Behaviour Based Robot Control Architectures
1 – Biological Foundations

February 20, 2012

Criticisms

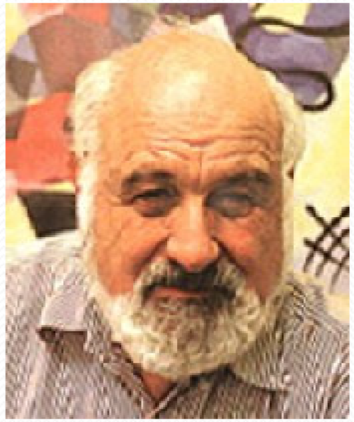
- Modelling the world too hard and slow
- Planning intractable (NP-complete)
- Feedback through world model cumbersome
- Single <u>chain</u> mapping sensing to action
- Very general ⇨ poor at lots of tasks
- Passing representations between modules is slow

Turn the problem on its head

- Don't build (abstract) world models
- Don't plan
- Use short feedback loops
- Create many chains that map sensing to action
- Very specific ⇒ good at one or two tasks
- Don't pass representations between modules

"There are no general purpose animals… why should there be general purpose robots?" D. MacFarland

After Top-Down Approach, Trend toward Biological Insight to Intelligence



- Late 1970s and early 1980s, Michael Arbib (while at U. Massachusetts; now at U. of Southern Cal.) investigation of animal intelligence from biological and cognitive sciences

- Goal: gain insight into what is missing in robotics

- At about same time: Braitenberg's Vehicles

- Idea of biological parallels: Caught on rapidly in robotics research

Ethology

- Ethology: The study of animal behavior in natural conditions

- "Founding fathers" of Ethology: Konrad Lorenz and Niko Tinbergen (Nobel prize winners in 1973)
  - They studied:
    - Individual animal behaviors
    - How animals acquire behaviors
    - How animals select or coordinate groups of behaviors

