Perception-Action paradigm: action in embodied AI / robots

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Additional reading

- From textbooks (available at LRC; see reading list on Module Guide):
  - From *Behavior-Based Robotics*: Chapter 3
  - From *Understanding Intelligence*: Chapter 12
- Specialist papers made available on Canvas under this unit

Actuators

- Controlled by motors, servos
- **Locomotion**: wheels, legs, belts, fins, wings, flippers
  - *Wheels*: various arrangements
    - **Differential drive**: two wheels on common axis, each driven independently
    - **Synchro drive**: rotates all the wheels together
    - **Tricycle drive**: steering motor on one wheel, driving motor on back pair of wheels
    - **Car drive** (Ackerman steering): rotates the front (two) wheels together
  - *Legs*: various numbers and gaits
    - **1 leg**: jumping
    - **2 legs**: human-like walking
    - **4 legs**: 1 leg up at a time (3 point of contact), 2 legs up at a time (same side, opposite sides), tricky
    - **6 legs**: tripod gait
- **Other actuators**: heads, manipulators (hands, arms, grippers)

Example of early EAI robot: Ghenghis (Rodney Brooks, MIT)

Behavior-based systems

- **Behaviors serve as the basic building blocks for robotic actions**
  - Behavior: perceptual-motor pair, competence
  - Behaviors can be defined at different granularities
- **Use of explicit representational knowledge is avoided in the generation of a response**
  - Reaction to the world
  - Very useful in highly dynamic and unpredictable environments
- **Animal models of behavior serve as a basis for these systems**
  - Biological models as source of inspiration. Fidelity to model varies
- **Systems are modular from a software design perspective**
  - The robot's competences can be expanded by adding new behaviors
  - Old behaviors are nor discarded or redesigned

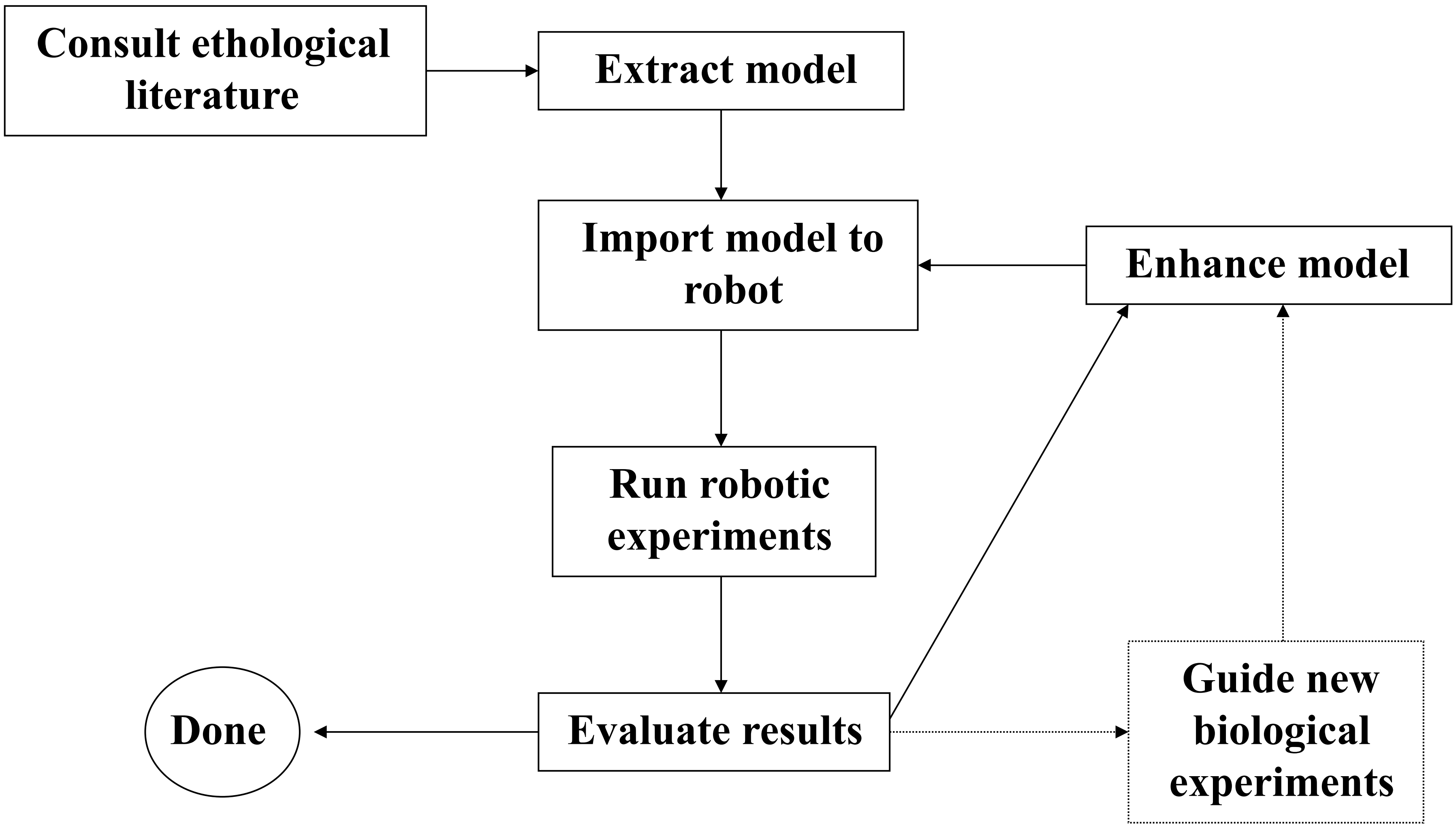
Basis for robotic behavior

- **Where do robotic behaviors come from?**
  - *What competences does the robot need in a particular environment?*
- **How to provide a robot with behavioral control?**
  - *How does the robot decide what behavior it must execute?*
- **What are the right behavioral building blocks for robots?**
  - *Different granularities are possible: how to choose?*
- **What really is a primitive behavior?**
  - *"Primitive" is always a relative notion*
- **How are behaviors effectively coordinated?**
  - *How to make them work towards efficient global behavior?*
- **How are these behaviors grounded to sensors and actuators?**
  - *How to design the closed perception-action loop?*

