CS 460: Artificial Intelligence

- **Instructor:** Prof. Laurent Itti, itti@pollux.usc.edu
- **Lectures:** Th 5:00-7:50, THH-208
- **Office hours:** Mon 3:00 – 5:00 pm, HNB-30A, and by appointment

- **Course web page:** [http://iLab.usc.edu/classes/2003cs460](http://iLab.usc.edu/classes/2003cs460)
  - Up to date information
  - Lecture notes
  - Relevant dates, links, etc.

- **Course material:**
CS 460: Artificial Intelligence

- **Course overview:** foundations of symbolic intelligent systems. Agents, search, problem solving, logic, representation, reasoning, symbolic programming, and robotics.

- **Prerequisites:** CS 455x, i.e., programming principles, discrete mathematics for computing, software design and software engineering concepts. Some knowledge of C/C++ for some programming assignments.

- **Grading:** 35% for midterm + 35% for final + 30% for mandatory homeworks/assignments
Practical issues

• **Class mailing list:** will be setup on the backboard system at learn.usc.edu

• **Submissions:** See class web page under Assignments
Why study AI?

Search engines

Science

Yahoo!

Medicine/
Diagnosis

Google

Labor

Appliances

What else?

CS 460, Lecture 1
Honda Humanoid Robot

Walk

Turn

Stairs

http://world.honda.com/robot/

CS 460, Lecture 1
Sony AIBO

http://www.aibo.com
Natural Language Question Answering


CS 460, Lecture 1
Robot Teams

USC robotics Lab

CS 460, Lecture 1
## What is AI?

<table>
<thead>
<tr>
<th>The exciting new effort to make computers think ... <em>machine with minds</em>, in the full and literal sense” (Haugeland 1985)</th>
<th>“The study of mental faculties through the use of computational models” (Charniak et al. 1985)</th>
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<tbody>
<tr>
<td>“The art of creating machines that perform functions that require intelligence when performed by people” (Kurzweil, 1990)</td>
<td>A field of study that seeks to explain and emulate intelligent behavior in terms of computational processes” (Schalkol, 1990)</td>
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</table>

| Systems that think like humans | Systems that think rationally |
| Systems that act like humans | Systems that act rationally |
Acting Humanly: The Turing Test

• Alan Turing's 1950 article *Computing Machinery and Intelligence* discussed conditions for considering a machine to be intelligent

• “Can machines think?” $\leftrightarrow$ “Can machines behave intelligently?”

• The Turing test (The Imitation Game): Operational definition of intelligence.
Acting Humanly: The Turing Test

- Computer needs to possess: Natural language processing, Knowledge representation, Automated reasoning, and Machine learning

- Are there any problems/limitations to the Turing Test?
What tasks require AI?

• “AI is the science and engineering of making intelligent machines which can perform tasks that require intelligence when performed by humans …”

• What tasks require AI?
What tasks require AI?

- Tasks that require AI:
  - Solving a differential equation
  - Brain surgery
  - Inventing stuff
  - Playing Jeopardy
  - Playing Wheel of Fortune
  - What about walking?
  - What about grabbing stuff?
  - What about pulling your hand away from fire?
  - What about watching TV?
  - What about daydreaming?
Acting Humanly: The Full Turing Test

• Alan Turing's 1950 article *Computing Machinery and Intelligence* discussed conditions for considering a machine to be intelligent
  • “Can machines think?” $\iff$ “Can machines behave intelligently?”
  • The Turing test (The Imitation Game): Operational definition of intelligence.

• Computer needs to posses: Natural language processing, Knowledge representation, Automated reasoning, and Machine learning

• **Problem:** 1) Turing test is not reproducible, constructive, and amenable to mathematic analysis. 2) What about physical interaction with interrogator and environment?

• **Total Turing Test:** Requires physical interaction and needs perception and actuation.
Problem:
1) Turing test is not reproducible, constructive, and amenable to mathematic analysis.
2) What about physical interaction with interrogator and environment?
Acting Humanly: The Full Turing Test

Problem:
1) Turing test is not reproducible, constructive, and amenable to mathematic analysis.
2) What about physical interaction with interrogator and environment?

Trap door
What would a computer need to pass the Turing test?

• **Natural language processing**: to communicate with examiner.

• **Knowledge representation**: to store and retrieve information provided before or during interrogation.

• **Automated reasoning**: to use the stored information to answer questions and to draw new conclusions.

• **Machine learning**: to adapt to new circumstances and to detect and extrapolate patterns.
What would a computer need to pass the Turing test?

- **Vision** (for Total Turing test): to recognize the examiner’s actions and various objects presented by the examiner.