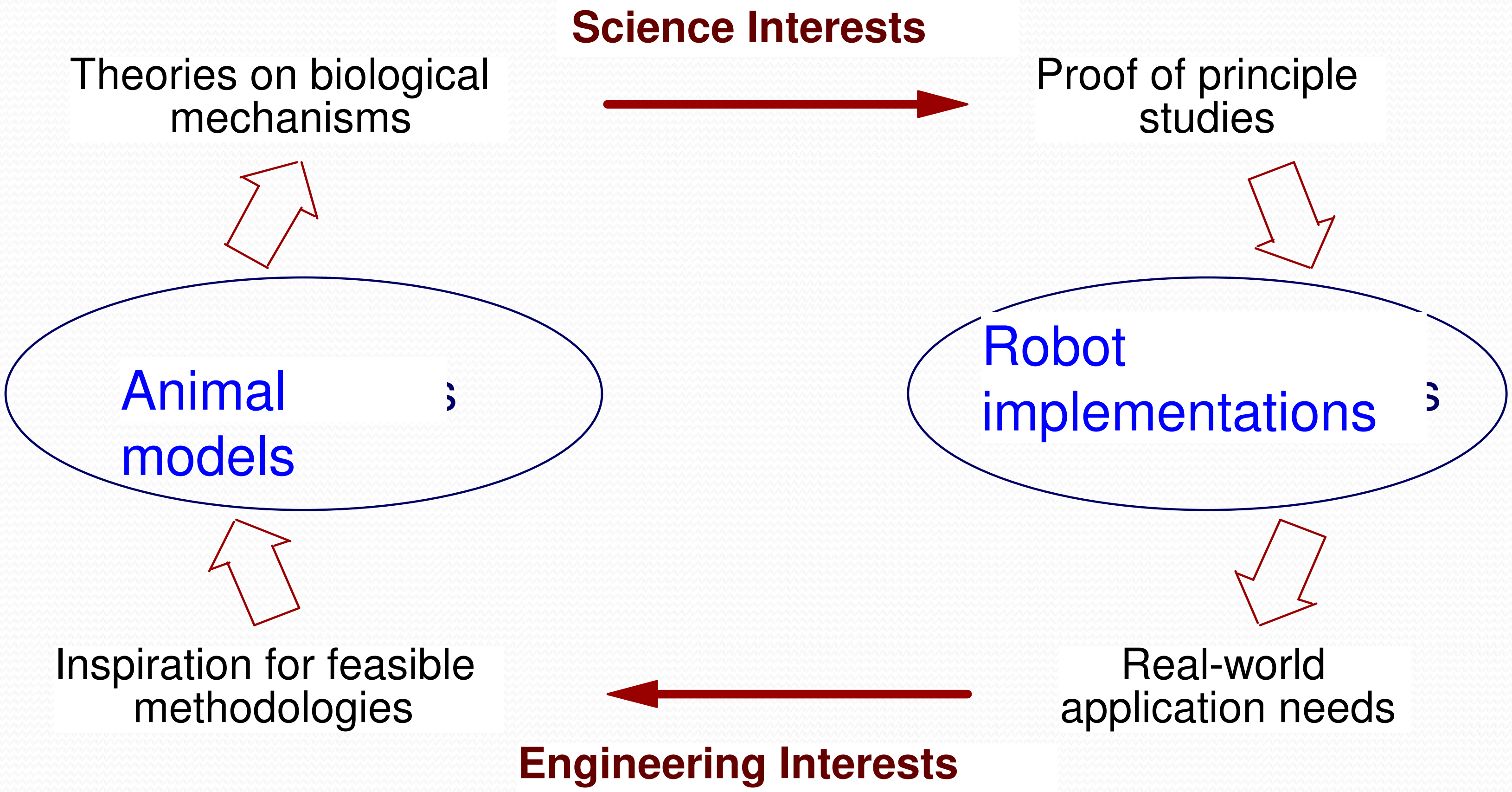
Lorenz

Tinbergen

Why Study Biological Sciences for Robotics?

- Reasons to study biological sciences for robotics:
  - Animals and humans provide existence proofs of different aspects of intelligence
  - Even “simple” animals (insects, fish, frogs) exhibit intelligent behavior
  - Animal studies can provide models that a roboticist can operationalize within a robotic system
    - Models can be implemented with high fidelity to animal counterparts, or,
    - Models may serve only as inspiration for the robotics researcher

Reasons for Operationalizing Animal Models in Robots



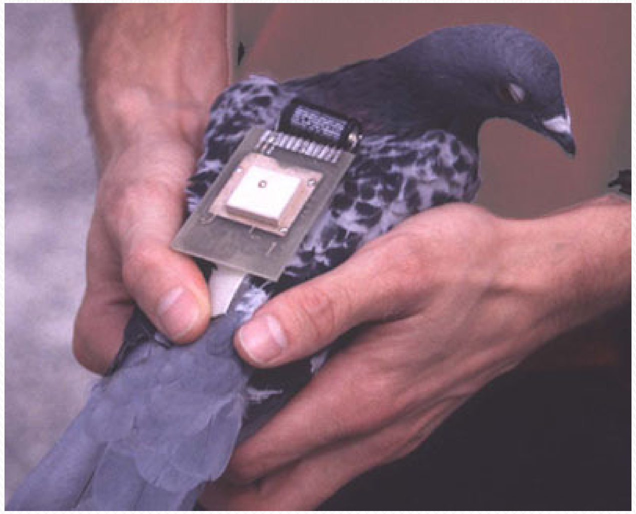
Examples of Interesting Biological Systems to Study

Example 1: Frog's visual system

- Used to find prey or detect predators
- Basic algorithm:
  - If frog finds prey, it orients toward it
  - If it detects predator, frog jumps towards darkest region it can see

