's current state and its goal state.
3. Search (exhaustively) for an action (operator) that the robot can take that will reduce this distance
4. If an operator has new unsatisfied preconditions: push the operator onto the plan stack, define a new goal state and recursively find plans for that (step 2-4)
5. If no unsatisfied preconditions: Simulate execution of the operator, and return

Executing the plan:

- Perform the operators found in 3, in reverse order

STRIPS : SET UP

For example using an arbitrary frame of reference that put Tampa at the center of the world with made-up distances to Stanford:

"Go to Stanford AI Lab (SAIL)"

INITIAL STATE:	Tampa, Florida (0,0)
GOAL STATE:	Stanford, California (1000,2828)
Difference:	3000 miles

DIFFERENCE TABLE

- This could lead to a data structure called a *difference table* of how to make decisions:
  - Different modes of transportation are appropriate for different distances.
  - A mode of transportation, *fly*, *train*, *drive*, and *walk*, in the table is really a function in the robot's program.
  - A robot following this difference table would begin by flying as close as it could to SAIL.

Difference (distance)	Operator (mode of transportation)
d≥200	Fly
100<d<200	Train
d≤100	Drive
d<1	Walk

PRECONDITIONS

The preconditions are a column in the difference table, where a single operator can have multiple preconditions.

Difference	Operator	Preconditions
d≥200	Fly	
100<d<200	Train	
d≤100	Drive_rental	At airport
	Drive_personal	At home
d<1	Walk	

MAINTAINING STATE OF THE WORLD: ADD AND DELETE LISTS

These two lists are stored in the difference table so that when the robot picks an operator based on the difference and operator, it can easily apply the appropriate modifications to the world.

Difference	Operator	Pre-conditions	Add-list	Delete-list
$d \geq 200$	Fly		At city Y At airport	At city X
$100 < d < 200$	Train		At city Y At train station	At city X
$d \leq 100$	Drive_rental	At airport		
	Drive_personal	At home		
$d < 1$	Walk			

STRIPS SUMMARY

- Designer must set up a:
  - World model representation.
  - Difference table with operators, preconditions, add & delete lists.
  - Difference evaluator.
- Strips plans rather than execute
  - It creates a list of operators to apply, it does not execute them as it goes
- Strips is still used for solving planning problems
  - An example for Starcraft: https://github.com/primaryobjects/strips#starcraft
- The compendia (Murphy) also contains a more realistic example with more details

PROBLEMS WITH STRIPS

- The **Closed world assumption**
  - The world model contains everything that is needed (no surprises)
  - Not realistic! The robot lives in a dynamic open world (surprises shouldn't come as a surprise!)
  - Leads to huge models
- The **Frame Problem**
  - How can we represent ALL facts (in particular nonchanges) in a tractable way?
  - Updating and maintaining it can bee too computationally expensive

PROBLEMS WITH THE DELIBERATIVE (HIERARCHICAL) APPROACH

- Inherent problems with Planning
  - Closed world problem
  - Frame problem
- Replanning is necessary as soon as anything unexpected happens in the world
- What should the robot do while replanning?
  - Stop? (Slow!)
  - Move blindly? (Dangerous!)

NEW INSPIRATION NEEDED!

BIOLOGY?
PSYCHOLOGY?
ETHOLOGY?

