STRONG REMINDER: Academic Conduct

• When you applied for admission to The University of Tennessee, you signed the following statement (see UT Graduate School Catalog, 2002-2003, page 19):

  “An essential feature of The University of Tennessee is a commitment to maintaining an atmosphere of intellectual integrity and academic honesty. As a student of the University, I pledge that I will neither knowingly give nor receive any inappropriate assistance in academic work, thus affirming my own personal commitment to honor and integrity.”
You also signed an affirmation for this class

• One of the class policies stated on the syllabus for this course:

  “Collaboration policy: Discussing and exchanging ideas is encouraged. However, except if specifically allowed by the instructor, copying from any outside sources (e.g., fellow students, Internet, etc.) on any material to be graded is not permitted, and will be considered cheating. Cheating will result in failure of the class. Each student is responsible for securing his or her work from copying. Each student is expected to abide by UT’s policies on Academic Conduct.”

• When you signed the initial roll for this class (CS594 – Software for Intelligent Robotics), you signed your name to affirm the following statement:

  “I have received, read, and understand the CS594 Section 30586 course syllabus.”
Consequences of Academic Dishonesty

• HillTopics student handbook, 2002-2003 states (page 31):

“Student classroom conduct, including academic dishonesty, is the immediate responsibility of the instructor. He/she has full authority to suspend a student from his/her class, to assign an “F” in an exercise or examination, or to assign an “F” in the course. In addition to or prior to establishing a penalty, the instructor may refer the case to an Academic Review Board by notifying the administrative head of his/her academic unit and the Office of the Dean of Students, which shall prepare and present the case to the appropriate Academic Review Board.”
Cheating will not be tolerated in this class.

• Period.
Objectives

- To develop an understanding of the possible relationships between animal behavior and robot control
- To provide a reasonable background in ethology for the roboticist
- To understand the 3 levels in a computational theory
- To understand the concepts/terms of reflexes, taxes, fixed-action patterns, schema, affordance
- To be able to write pseudo-code of an animal’s behaviors in terms of innate releasing mechanisms
- To examine a range of biologically motivated robotic systems
Recall History of Today’s Intelligent Robotics

- Cybernetics
  - Grey Walter’s tortoise

- Artificial Intelligence
  - Dartmouth Conference
  - AI Planning Tradition
  - Shakey (SRI)
  - Braitenberg’s Vehicles
  - Behavior-Based Robots

- Robotics
  - HILARE (LAAS)
  - Stanford Cart
  - Planetary rovers
  - Telemanipulators
  - Telerobotics
  - Manufacturing
After Hierarchical Approach, Trend toward Biological Insight to Intelligence

• Late 1970s and early 1980s, Michael Arbib (while at U. Massachusetts) 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
What do we mean by “Intelligence”? 

• Open question: where intelligence begins and ends

• Intelligence (our working definition): the ability to improve an animal or human’s likelihood of survival within the real world, and, where appropriate, to compete or cooperate successfully with other agents to do so.

• For our purposes, we call certain animal behaviors “intelligent”
What is Ethology? What is Cognitive Psychology?

- **Ethology:** The study of animal behavior in natural conditions

- “**Founding fathers**” of ethology: Konrad Lorenz and Niko Tinbergen
  - They studied:
    - Individual animal behaviors
    - How animals acquire behaviors
    - How animals select or coordinate groups of behaviors

- **Cognitive psychology:** The study of how humans think and represent knowledge
Why Study Biological Sciences for Robotics?

• “Airplanes don’t flap their wings”
• But, almost everything else about plane’s aerodynamics duplicates a bird’s wing.

• 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 while at the same time overcoming the closed world assumption.
  – 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

Science Interests

- Theories on biological mechanisms
- Proof of principle studies

Animal models

Inspiration for feasible methodologies

Engineering Interests

- Real-world application needs
- Robot implementations
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’s “hardware”:
  - Retina has about 1 million receptors connected to thousands of neurons (ganglions)
  - Ganglions form 4-layer maps stacked on each other
  - All layers operate in parallel and specialize in different kinds of object recognition
  - One map: reacts to moving objects that are 3 degrees or smaller. (It’s a “bug detector”.)
  - Another map: consists of 15 degree fields, responding only to reductions in overall brightness. Often corresponds to arrival of predator.
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 (con’t)

• So, Pigeon flight algorithm seems to be:

```java
if (sunny)
    followSun();
else
    followMagneticCues();
sometimes
    { useUltravioletLight();
      usePolarizationOfLight();
      useSmell();
      useThunderstormDetector();
      useDetectionOfLowFrequencySound();
    }
```
How can we compare animals to robots?

• “Agent”: Entity that is self-contained, independent, has own “brains”, can interact with the world to make changes or to sense what is happening.