Frog Tongue © ANT/ Gerard Lacz

Example 2: Homing Pigeon's Orientation



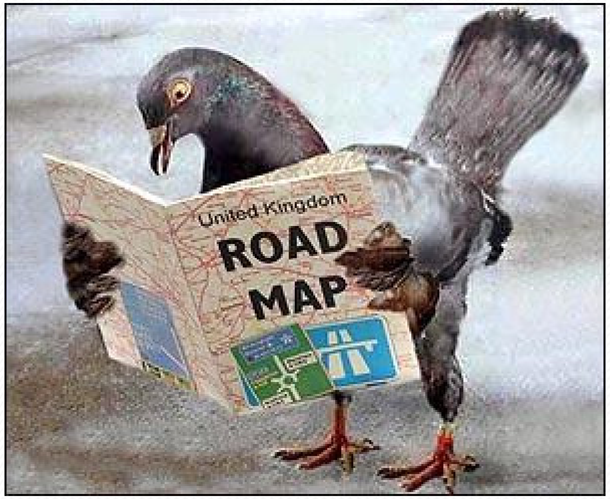
- Pigeons can navigation hundreds of miles to a goal destination
- Frequently, they have no visual cues to the path home
- Appears that they have multiple cues:
  - If sunny day, pigeons seem to use biological clocks and sun angle
  - When birds have clocks shifted by 6 hours (using artificial lighting), departure orientation is off by 90 degrees
  - However, when sky is overcast with sun not visible, clock-shifted birds head off in correct direction. Appear to be using another mechanism independent of time of day.
  - When birds are wearing magnets, they are confused on overcast days, but not on sunny days.

Example 2: Homing Pigeon's Orientation

- So, Pigeon flight algorithm seems to be:

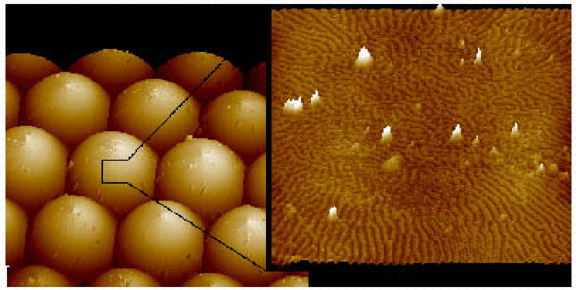
```
if (sunny)
     followSun();
else
     followMagneticCues();

sometimes
   { useUltrvioletLight();
     usePolarizationOfLight();
     useSmell();
     useThunderstormDetector();
     useDetectionOfLowFrequencySound();
   }
```



Example 3: Fly Vision

- Housefly's visual navigation system consists of about 1,000,000 neurons
  - Neurons constantly adjust amplitude, frequency, and twist of wings, which are controlled by 17 muscles
  - Visual motion used for coarse control
- Eye of housefly:
  - Composed of 3,000 pixels
  - Each pixel has 8 photoreceptors and operates in parallel



Example 4: Ant Chemotaxis

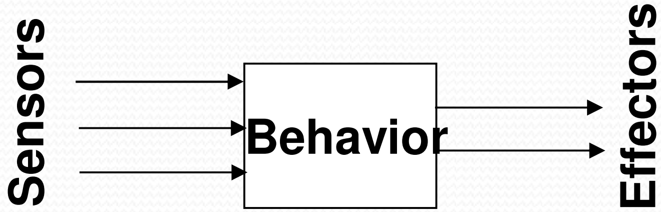
- Ants: relatively simple creatures capable of complex actions through their social behavior and their interactions with the environment

- Ant communication:
  - Predominantly chemical
  - Visited paths marked with volatile trail pheromone
  - Ants traveling path continually add to odor trail, strengthening it

- Many researchers studying this mechanism in simulation
  - Biologically plausible trail generation using mathematical behavior models
  - Production of species-specific foraging patterns

What is "Behavior"?