BIOLOGICAL FOUNDATIONS OF ROBOT BEHAVIOR

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Readings: UMINF-11.17

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THIS PART

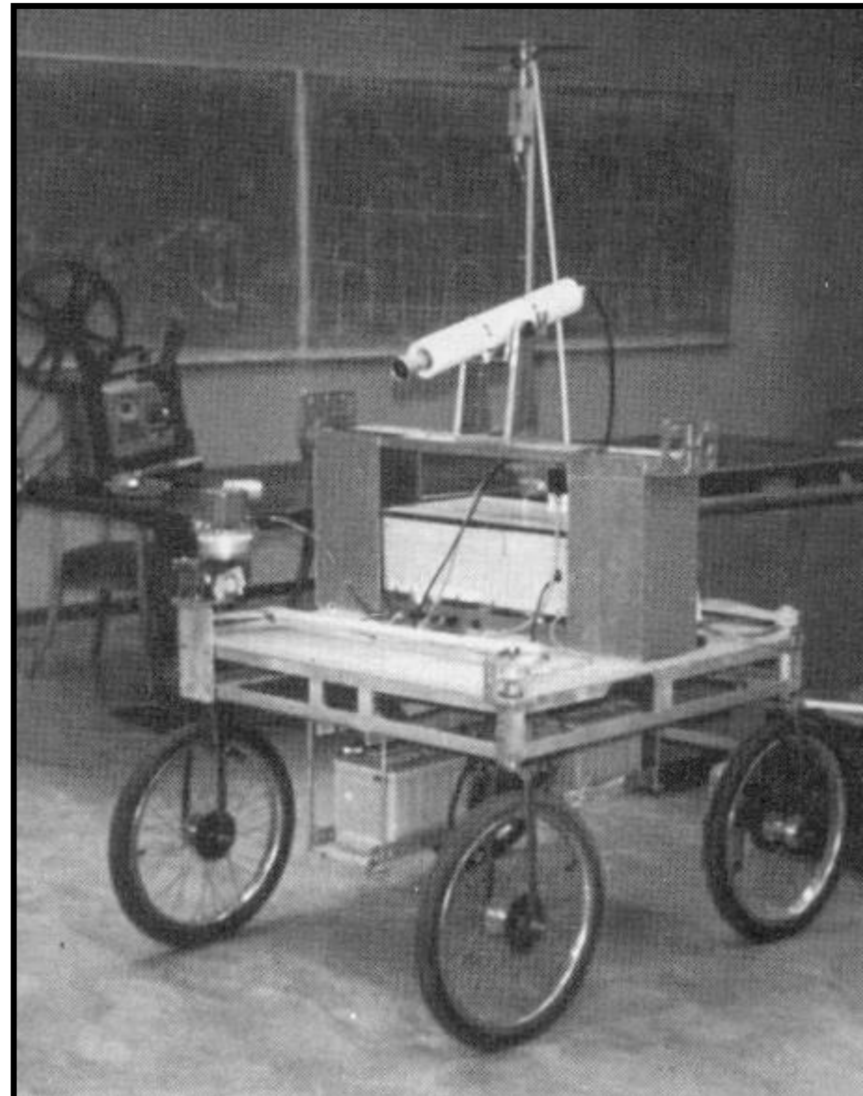
- Why involve biology?
- Animal behaviors
  - Different types of animal behaviors
  - Examples of animal behaviors
- Perception
  - Animal perception
  - Extracting basic principles and ideas for robotics
- Formal models suitable for robotics

SLOW PROGRESS IN THE 1970'S

Slow robots...

Stanford Cart (1977)

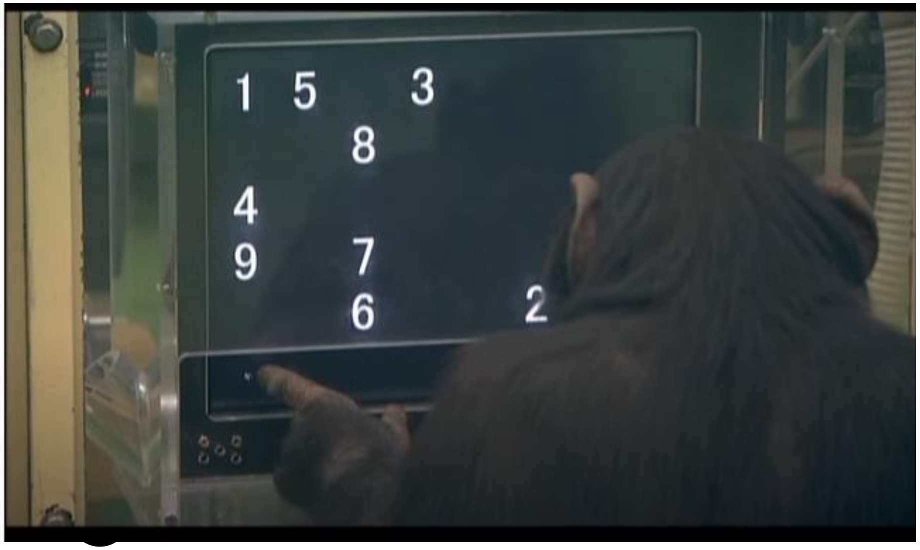
- Stereo vision and an internal map of the world
- Average speed: 1 meter / 10 minutes
- Caused by the lack of computing power, but also by the planning approach



WHY NOT EXPLORE BIOLOGY?

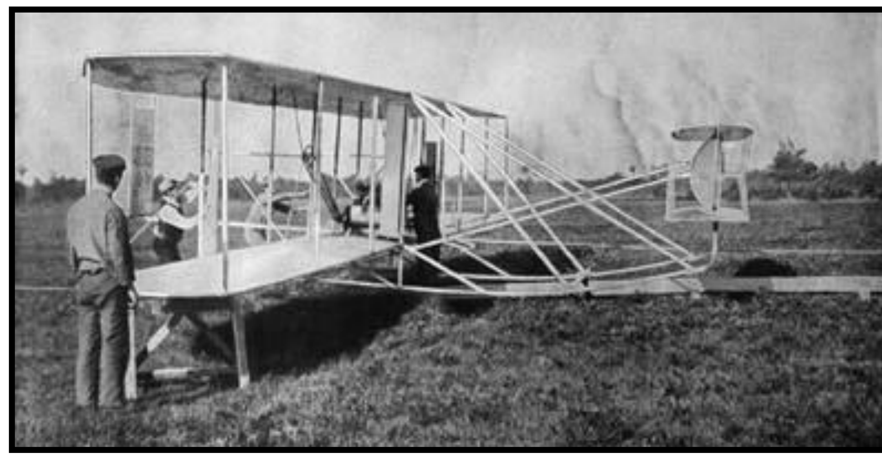
- Animals and humans provide **existence proofs** of different aspects of intelligence
- Many ”simple” animals such as insects, fish and frogs exhibit intelligent behaviors **with virtually no brain**
- Animal studies **can yield computational models**