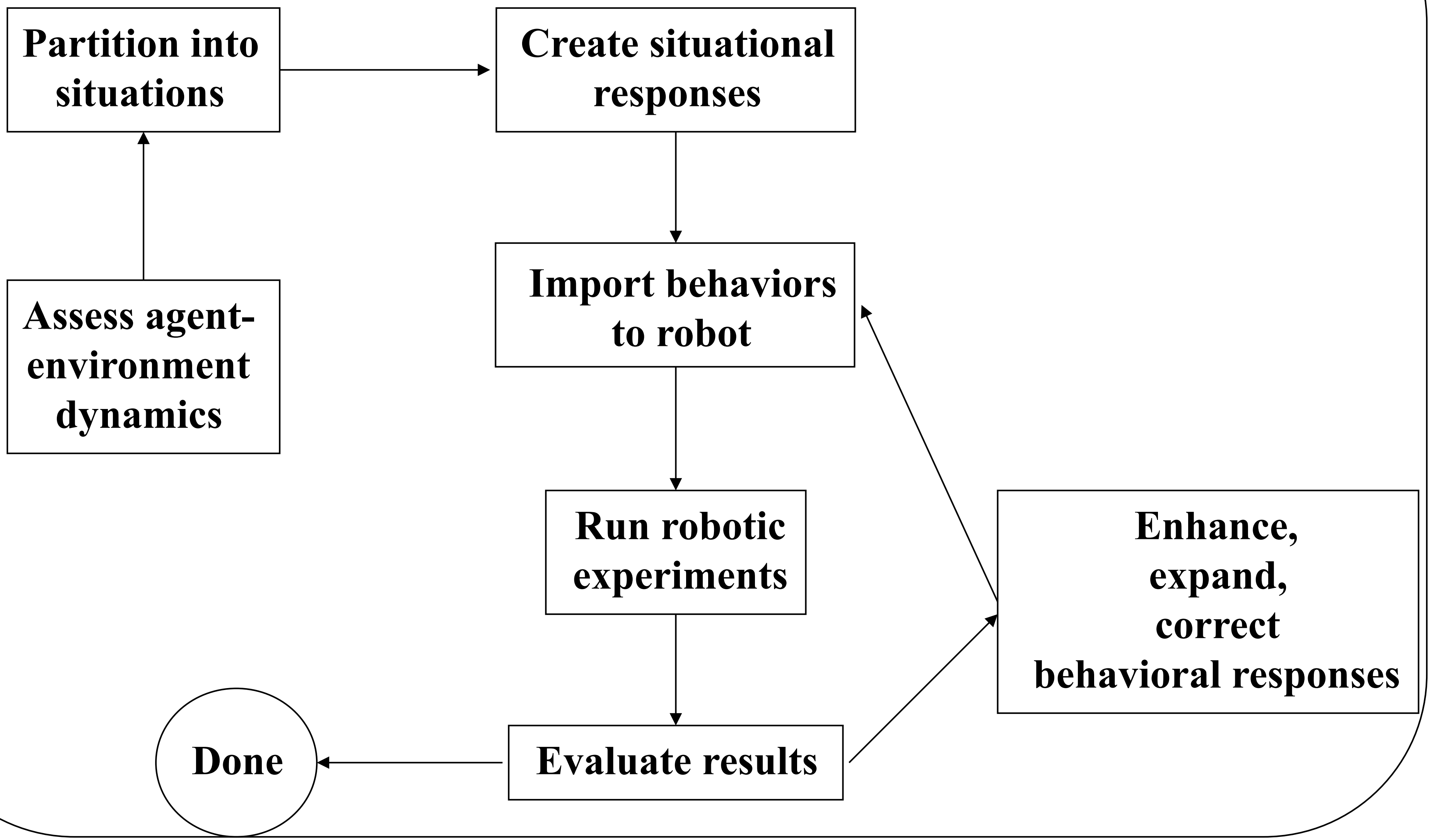
Main design approaches

1. **Ethologically guided/constrained design**:
   - High fidelity to biological models (reproduce animal behavior)
   - This approach highly constrains robot design, but it can potentially answer questions regarding actual biological behavior (e.g. predictive modeling)
2. **Situated activity-based design**:
   - A robot's action are predicated upon the situations in which it finds itself; solid understanding of the relationship between the robot and its environment
   - Perception problem => recognizing the current situation and selecting an action (or several) to undertake (situations = microbehaviors)
   - Arbitrarily complex situations can be created that may have no biological basis
3. **Experimentally driven design** ("do whatever works"):
   - Behaviors created in a bottom-up manner, starting from small set of competences, testing in the world (what works, what doesn't work) and debugging/adding behaviors as needed to achieve desired performance