- Behavior: Mapping of sensory inputs to a pattern of motor actions that are used to achieve a task



- Three broad categories of behaviors:
  - Reflexive behaviors:
    - Stimulus-response
    - Hard-wired for fast response
    - Example: (physical) knee-jerk reaction
  - Reactive behaviors:
    - Learned
    - "Compiled down" to be executed without conscious thought
    - Examples: "muscle memory" – playing piano, riding bicycle, running, etc.
  - Conscious behaviors:
    - Require deliberative thought
    - Examples: writing computer code, completing your tax returns, etc.

Three Types of Reflexive Behaviors

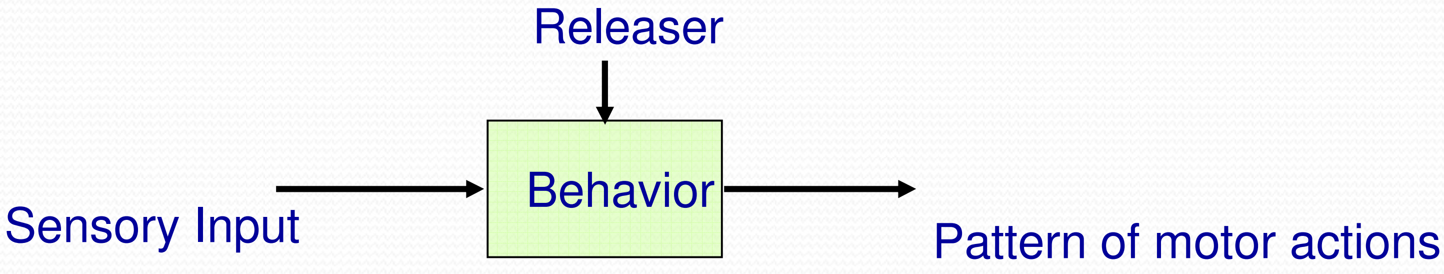
- **Reflexes**:
  - Rapid, automatic, involuntary responses triggered by certain environmental stimuli
  - Response persists only as long as the duration of the stimulus
  - Response intensity correlates with the stimulus' strength
  - Used for locomotion and other highly coordinated activities

- **Taxes**:
  - Behavioral responses that orient animal toward or away from a stimulus
  - Occur in response to visual, chemical, mechanical, and electromagnetic phenomena
  - Example: pheromone trail following of ants

- **Fixed-Action Patterns:**
  - Time-extended response patterns triggered by a stimulus
  - Last longer than the stimulus itself
  - Intensity and duration of response is not governed by the strength and duration of the stimulus
  - May be motivated, may result from a much broader range of stimuli
  - Examples: the song of crickets, fleeing predator, etc.

Innate Releasing Mechanisms (IRMs)

- IRM: a combination of stimuli that elicit a specific, perhaps complex, response to a particular biological situation
- Releaser:
  - Similar to a latch or Boolean variable that has to be set by a stimulus
  - Acts as a control signal to activate a behavior



Example Code for an IRM

```
enum         Releaser={PRESENT, NOT_PRESENT};
Releaser     predator;
while (TRUE)
  { predator = sensePredators();
    if (predator == PRESENT)
        flee();
  }
```

Compound Releasers

```
enum          Releaser={PRESENT, NOT_PRESENT};
Releaser      food;
while (TRUE)
  { food = senseFood();
    hungry=checkState();
    if (food == PRESENT && hungry == PRESENT)
        feed();
  }
```

Implicit Chaining

```
enum              Releaser={PRESENT, NOT_PRESENT};
Releaser          food, hungry, nursed, predator;
while (TRUE)
  { predator = sensePredator();
    if (predator == PRESENT)
        flee();
    food = senseFood();
    hungry = checkStateHunger();
    child = checkStateChild();
    if (hungry == PRESENT)
        searchForFood();
    if (hungry == PRESENT && food == PRESENT)
        feed();
    if (hungry == NOT_PRESENT && child == PRESENT)
        nurse();
    if (nursed == PRESENT)
        sleep();
  }
```