AYUMU2007 video
https://www.youtube.com/watch?v=zeq2-HK1k4g



AND IT HAD ALREADY BEEN DONE

- Wright brothers' airplane was clearly inspired by birds
- Almost everything about a plane's aerodynamics imitates a bird's flight (except that airplanes don't flap their wings…)



NEW SOURCES OF INFORMATION

- Ethology
  - Animal behavior
- Cognitive psychology
  - How humans think and represent knowledge
- Neuro science
  - How perception and actions are controlled by the nervous system
- Biology
  - How actuators and effectors, like a hand is constructed

ANIMAL BEHAVIORS

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WHAT ARE ANIMAL BEHAVIORS

The basis for the Reactive Paradigm in robotics

- Reflexive
  - Innate stimulus-response mappings $S \rightarrow R$.
  - E.g. knee reflex

- Reactive
  - Learned but automatic ("muscle memory").
  - E.g. biking, skiing

- Conscious
  - Deliberately chained behaviors.
  - E.g. eating with fork and knife

Roboticists most often use the term "reactive behavior" instead of "reflexive", and refer to reactive behaviors as "skills"

ANIMAL REFLEXIVE BEHAVIORS

- **Reflexes** - Rapid, automatic involuntary responses triggered by a stimulus. Stop when stimulus disappears. Response proportional to stimulus.
  - E.g.: dogs raise their hackles when threatened.
- **Fixed-action patterns** - Time-extended responses to stimuli – run till completion. Response not proportional to stimulus.
  - E.g.: a fleeing deer
- **Taxes** - Orient the animal toward or away from a stimulus.
  - E.g.: Chemotaxis (ants), Phototaxis (cockroaches, turtles)

EXAMPLES OF REFLEXES

- Arctic terns live in Arctic
  (black, white, gray environment, some grass)

- When hungry, baby pecks at parent’s beak, who regurgitates food for baby to eat

- How does the baby recognize its parent?
  - It doesn’t, it just goes for the largest red spot in its field of view
  - Only red thing should be an adult tern
  - Closer = large red

A SEQUENCE OF REFLEXES

<u>Mating Cycle of Digger Wasp:</u>

- Female mates with male
- Female builds nest
- Female lays eggs

<u>Logical sequence, but:</u>

- The wasp doesn’t need to “know” the sequence
- Each step in the sequence is “triggered” by internal or external signals

FIXED-ACTION PATTERNS
(Konrad Lorenz, Niko Tinbergen 1938)

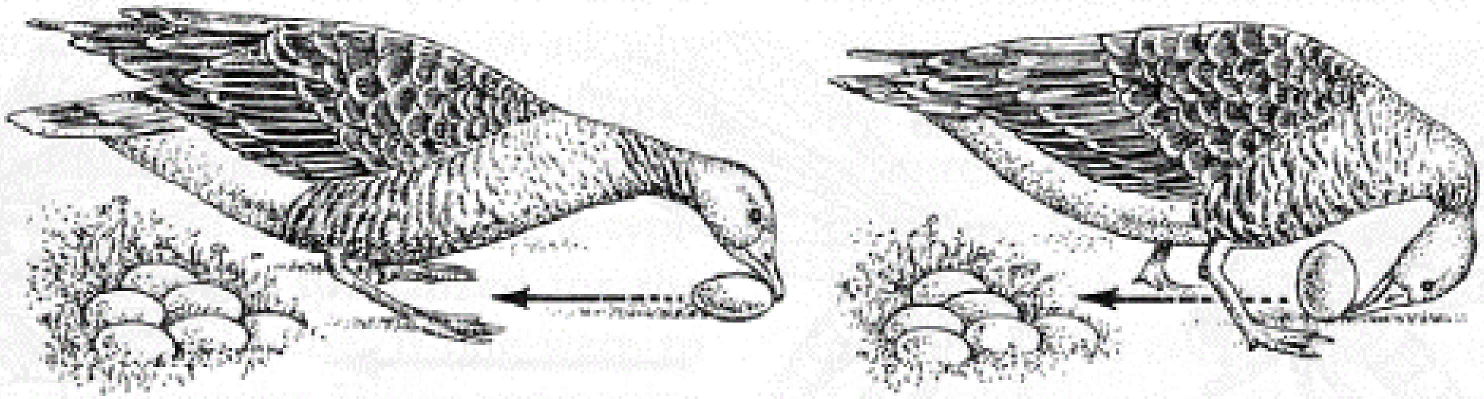


FIGURE 2.5 The egg retrieval response of the greylag goose. The chin-tucking movements used by the female as she rolls the egg back to the nest are highly stereotyped and are an example of a fixed action pattern. The side-to-side movements that correct for any deviations in the path of the egg are called the taxis component of the response. If the egg is removed, the female will continue to roll an imaginary egg back to the nest. One defining characteristic of a fixed action pattern is that it will continue to completion even in the absence of guiding stimuli. (Drawn from a photograph in Lorenz and Tinbergen 1938.)