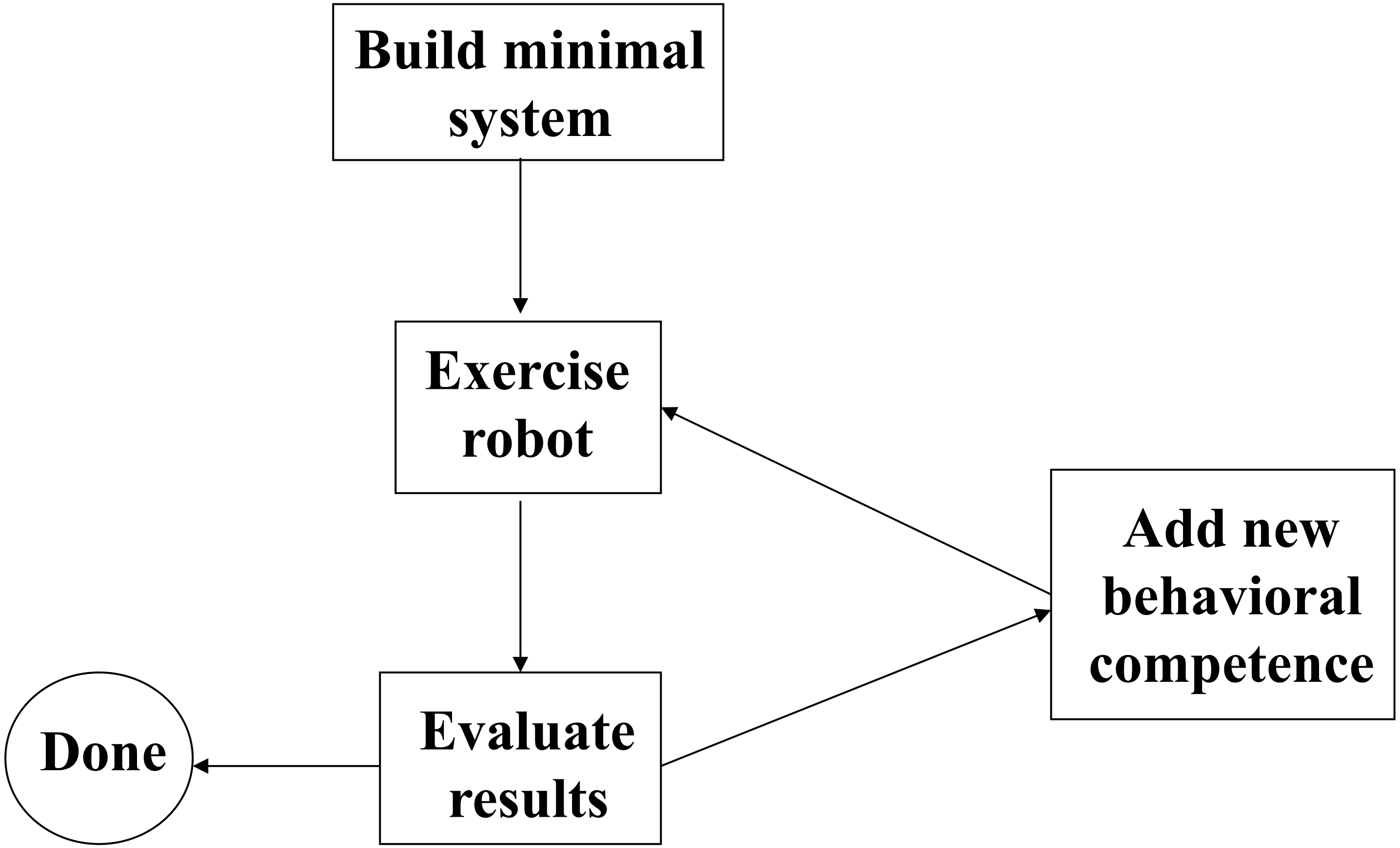
Ethologically-constrained design



Situated activity design



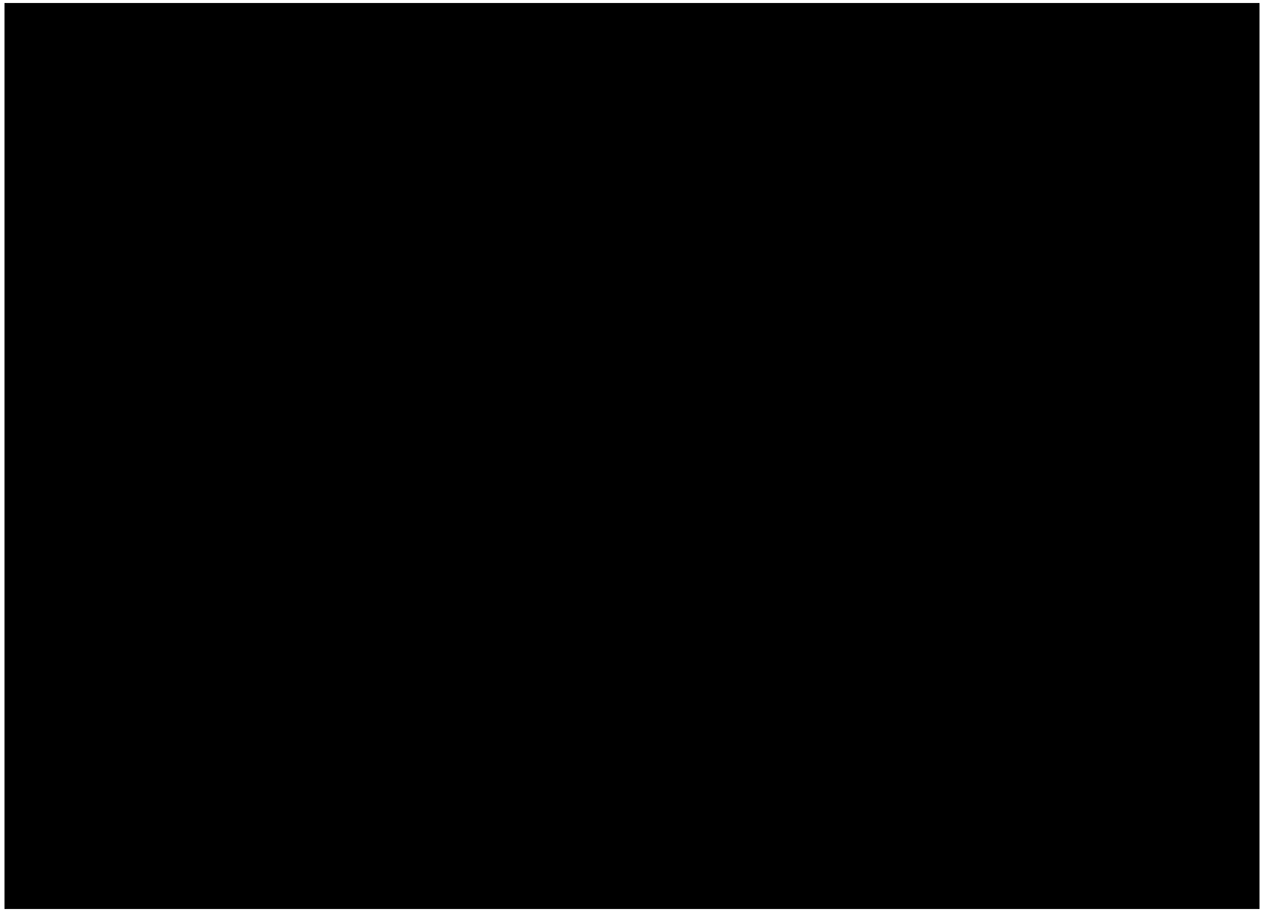
Experimentally-driven design methodology



Common stereotyped behaviors

- **Tropism**: growth or turning of a biological entity (usually plant) in response to environmental stimulus
- **Taxis**: behavioral responses involving movement that orient the animal toward or away from a stimulus (attractive or aversive)
- **Kinesis**: behavioral response to the magnitude of a stimulus, but there is no orientation response
- **Reflex**: rapid, automatic involuntary responses triggered by certain environmental stimuli
- **Fixed-action patterns**: time-extended response patterns triggered by a stimulus but persisting for longer than the stimulus itself

Example of kinesis



Examples of taxes: phototaxis, thigmotaxis

Typical robot behaviors (navigation)

- Exploration/directional:
  - Heading
  - Wandering
- Goal-oriented appetitive behaviors:
  - Discrete object attractor
  - Area attractor
- Aversive/protective behaviors:
  - Avoid static objects
  - Avoid moving objects (dodge, escape)
- Path following behaviors:
  - Road, stripe following
  - Hallway navigation
- Postural behaviors:
  - Balance
  - stability
- Cooperative behaviors:
  - Sharing
  - Foraging
  - Flocking, herding
- Perceptual behaviors:
  - Saccades
  - Visual search
  - Ocular reflexes
- Walking behaviors:
  - Gait control
- Manipulator-specific behaviors:
  - Reaching
  - Grasping
  - Enveloping

Behavioral encoding

➢ *To encode the behavioral response evoked by a stimulus, we must create a **functional mapping** from stimulus to motor action*

- **Dimensionality** of a robotic motor response: strength and orientation
  - *Strength*: magnitude of the response
    - It may or may not be related to the strength of a stimulus, and may be modulated by factors such as motivation (robot's internal goals), emotion, habituation, etc.
    - It might manifest itself as e.g., speed, force, or duration of a behavior
  - *Orientation*: direction of action of the response (e.g. away from, towards stimulus)
    - It may or may not depend on the stimulus's strength
- A behavior can be expressed as a triple (S, R, β), where
  - S: domain of all interpretable stimuli
  - R: range of possible responses (motor actions)
  - β: mapping $S \rightarrow R$.