Interaction of Concurrent Behaviors

- Usually, behaviors follow a fixed sequence
- However, can have multiple behaviors activated in certain environmental situations
- How do behaviors interact?
  - Equilibrium:
    - Behaviors balance each other out
    - Example: squirrel with food close to human
  - Dominance of one / winner-take-all
  - Cancellation:
    - Example: Male stickleback fish: if want to defend and fight (due to overlapping territories), ends up building a nest

Perception in Behaviors

- Two functions of perception:
  - Release: To release a behavior
  - Guide: To provide information needed to accomplish a behavior

- Action-oriented perception:
  - Perception filters the incoming sensory stream to extract information specific to the task at hand
  - Note: difference from hierarchical world-model building

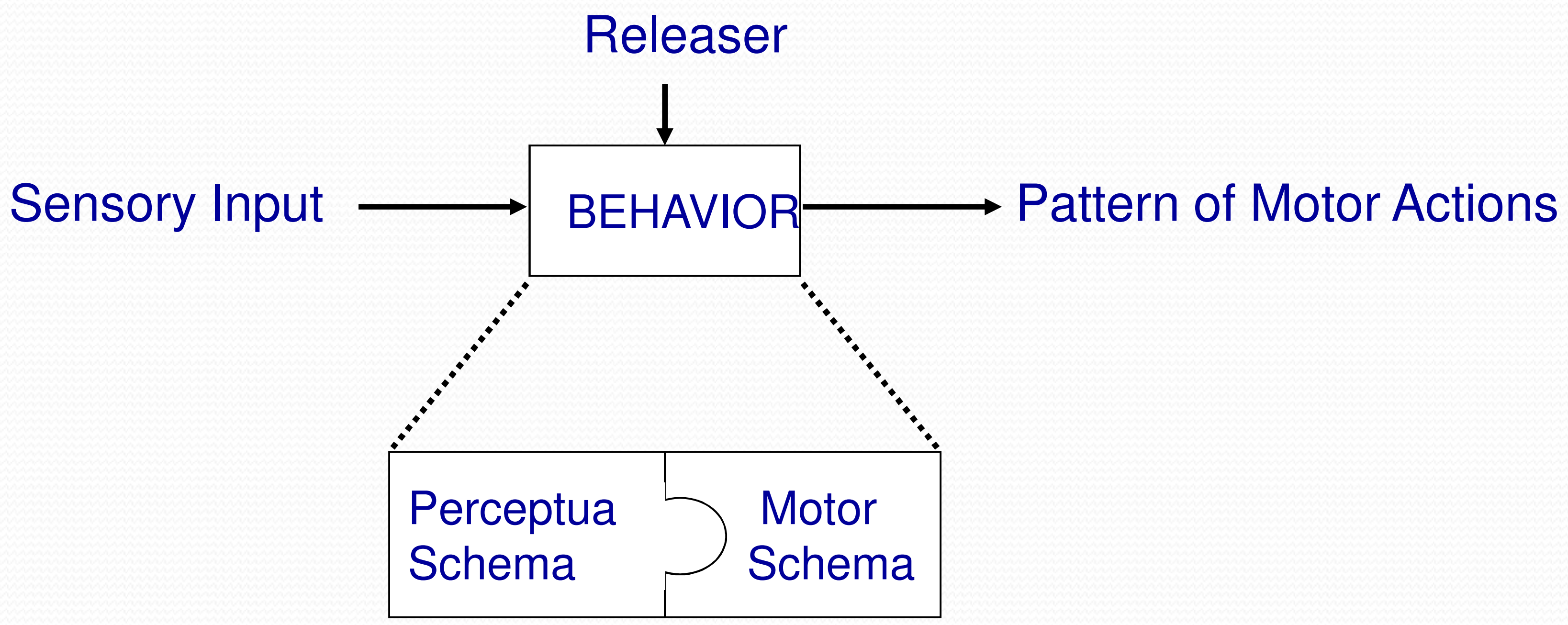
- Affordance: “perceivable potentialities of the environment for an action”
  - Example: Color “red” to a baby arctic tern is perceivable, and represents the potential for feeding