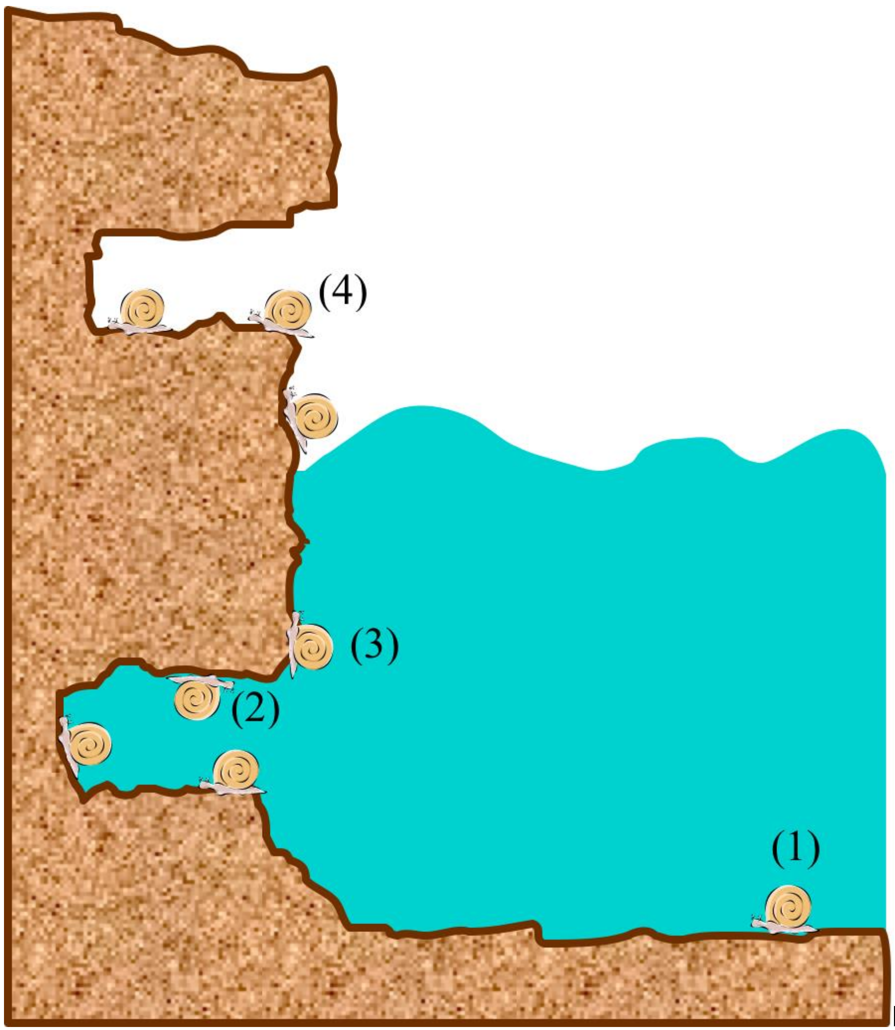
TAXES

- Jacques Loeb 1859-1924 was fed up with the psychologists anthropomorphic views on animals' behaviors

  "In no case is an animal activity to be interpreted in terms of higher psychological processes, if it can be fairly interpreted in terms of processes which stand lower in the scale of psychological evolution and development"

- He developed a theory of forced movement or tropism – he coined the term *taxis* (plural *taxes*): *movement towards or away from a stimulus source*

A SEQUENCE OF TAXES



Searching for food above the surface (the costal snail):

Sequence of taxes (trigger):

1. Negative phototaxis (upright)
2. Positive phototaxis (upside down)
3. Negative geotaxis (turning vertically up and wet)
4. Negative phototaxis (not wet)

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SEQUENCING

- Several (reactive) behaviors may be perceived as a ”conscious” sequence of actions by an outside observer
- Sequencing is caused by *perception* of the outer world, and internal states

PERCEPTION

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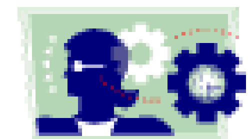
PERCEPTION

Cognitive psychologists:
J.J Gibson
Ulrich Neisser



"perception is the process of acquiring, interpreting, selecting, and organizing sensory information" (Pomerantz 2003)

HOMING PIEGON'S ORIENTATION

An example of advanced perception in the animal kingdom

Pigeons can navigate hundreds of km to a goal, even with no visual cues (hints) to the path home. Appears that they have multiple cues.

- If sunny day, pigeons seem to use biological clocks and sun angle.
- If not a sunny day, they seem to use an internal compass.