Types of mappings *(β: $S \rightarrow R$)*

1. **Null**:
   – The stimulus produces no motor response
2. **Continuous**:
   – The stimuli produce a motor response that is continuous over the range of the motor responses available to the robot (specific stimuli are mapped into an infinite set of response encodings)
   – ΔS_m (sensor reading) $\rightarrow$ ΔR_m (motor response)
   – *Example*: Braitenberg Vehicles
3. **Discrete**:
   – The stimulus produces a response from a discrete set of prescribed choices (*repertoire of behaviors*)
   – R consists of a bounded set of stereotypical responses
   – The repertoire of behaviors can be of different granularity levels:
     - Simpler actions: turn-right, turn-left, go-straight, stop, travel-at-speed-5
     - Higher-level competencies: recharge, avoid-obstacle, go-to-food, eat
   – *Example:* robot control architectures based on actions, behaviors and motivations to be discussed in this and next lecture

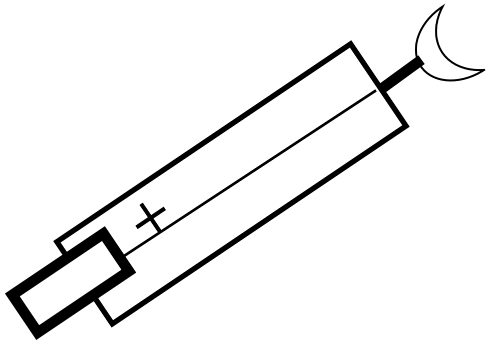
Continuous mapping example: V. Braitenberg's *Vehicles* (1984)

- Autonomous machines (fictional):
  - Very simple internal mechanisms
    + environment
  - Complex emergent behavior
- Evolution:
  - Increasing architectural and behavioral complexity
  - Addition of new "machinery" to existing one
- "Model" of the brain and its evolution

1. Getting around
2. Fear and aggression
3. Love
4. Values and special tastes
5. Logic
6. Selection, the impersonal engineer
7. Concepts
8. Space, things, and movements
9. Shapes
10. Getting ideas
11. Rules and regularities
12. Trains of thought
13. Foresight
14. Egotism and optimism

Vehicle 1

Machinery:



1 sensor (e.g., temperature)
1 motor or actuator
Direct coupling sensor/motor
Speed proportional to stimulation

Behavior:

- Motion forward in the direction of sensor stalk; speed controlled by sensor
- World without friction: faster with heat, slower with cold. Travels in straight line, never stops.
- World with friction: faster with heat, slower with cold; environmental perturbations (forces, slippage, etc) produce changes in direction

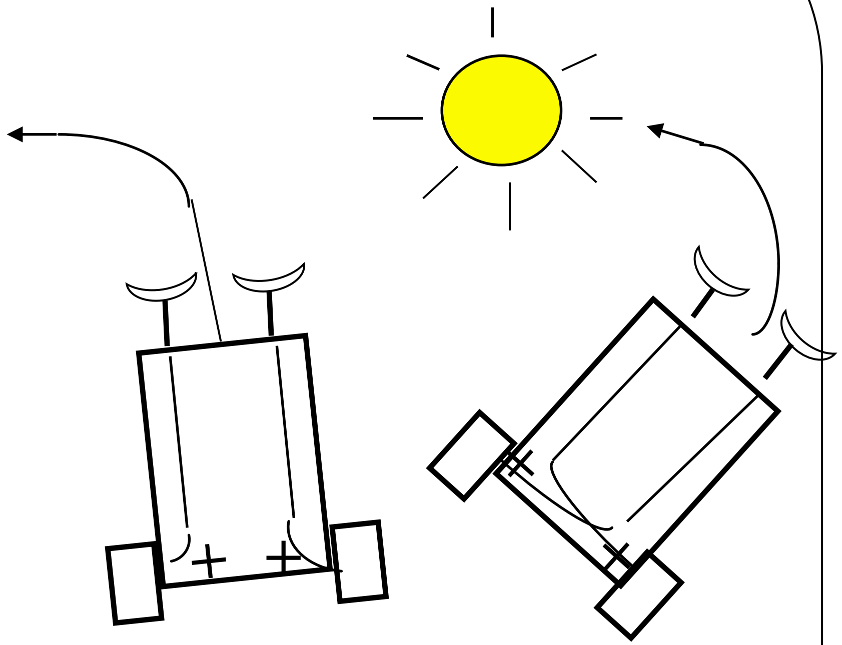
"Lesson":

The behavior of the vehicle (creature) depends on the environment in which it is situated

Vehicle 2

Machinery:

2 sensors, 2 motors
Connections:
- lateral (v2a)
- counter-lateral (v2b)



Behavior:

- Frontal source: hit source
- Source laterally located:
  a) Away from source (positive feedback.)
  b) Approach source (negative feedback)

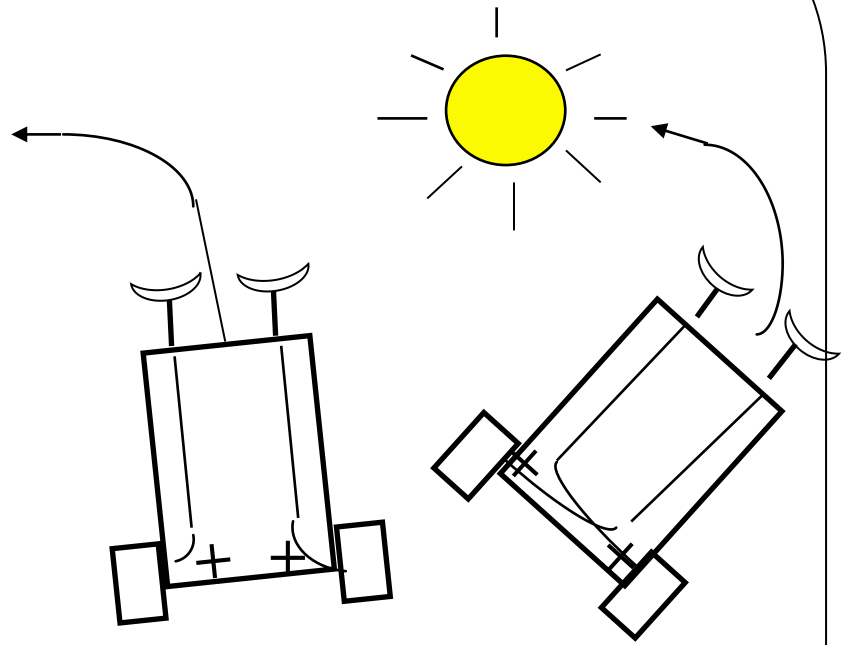
"Lesson":

The actions of the vehicle are part of the dynamics of the interactions with the environment and feed back into the vehicle's perceptions through physical coupling

Vehicle 2

Machinery:

2 sensors, 2 motors
Connections:
- lateral (v2a)
- counter-lateral (v2b)



a) fear b) aggression

Behavior:

- Frontal source: hit source
- Source laterally located:
  - a) Away from source (positive feedback.)
  - b) Approach source (negative feedback)