Schema Theory

- Schema theory:
  - Used by psychologists since early 1900s
  - Brought to attention of roboticists in 1980s (Arbib, Arkin, Murphy, etc.)
  - Provides way to cast biological insights into a formalism
  - Way of expressing basic unit of activity

- Schema:
  - Consists of:
    - Information on how to act and/or perceive (knowledge, data structures, models)
    - Computational process by which it achieves the activity (algorithm)
  - Is a generic template for how to do some activity
  - Examples:
    - Bike-riding
    - Obtaining food from a restaurant
    - Buying a car

Behaviors and Schema Theory



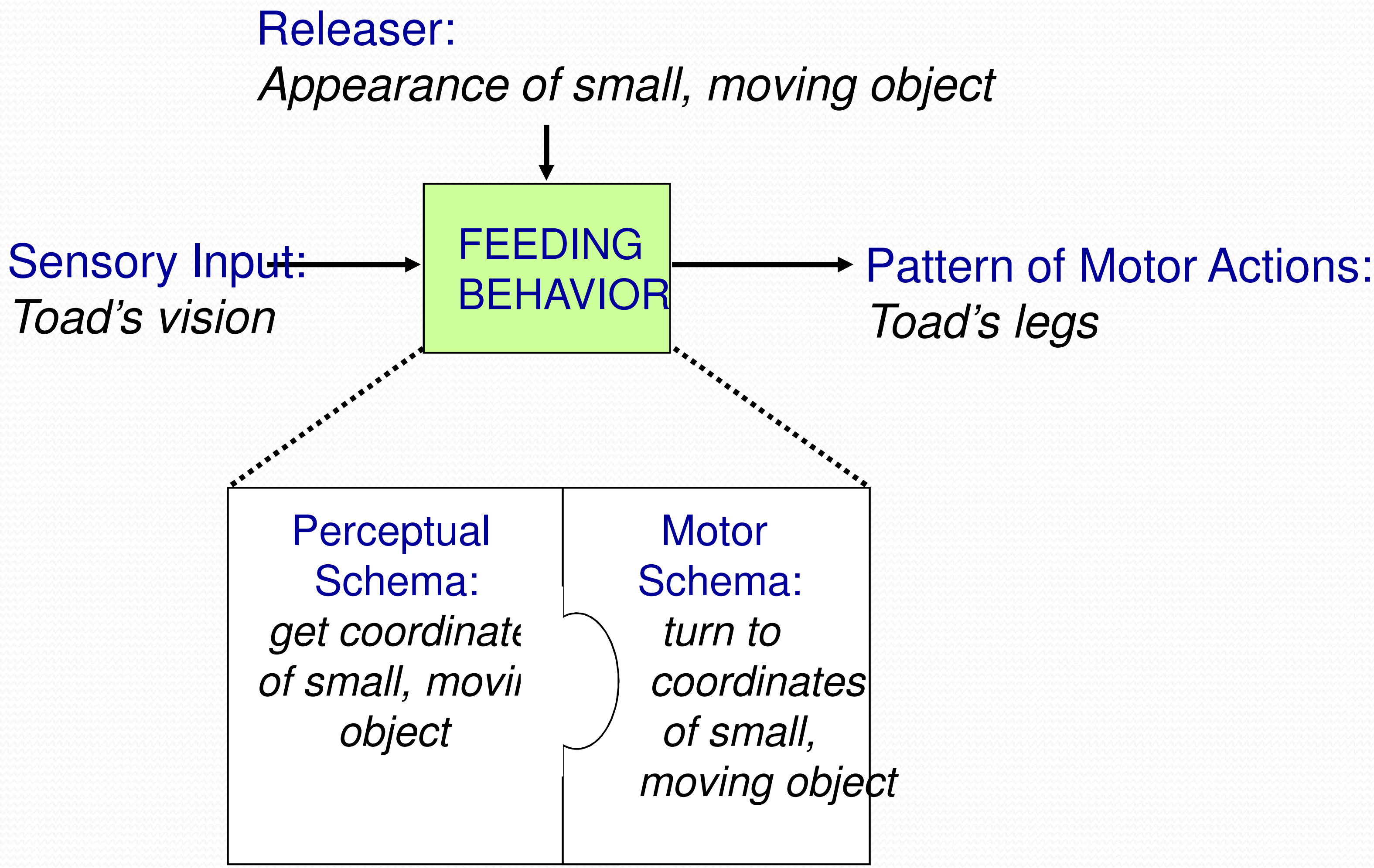
- Behavior takes sensory inputs and produces motor actions as output