HOW DO WE KNOW THAT?

- Study of birds with clocks shifted by 6 hours (using artificial lighting):
  - If sun is not visible: Direction is correct
  - If sun is visible: Direction is off by 90 deg
- When birds are wearing magnets, they are confused on overcast days, but not on sunny days.

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TWO FUNCTIONS OF PERCEPTION

- **Release**: To enable a behavior (navigation)
  - Sun visible/not visible
- **Guide**: To provide information needed to accomplish a behavior (navigation):
  - Direction of the sun and internal clock, magnetic field

NEISSER:
TWO KINDS OF PERCEPTION IN THE BRAIN

- **Direct perception**:
  - Doesn’t require memory, inference, or interpretation
  - Minimal computation
  - Rapid execution time

- **Recognition**:
  - Requires problem solving and other cognitive activities
  - Top-down and model based
  - Example: find your bike outside the university building

FORMAL DESCRIPTION OF BEHAVIORS

THE ARCTIC TERN FEEDING BEHAVIOR

RED BLOB LOCATION

(Stimulus)

FEEDING BEHAVIOR

PECK AT RED

(Response)

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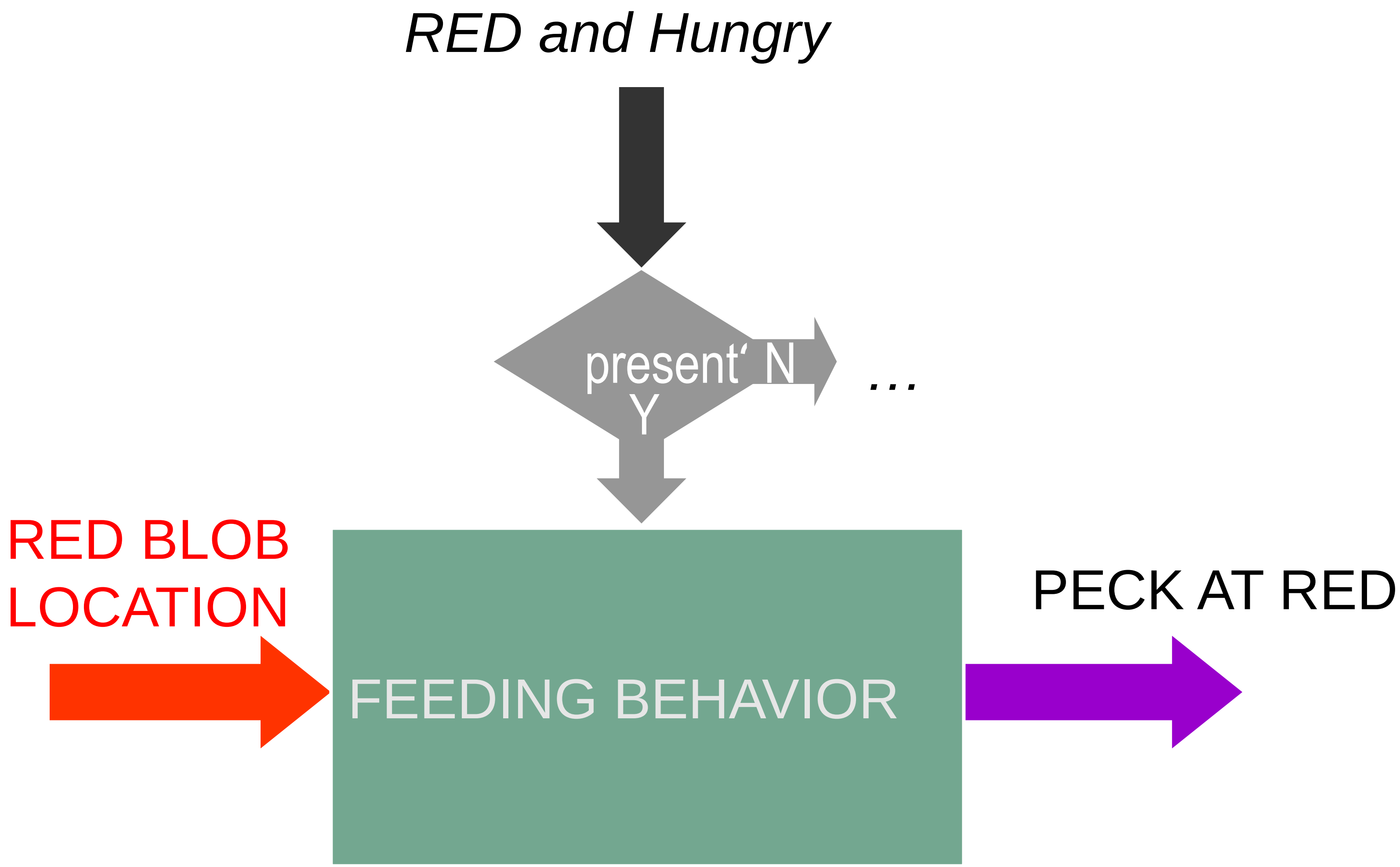
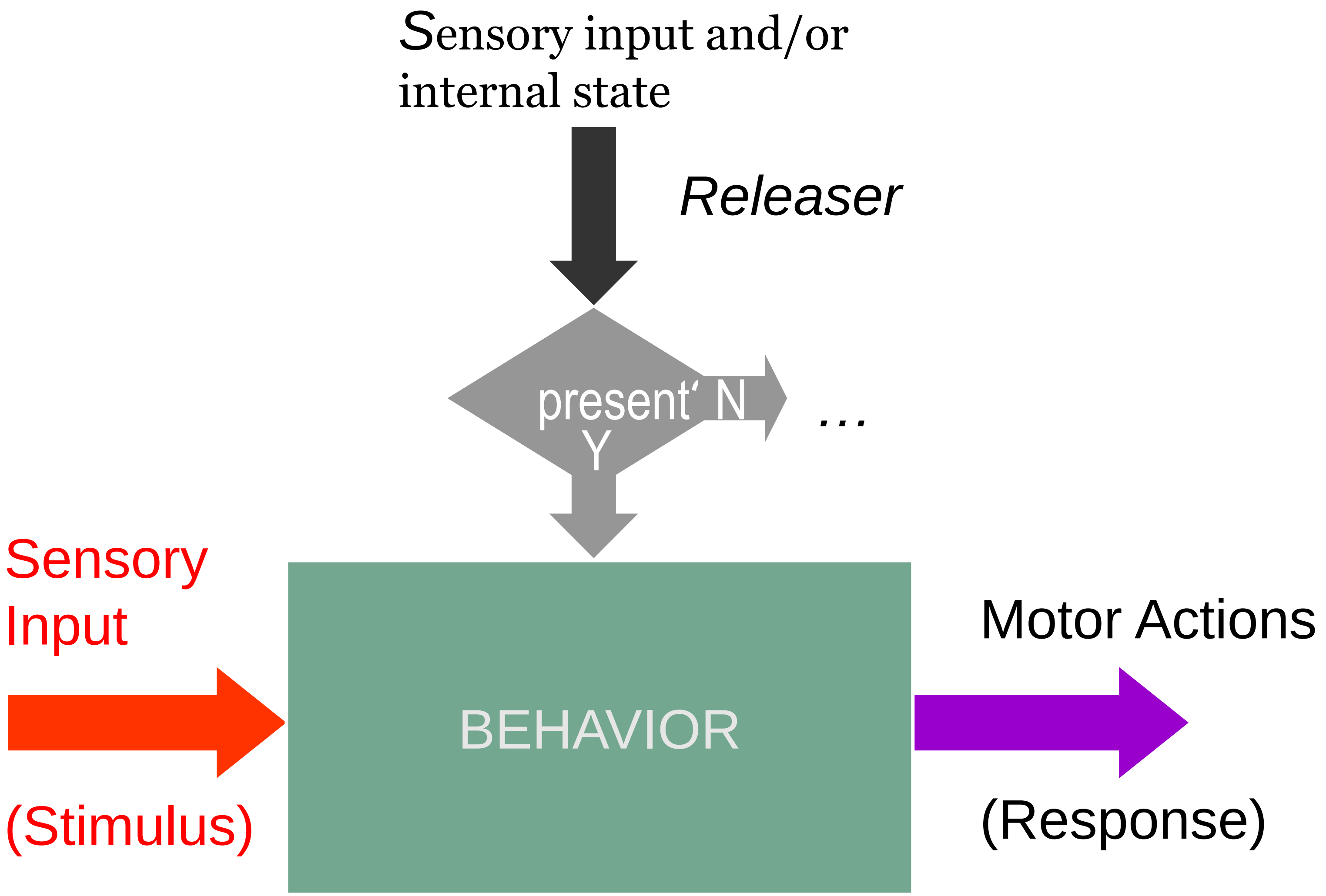
THE FEEDING RELEASER



INNATE RELEASING MECHANISMS (IRM)