- **Motor control** (total test): to act upon objects as requested.

- **Other senses** (total test): such as audition, smell, touch, etc.
Thinking Humanly: Cognitive Science

• 1960 “Cognitive Revolution”: information-processing psychology replaced behaviorism

• Cognitive science brings together theories and experimental evidence to model internal activities of the brain
  • What level of abstraction? “Knowledge” or “Circuits”?
  • How to validate models?
    • Predicting and testing behavior of human subjects (top-down)
    • Direct identification from neurological data (bottom-up)
    • Building computer/machine simulated models and reproduce results (simulation)
Thinking Rationally: Laws of Thought

• Aristotle (~ 450 B.C.) attempted to codify “right thinking”
What are correct arguments/thought processes?

• E.g., “Socrates is a man, all men are mortal; therefore Socrates is mortal”

• Several Greek schools developed various forms of logic: notation plus rules of derivation for thoughts.
Thinking Rationally: Laws of Thought

• **Problems:**
  1) Uncertainty: Not all facts are certain (e.g., *the flight might be delayed*).

  2) Resource limitations:
     - Not enough time to compute/process
     - Insufficient memory/disk/etc
     - Etc.
Acting Rationally: The Rational Agent

• Rational behavior: Doing the right thing!

• The right thing: That which is expected to maximize the expected return

• Provides the most general view of AI because it includes:
  • Correct inference (“Laws of thought”)
  • Uncertainty handling
  • Resource limitation considerations (e.g., reflex vs. deliberation)
  • Cognitive skills (NLP, AR, knowledge representation, ML, etc.)

• Advantages:
  1) More general
  2) Its goal of rationality is well defined
How to achieve AI?

• How is AI research done?

• AI research has both _theoretical_ and _experimental_ sides. The experimental side has both basic and applied aspects.

• There are two main lines of research:
  • One is _biological_, based on the idea that since humans are intelligent, AI should study humans and imitate their psychology or physiology.
  • The other is _phenomenal_, based on studying and formalizing common sense facts about the world and the problems that the world presents to the achievement of goals.

• The two approaches interact to some extent, and both should eventually succeed. It is a race, but both racers seem to be walking. [John McCarthy]
Branches of AI

- Logical AI
- Search
- Natural language processing
- Pattern recognition
- Knowledge representation
- Inference From some facts, others can be inferred.
- Automated reasoning
- Learning from experience
- Planning To generate a strategy for achieving some goal
- Epistemology Study of the kinds of knowledge that are required for solving problems in the world.
- Ontology Study of the kinds of things that exist. In AI, the programs and sentences deal with various kinds of objects, and we study what these kinds are and what their basic properties are.
- Genetic programming
- Emotions???
- ...
# AI Prehistory

<table>
<thead>
<tr>
<th>Field</th>
<th>Key Concepts</th>
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<tbody>
<tr>
<td>Philosophy</td>
<td>logic, methods of reasoning, mind as physical system, foundations of learning, language, rationality</td>
</tr>
<tr>
<td>Mathematics</td>
<td>formal representation and proof, algorithms, computation, (un)decidability, (in)tractability, probability</td>
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<tr>
<td>Psychology</td>
<td>adaptation, phenomena of perception and motor control, experimental techniques (psychophysics, etc.)</td>
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<tr>
<td>Linguistics</td>
<td>knowledge representation, grammar</td>
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<tr>
<td>Neuroscience</td>
<td>physical substrate for mental activity</td>
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<tr>
<td>Control theory</td>
<td>homeostatic systems, stability, simple optimal agent designs</td>
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</table>
### AI History

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1943</td>
<td>McCulloch &amp; Pitts: Boolean circuit model of brain</td>
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<tr>
<td>1950</td>
<td>Turing’s “Computing Machinery and Intelligence”</td>
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<tr>
<td>1952–69</td>
<td>Look, Ma, no hands!</td>
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<td>1950s</td>
<td>Early AI programs, including Samuel’s checkers program, Newell &amp; Simon’s Logic Theorist, Gelernter’s Geometry Engine</td>
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<td>1956</td>
<td>Dartmouth meeting: “Artificial Intelligence” adopted</td>
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<tr>
<td>1965</td>
<td>Robinson’s complete algorithm for logical reasoning</td>
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<td>1966–74</td>
<td>AI discovers computational complexity</td>
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<td></td>
<td>Neural network research almost disappears</td>
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<td>1969–79</td>
<td>Early development of knowledge-based systems</td>
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<tr>
<td>1980–88</td>
<td>Expert systems industry booms</td>
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<td>1985–95</td>
<td>Neural networks return to popularity</td>
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<tr>
<td>1988–</td>
<td>Resurgence of probabilistic and decision-theoretic methods</td>
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<td></td>
<td>Rapid increase in technical depth of mainstream AI</td>
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<td></td>
<td>“Nouvelle AI”: ALife, GAs, soft computing</td>
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</table>
AI State of the art