- Behavior can be represented as a schema

- Behavior is activated by releasers

- The transformation of sensory inputs into motor action outputs can be divided into two sub-processes: a perceptual schema and a motor schema

Example of Toad's Feeding Behavior Using Schema



Schemas Described in Object-Oriented Programming

Example 1: Primitive behavior

-- one motor schema, one perceptual schema

Behavior::Schema

Data	
Methods	**Perceptual_schema()** **Motor_schema()**

Schemas Described in Object-Oriented Programming

Example 2: Meta-behavior -- consists of several primitive behaviors, with

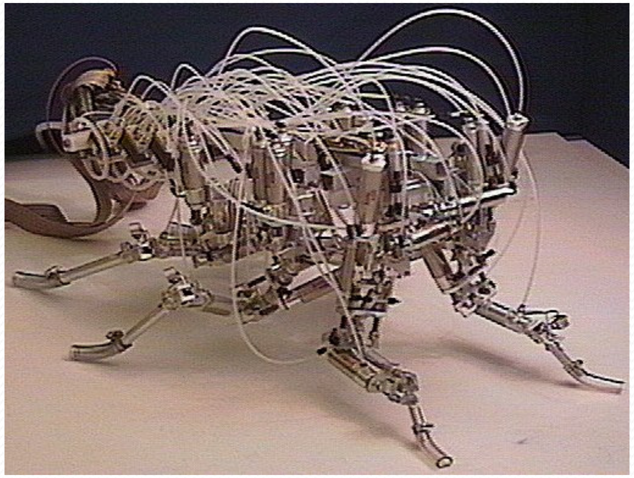
releasing logic of when to activate each behavior

Behavior::Schema

Data	**releaser1** **releaser2** **releaser3** **IRM_logic**
Methods	**behavior1()** **behavior2()** **behavior3()**