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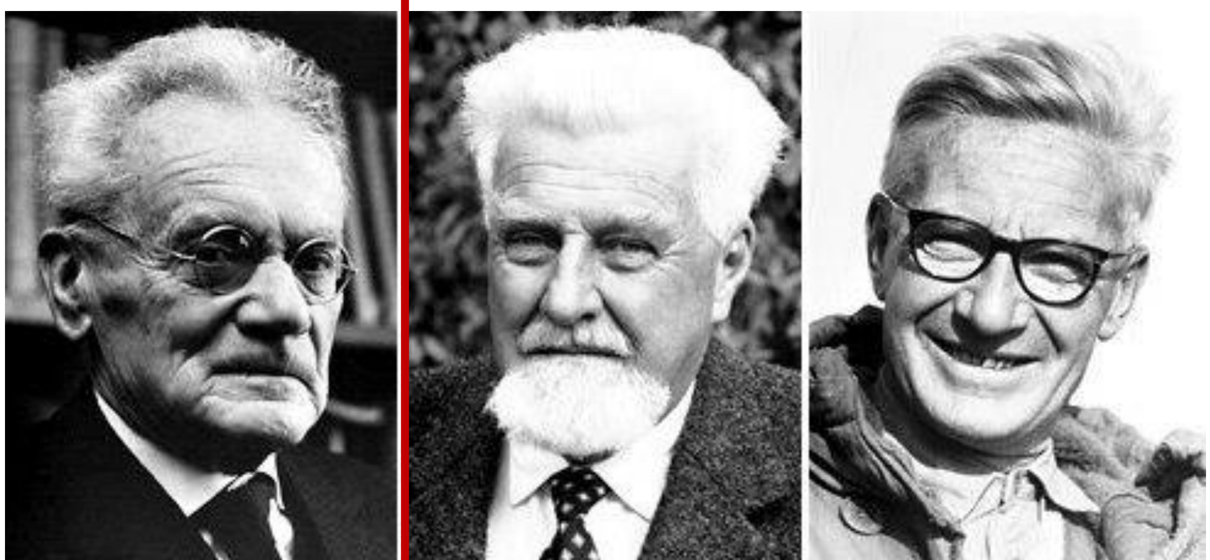
INNATE RELEASING MECHANISMS

Nobel prize in medicine 1973

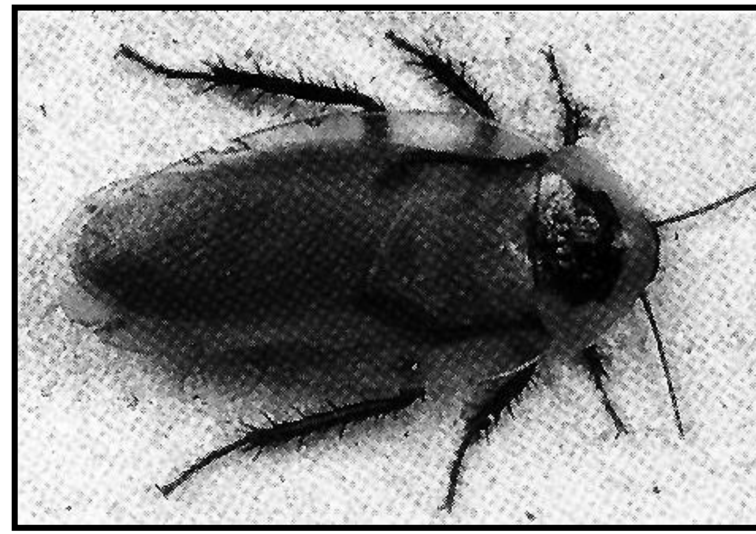


Karl von Frisch (1886 - 1982) | Konrad Lorenz (1903 - 1989) | Nikolaas Tinbergen (1907 - 1988)

Founders of ethology

EXAMPLE: COCKROACH HIDE

1. Light goes on, the cockroach turns and runs
2. When it gets to a wall, it follows it
3. When it finds a hiding place, goes in and faces outward
4. Waits until not scared, then comes out, even if the lights are turned back off earlier



RELATED TO WHAT WE'VE LEARNED

1. light goes on, the cockroach turns and runs — *S→R*
2. when it gets to a wall, it follows it — *S→R*
3. when it finds a hiding place, goes in and faces outward — *Taxis*
4. waits until not scared, then comes out, even if the lights are turned back off earlier — *Fixed-action patterns*