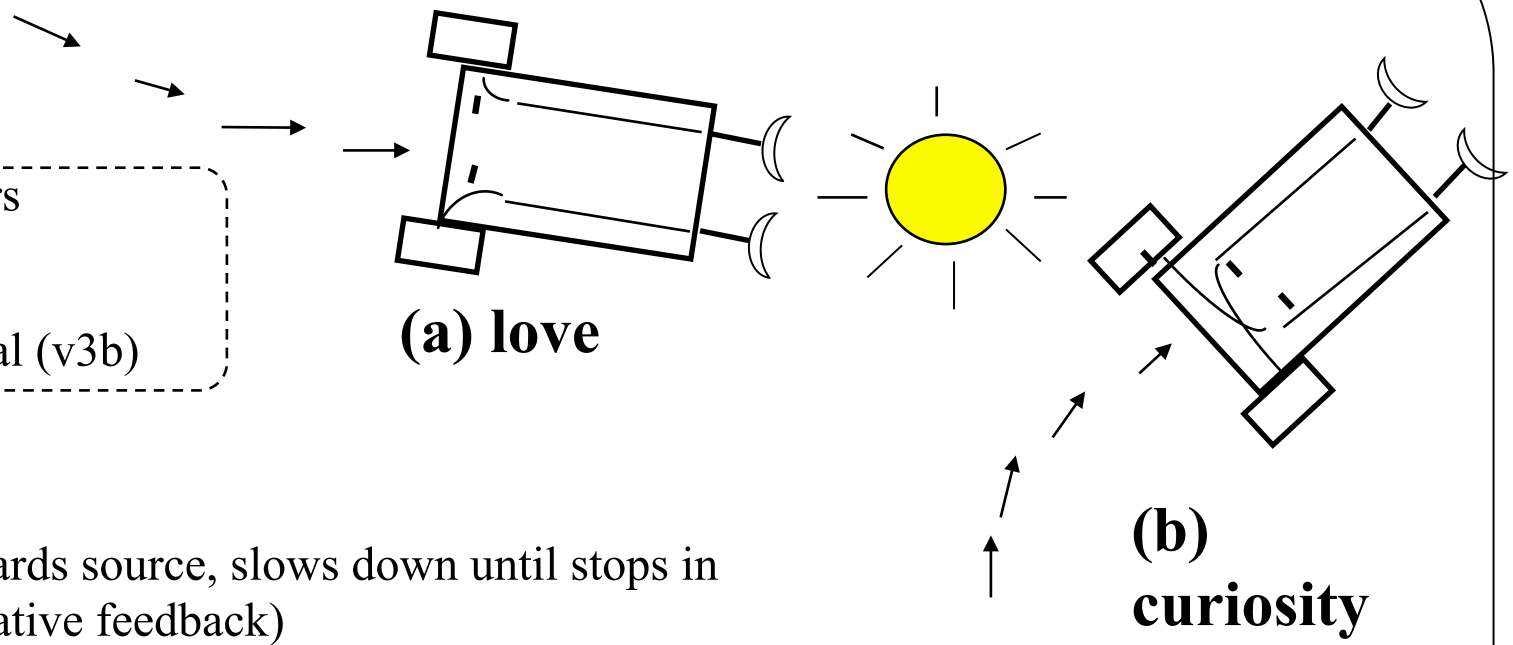
"Lesson 2":

Intentional terms used to describe the vehicle's behavior are in the eye of the beholder

Vehicle 3

Machinery:

Sensors inhibit motors
Connections:
- lateral (v3a)
- counter-lateral (v3b)



Behavior:

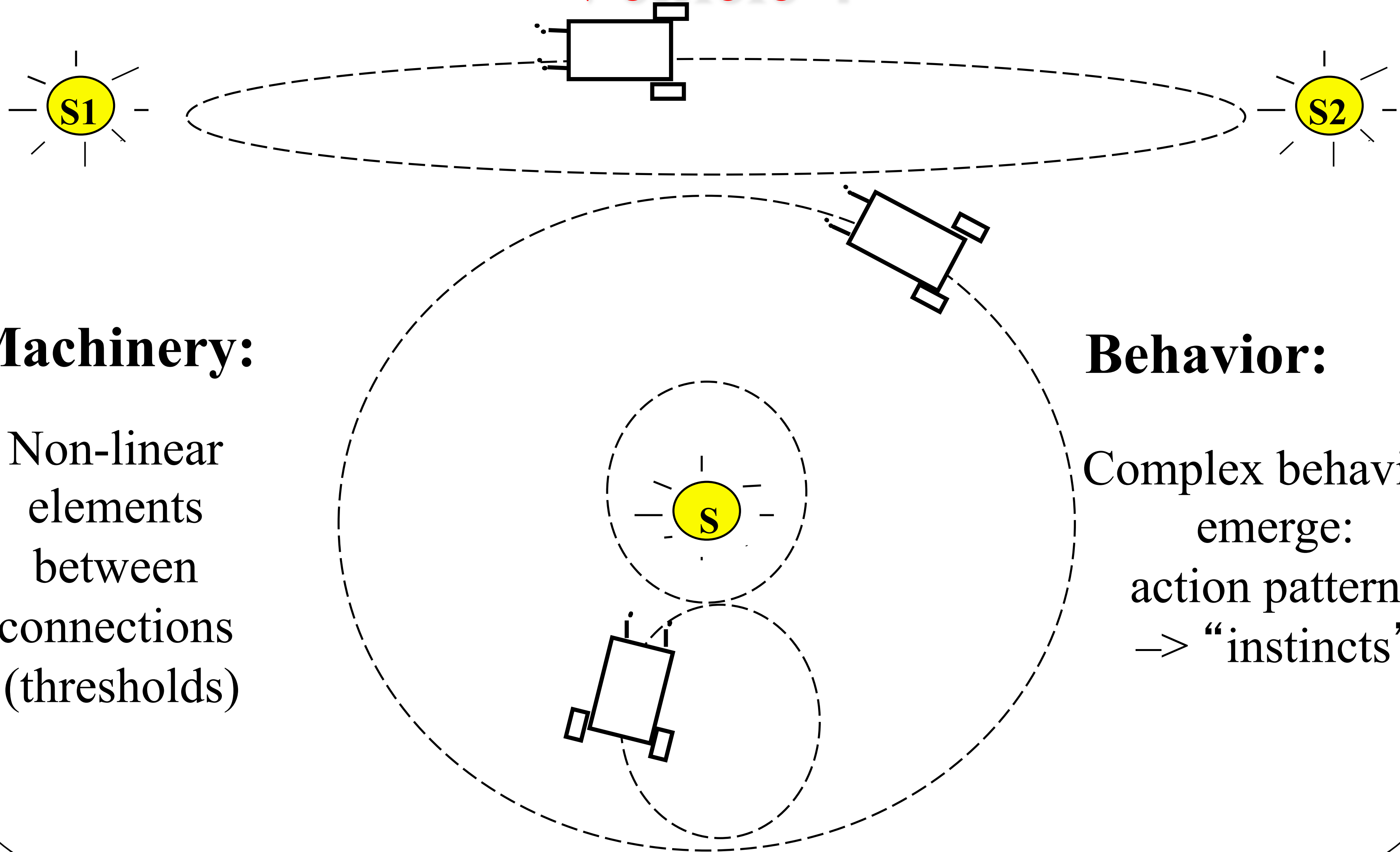
a) Orientation towards source, slows down until stops in front of it (negative feedback)

b) Slows down towards source, turns away when close, environment can become more attractive

"Lesson":

⇨ *Intelligence emerges from the interactions of the vehicle with its environment and from the interactions among the creature's components*

Vehicle 4



Machinery:

Non-linear elements between connections (thresholds)

Behavior:

Complex behaviors emerge: action patterns –> "instincts"