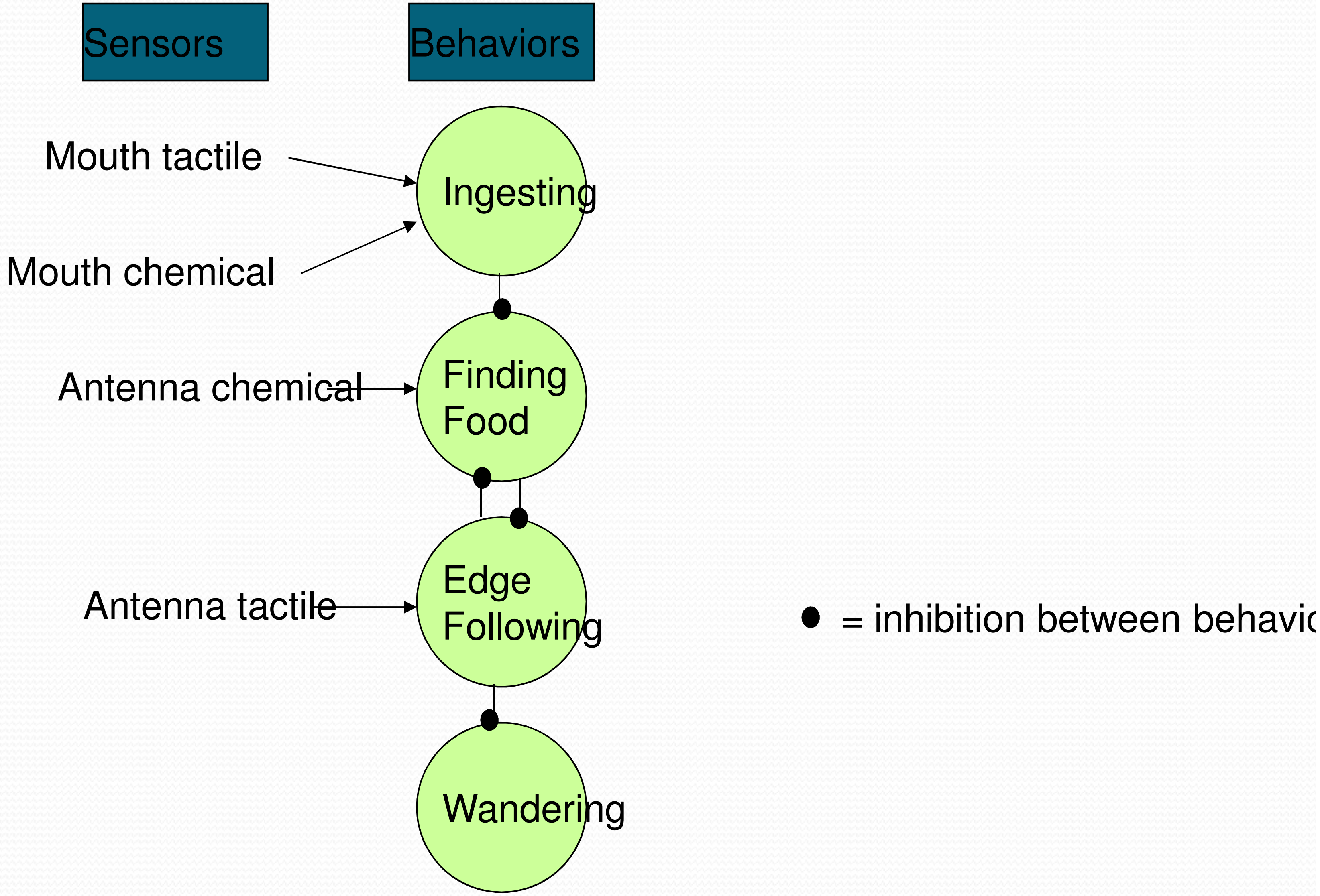
Example

- Case Western Biologically Inspired Robotics Laboratory (Roger Quinn)
- Studied mechanisms of locomotor behavior in American cockroach
- Developed a neural model faithful to biology:
  - Uses cell membrane properties
  - Synaptic currents
  - Generates outputs in terms of neuron’s firing frequency
- In simulation studies, achieved spontaneous generation of gaits observed in natural insect
- Behaviors included:
  - Wandering
  - Edge following
  - Appetitive orientation and attraction to food
  - Fixed-action pattern representing food consumption



Robot III

Simplified Model of Cockroach Behavior



Summary of Principles and Issues in Transferring Biological Insights to Robots

- Programs should decompose complex actions into independent behaviors, which tightly couple sensing and acting. Behaviors are inherently parallel and distributed.
- To simplify control and coordination of behaviors, agent should use straightforward, boolean activation mechanism (e.g., IRM)
- To simplify sensing, perception should filter sensing and consider only what is relevant to the behavior (i.e., action-oriented perception)
- Direct perception (affordances) reduces the computational complexity of sensing
- Behaviors are independent, but the output from one may be combined with another to produce a resultant output, or may serve to inhibit another