Sequencing

IDENTIFYING BEHAVIORS

Flee

light goes on, the robot turns and runs

Follow wall

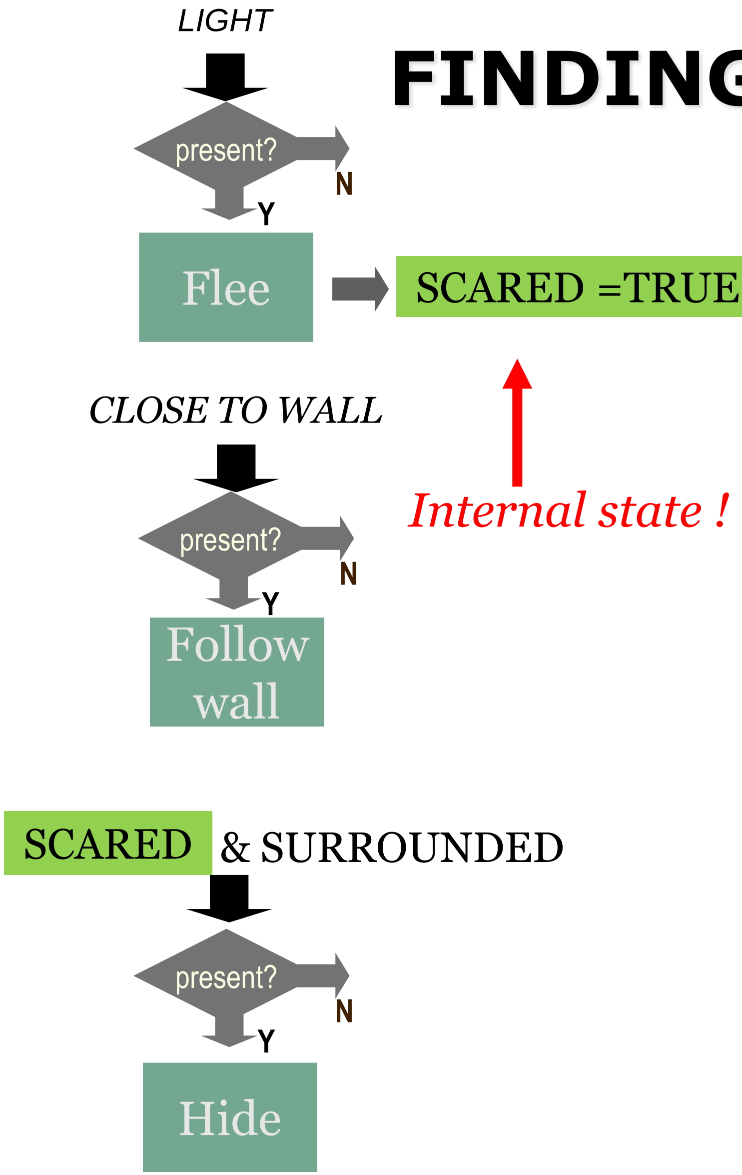
when it gets to a wall, it follows it

Hide

when it finds a hiding place goes in and faces outward

waits until not scared, then comes out

FINDING RELEASERS



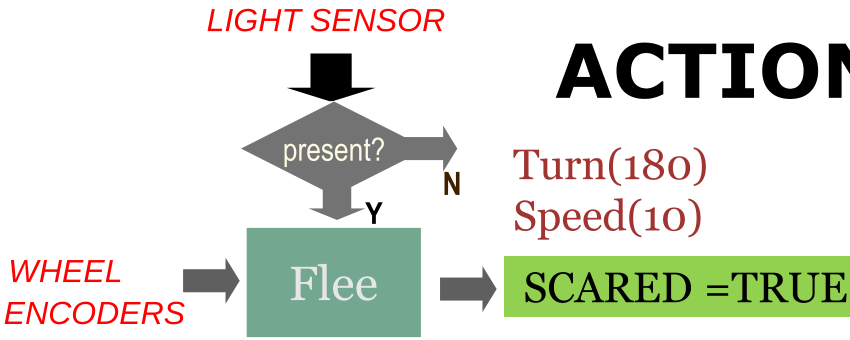
light goes on, the robot turns and runs

when it gets to a wall, it follows it

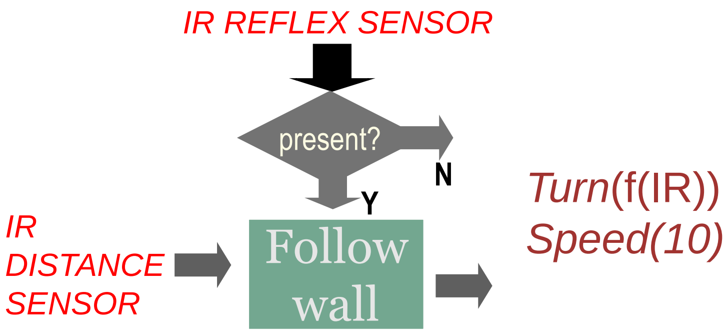
when it finds a hiding place goes in and faces outward.

waits until not SCARED, then comes out

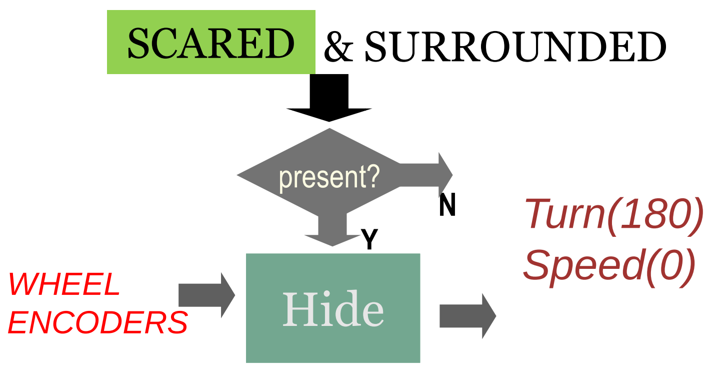
ACTION AND SENSING



light goes on, the robot turns and runs



when it gets to a wall, it follows it



when it finds a hiding place goes in and faces outward.

waits until not SCARED, then comes out

Sequencing appears from parallel behaviors activated by releasers

NEXT TIME:

Reactice paradigm

Potential fields

Subsumption