Discrete behaviors

➢ *Two main types of behaviors distinguished in ethology:*

- **Consummatory behaviors**:
  - Contribute to the balance of resources that ensure a creature's self-sufficiency
  - Goal-achieving systems that can recognize a stimulus when it's present, but the process of arriving at the stimulus is determined by the environment
  - Pre-programmed recognition of the incentive stimulus
  - E.g., recharge, eat, attack
- **Appetitive behaviors**:
  - They make more likely that the conditions needed to satisfy a basic need hold
  - Goal-directed systems: behavior is guided by an explicit "representation" of the goal to be achieved
  - They do not have pre-programmed recognition of an incentive stimulus
  - E.g., go-toward, search, avoid, escape

Elements of a behavior

- **A behavior is defined by:**
  - *Stimulus*: its presence causes the activation of the behavior (consummatory only)
    - Sensor reading (internal or external sensor), object
    - “Cortical” map, schema
    - Conditions: food-within-reach, nest-closer-than-2cm
  - *Relevance indicator*: measure of the relevance of executing that behavior in the current situation (stimuli present, environmental elements, internal needs, etc)
    - Activation level, weight, intensity
    - This can be passed on to other behaviors
  - *Behavioral processes*: motor response or sequence of actions or (simpler) behaviors that must be executed to achieve that behavior
  - *Consequences of the execution of the behavior* (optional):
    - E.g., changes in internal variables

Assembling behaviors

- **Emergent behavior**:
  - Emergence is a property of a collection of components. It implies a holistic capability where the sum (overall behavior) is greater than its parts (individual actions/behaviors)
  - In behavior-based systems, emergent behavior arises from the interactions of these behaviors among themselves *and with a highly unpredictable environment*
- **Behavioral coordination**
  - <u>*Competitive methods*</u>: competition resolves conflict when two or more behaviors are active, each with its own independent response; only one behavior is executed
    - Fixed prioritization networks, winner-takes-all networks
  - <u>*Cooperative methods*</u>: behavioral fusion allows to use concurrently the output of more than one behavior at a time
    - Vector addition, potential fields
- **Behavioral assemblages**
  - Behaviors are assembled in bigger units (summation or sequencing)