• Computational Theory (based on David Marr’s work):
  – Level 1: Existence proof of what can/should be done
    • Agents share commonality of purpose or function
  – Level 2: Decomposition of “what” into inputs, outputs, and transformations
    • Creating flow chart of “black boxes”
    • Agents can exhibit common processes
  – Level 3: How to implement the process
    • Specific hardware (neurons, circuit), software (neural network, code) to achieve process
    • Agents may have little or no commonality in their implementation
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, predator fleeing, etc.
Lorenz and Tinbergen identified four ways to acquire a behavior:

- **Innate:**
  - Born with it
  - Simple, effective, computationally inexpensive

- **Sequence of innate behaviors:**
  - Born with a sequence of behaviors
  - Several steps follow one after the other
  - Similar to computer science’s Finite State Machines

- **Innate with memory:**
  - Born with behaviors that need initialization, customization
  - Agent has to learn parameters of behaviors

- **Learned:**
  - Can be complex behaviors
  - Learn the releasing mechanism and the actions, and how to put them together
Innate Releasing Mechanisms (IRM)s

• **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

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

Releaser food;

while (TRUE)
{
   food = senseFood();
   hungry=checkState();
   if (food == PRESENT && hungry == PRESENT)
      feed();
}

Compound Releasers
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();
}

** Slightly different from Murphy text, page 80, to correct errors (typos)**
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), end 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
Hypothesis: Two kinds of Perceptual Systems in the Brain

• Speculated by Neisser

• Direct perception:
  – Doesn’t require memory, inference, or interpretation
  – Minimal computation
  – Rapid execution time
  – Example: Optic flow

• Recognition:
  – Ties in problem solving and other cognitive activities
  – Deals with more “top-down”, “model-based” perception
  – Example: find your car in the parking lot
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

Releaser

Sensory Input → BEHAVIOR → Pattern of Motor Actions

Perceptual Schema ↔ Motor Schema
Example of Toad’s Feeding Behavior Using Schema

Releaser:
Appearance of small, moving object

Sensory Input:
Toad’s vision

FEEDING BEHAVIOR

Perceptual Schema:
get coordinates of small, moving object

Motor Schema:
turn to coordinates of small, moving object

Pattern of Motor Actions:
Toad’s legs
Example 1: Primitive behavior -- one motor schema, one perceptual schema

<table>
<thead>
<tr>
<th>Data</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perceptual_schema()</td>
</tr>
<tr>
<td></td>
<td>Motor_schema()</td>
</tr>
</tbody>
</table>
Schemas Described in Object-Oriented Programming

Example 2: Meta-behavior -- consists of several primitive behaviors, with releasing logic of when to activate each behavior

<table>
<thead>
<tr>
<th>Behavior::Schema</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data</strong></td>
</tr>
<tr>
<td>releaser1</td>
</tr>
<tr>
<td>releaser2</td>
</tr>
<tr>
<td>releaser3</td>
</tr>
<tr>
<td>IRM_logic</td>
</tr>
<tr>
<td><strong>Methods</strong></td>
</tr>
<tr>
<td>behavior1()</td>
</tr>
<tr>
<td>behavior2()</td>
</tr>
<tr>
<td>behavior3()</td>
</tr>
</tbody>
</table>
Behaviors and Schema Theory vs. Ethology and Cognitive Psychology

- Schema correlate with ethology and cognitive psychology in that:
  - 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
Open Issues

• How do we resolve conflicts between concurrent behaviors?

• When are explicit knowledge representations and memory necessary?

• How do we set up and/or learn new sequences of behaviors?
Representative Examples of Bio-Robots

• Cockroach Locomotion

• Fly Vision

• Ant Chemotaxis
Cockroach Locomotion

- 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
Simplified Model of Cockroach Behavior

**Sensors**
- Mouth tactile
- Mouth chemical
- Antenna chemical
- Antenna tactile

**Behaviors**
- Ingesting
- Finding Food
- Edge Following
- Wandering

● = inhibition between behaviors
Fly Vision

- Researchers at France’s Neurocybernetics Research Group (CNRS) considered housefly’s compound eye as a useful way for robot to view world.

- 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.
Fly Vision (con’t.)

- CNRS developed reactive mobile robot that uses insect-like visual system

Figure 2.11
Robotic compound eye. (Reprinted with permission from Franceshini, Pichon, and Blanes 1992.)
Fly Vision (con’t.)

- Biological principles exploited include:
  - Use of compound optic design, generating a panoramic view
  - Visuomotor control conducted using optical flow induced by robot’s motion
  - Locomotion consisting of a succession of translational movements followed by abrupt rotations, typical of fly’s free-flight behavior
  - Motion detection circuitry based on electrophysiological analysis of the housefly using analog design
  - Use of space-preserving topographic (retinotopic) mappings onto the control system
  - Modeling from an invertebrate perspective, using an exoskeleton as opposed to a backbone
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 for 3 species
• Researchers in Australia (Russell, Thiel, Mackay-Sim): created robot systems capable of laying down and detecting chemical trails
• Camphor serves as chemical scent
• Depositing trail:
  – Robot drags a felt-tipped pen containing camphor across the floor as it moves, depositing trail 1 cm wide
• Sensing trail:
  – Two sensor heads separated by 50 mm
  – Inlet draws in air from immediately below sensor across a gravimetric detector crystal
  – Detector crystal treated with coating that absorbs camphor
  – As mass added, crystal’s resonant frequency changes in proportion to amount of camphor absorbed
  – Robot strives to keep odor trail between two sensor inlets
• Successful robot demonstrations of up to ½ hour after application of camphor trail
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.
• Robot Behavior
  – What are robot behaviors?
  – How do we express behaviors?
  – How do we encode behaviors?
  – How do we assemble behaviors?