Emergent behavior

perception

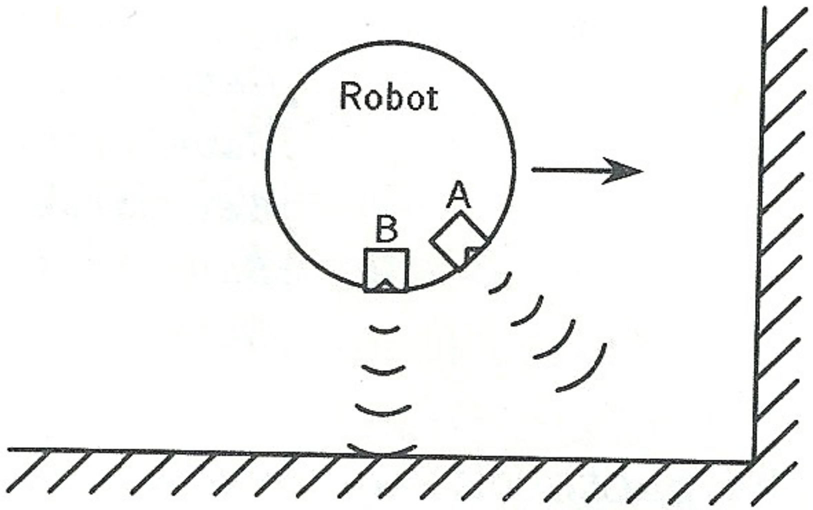
IR-A → Behavior-4 (turn right) →

IR-B → Behavior-3 (avoid object) →

IR-B → Behavior-2 (approach object) →

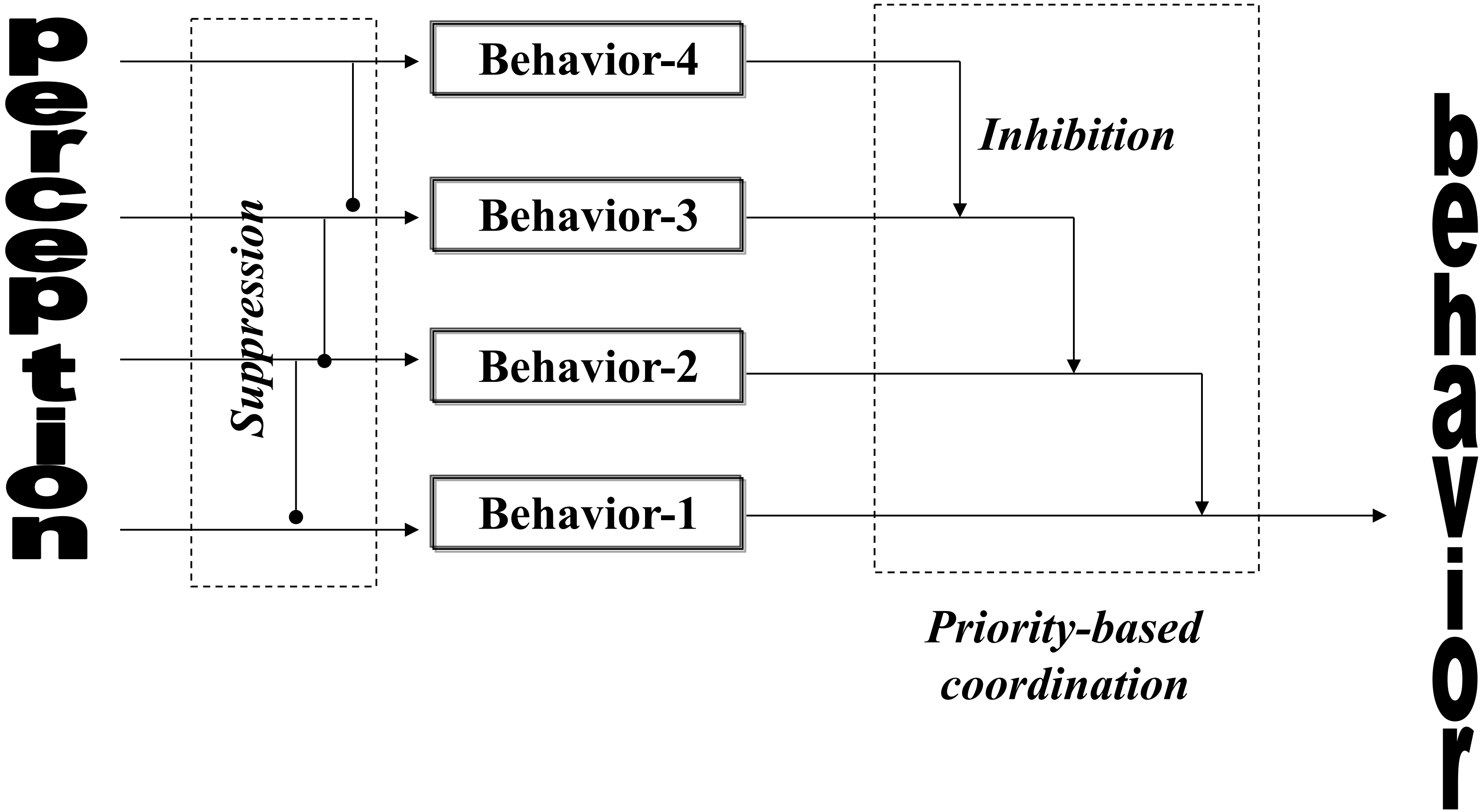
0 → Behavior-1 (forward) →

behavior



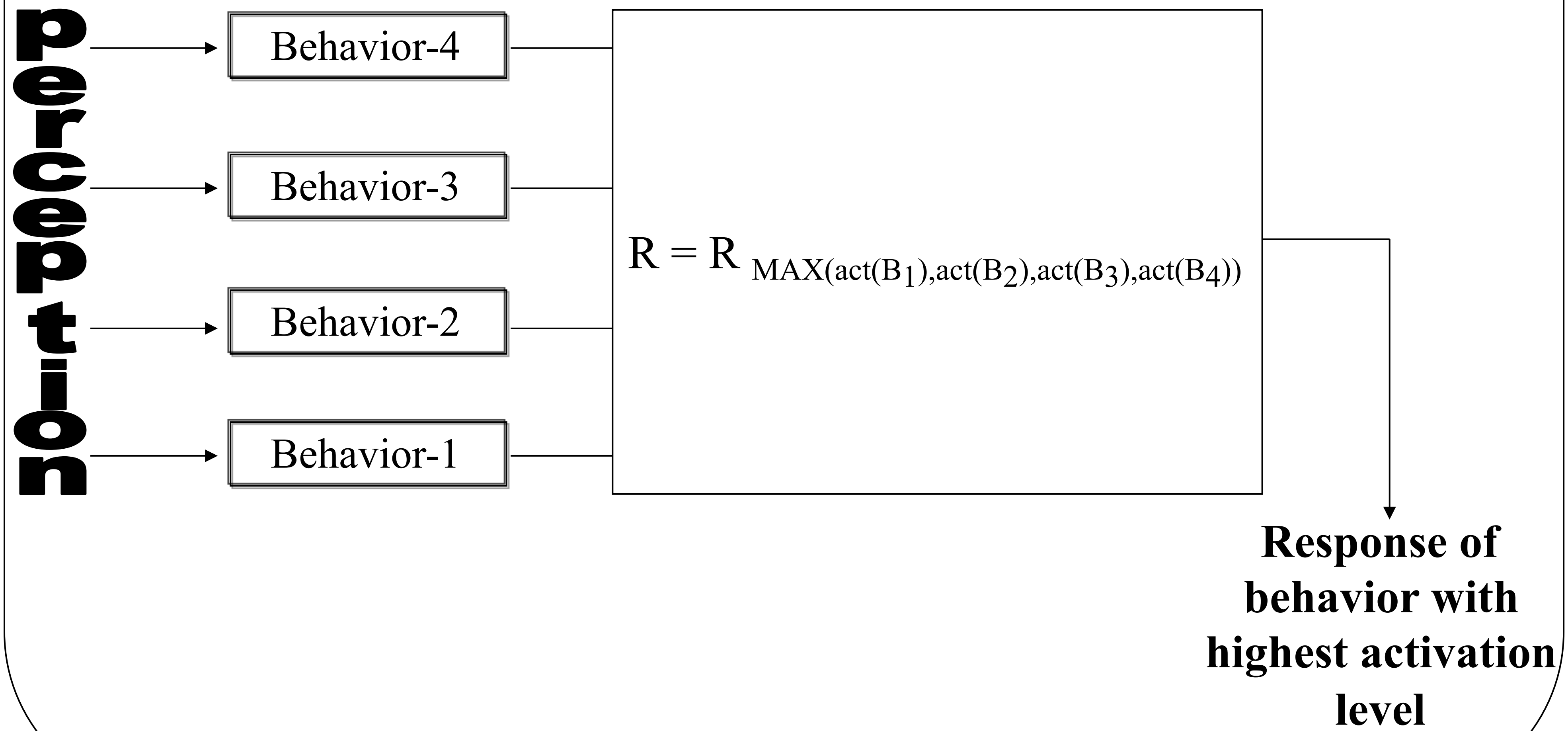
Example: emergent wall following

Arbitration via fixed prioritization network (example: Subsumption architecture)

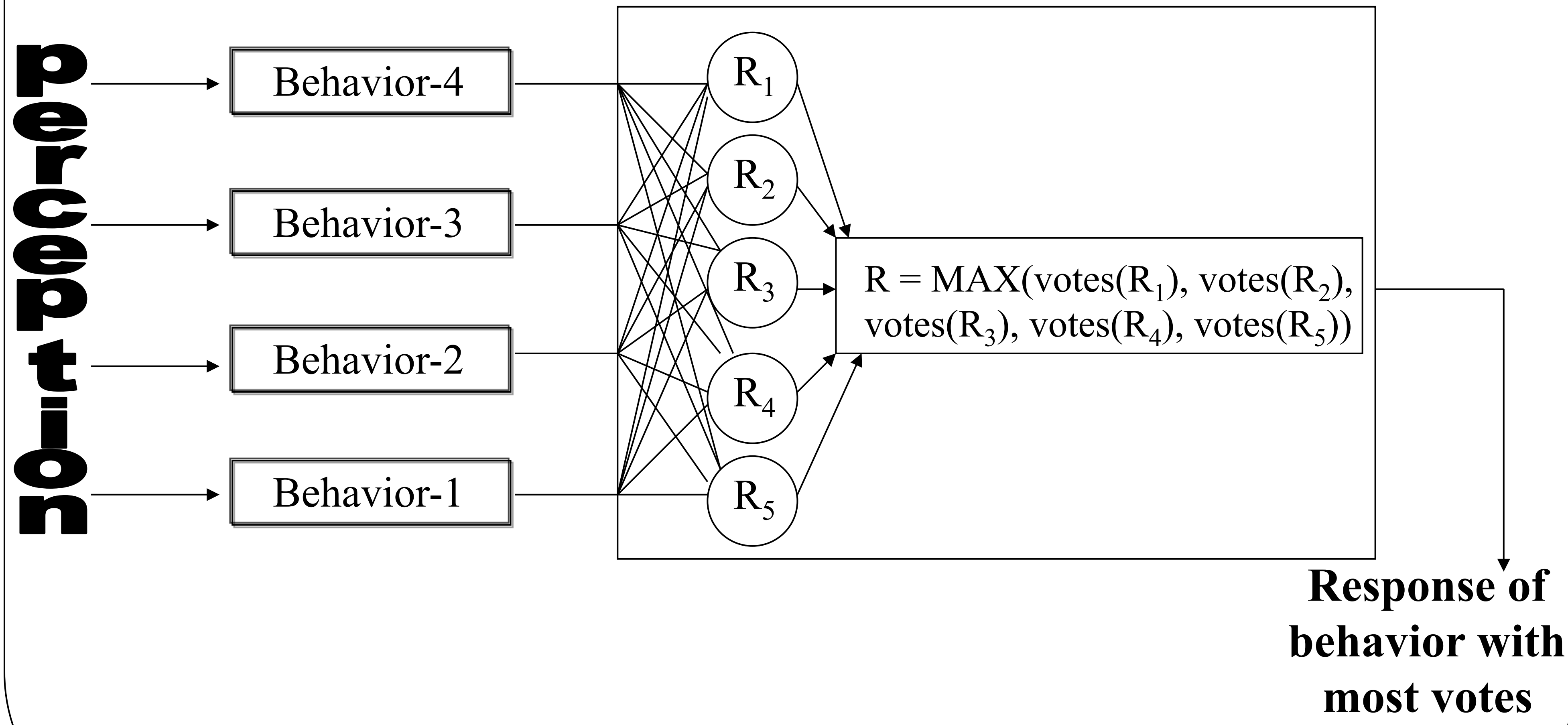


Example: wall following, coordination

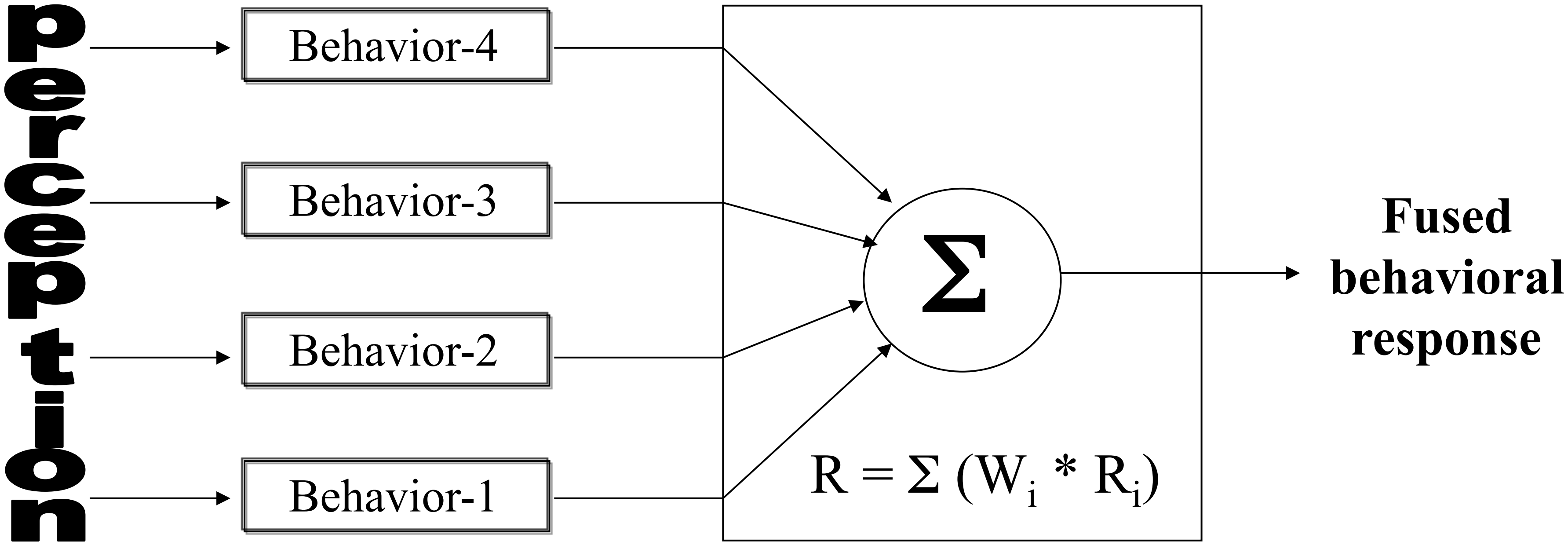
Winner-takes-all coordination



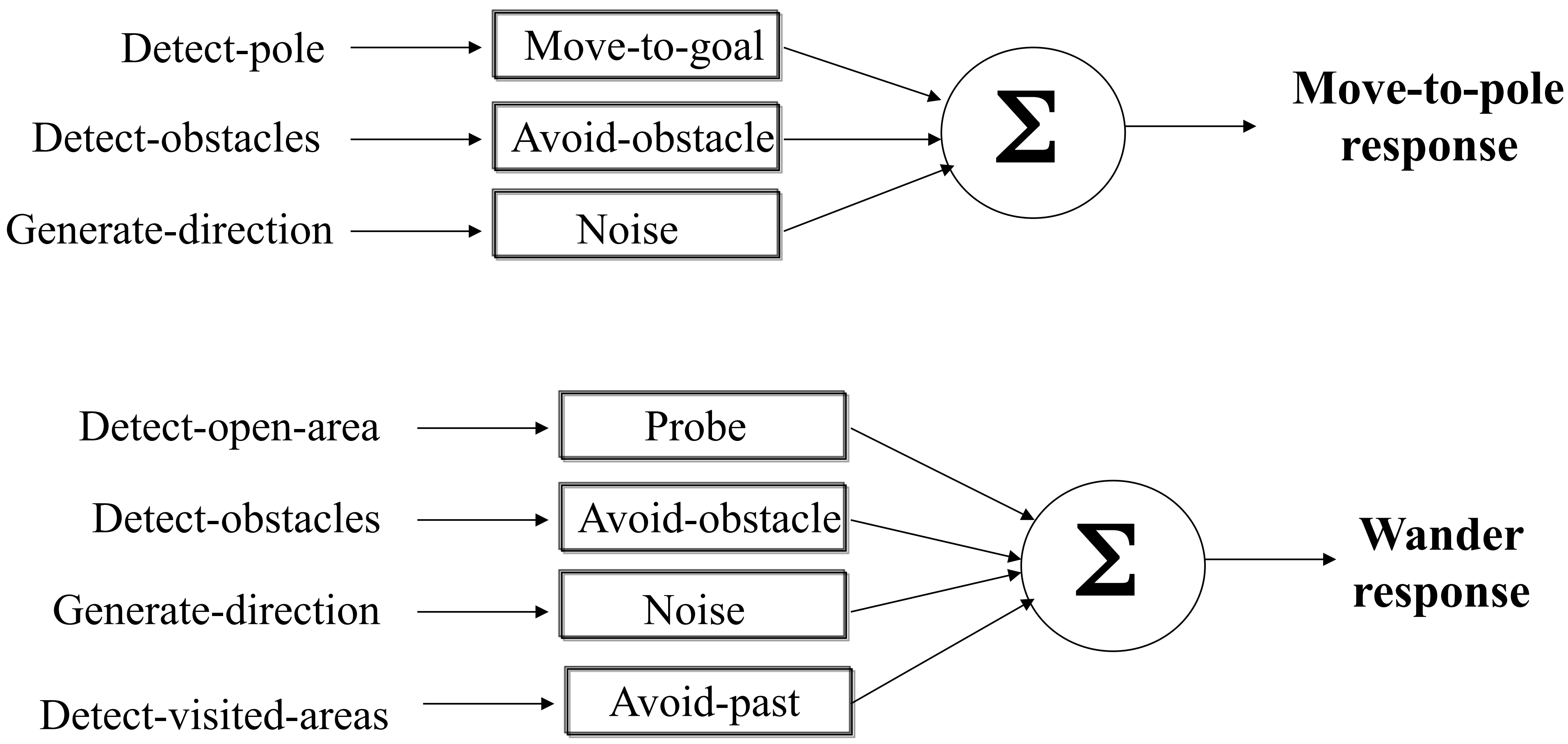
Voting-based coordination



Behavioral fusion via vector summation



Behavioral assemblages: fusion



Behavioral assemblages: sequencing