- Have the following been achieved by AI?
  - World-class chess playing
  - Playing table tennis
  - Cross-country driving
  - Solving mathematical problems
  - Discover and prove mathematical theories
  - Engage in a meaningful conversation
  - Understand spoken language
  - Observe and understand human emotions
  - Express emotions
  - ...
Course Overview

General Introduction


Course Overview (cont.)

How can we solve complex problems?


Using these 3 buckets, measure 7 liters of water.

Traveling salesperson problem
Course Overview (cont.)

**Practical applications of search.**

Towards intelligent agents

- **10-Agents that reason logically 1.** [AIMA Ch 6]
  Knowledge-based agents. Logic and representation. Propositional (boolean) logic.

- **11-Agents that reason logically 2.** [AIMA Ch 6]
Course Overview (cont.)

Building knowledge-based agents: 1st Order Logic


Course Overview (cont.)

**Representing and Organizing Knowledge**


An ontology for the sports domain
Course Overview (cont.)

Reasoning Logically


Example of backward chaining:

```
Faster(Pat,Steve)

1. \{y/Pat, z/Steve\}
   Pig(Pat)
   Slug(Steve)

2. \{z/Steve\}
   Slimy(Steve)
   Creeps(Steve)

3. \{\}

4. \{\}

5. \{\}
```
Course Overview (cont.)

Examples of Logical Reasoning Systems

Course Overview (cont.)

**Systems that can Plan Future Behavior**

Course Overview (cont.)

**Expert Systems**

- **21-Introduction to CLIPS. [handout]**

```clips
CLIPS> (clear)
CLIPS> (assert (animal-is duck))
  <Fact-0>
CLIPS> (assert (animal-sound quack))
  <Fact-1>
CLIPS> (assert (The duck says "Quack."))
  <Fact-2>
CLIPS> (facts)
f-0  (animal-is duck)
f-1  (animal-sound quack)
f-2  (The duck says "Quack.")
For a total of 3 facts.
CLIPS>
```

CLIPS expert system shell
Course Overview (cont.)

**Logical Reasoning in the Presence of Uncertainty**

- **22/23-Fuzzy logic.**

![Diagram showing center of gravity and center of largest area]
Course Overview (cont.)

**AI with Neural networks**

- **24/25-Neural Networks.**
  
  [Handout] Introduction to perceptrons, Hopfield networks, self-organizing feature maps. How to size a network? What can neural networks achieve?

\[
\begin{align*}
\mathbf{x}(t) &= [x_1(t), x_2(t), \ldots, x_n(t)] \\
\mathbf{w} &= [w_1, w_2, \ldots, w_n] \\
\theta &= \text{threshold} \\
y(t+1) &= f(\mathbf{w}^T \mathbf{x}(t) + \theta)
\end{align*}
\]
Course Overview (cont.)

Evolving Intelligent Systems

• **26-Generic Algorithms.**
  [Handout] Introduction to genetic algorithms and their use in optimization problems.
Course Overview (cont.)

What challenges remain?

- **28-Overview and summary.** [all of the above] What have we learned. Where do we go from here?
A driving example: Beobots

- **Goal**: build robots that can operate in unconstrained environments and that can solve a wide variety of tasks.
Beowulf + robot = “Beobot”
A driving example: Beobots

- **Goal:** build robots that can operate in unconstrained environments and that can solve a wide variety of tasks.

- **We have:**
  - Lots of CPU power
  - Prototype robotics platform
  - Visual system to find interesting objects in the world
  - Visual system to recognize/identify some of these objects
  - Visual system to know the type of scenery the robot is in

- **We need to:**
  - Build an internal representation of the world
  - Understand what the user wants
  - Act upon user requests / solve user problems
The basic components of vision

Scene Layout & Gist

Localized Object Recognition

Attention

Original      Downscaled      Segmented

Riesenhuber & Poggio, Nat Neurosci, 1999
Beowulf + Robot = “Beobot”
Main challenge: extract the “minimal subscene” (i.e., small number of objects and actions) that is relevant to present behavior from the noisy attentional scanpaths.

Achieve representation for it that is robust and stable against noise, world motion, and egomotion.
Prototype

Stripped-down version of proposed general system, for simplified
goal: drive around USC olympic
track, avoiding obstacles

Operates at 30fps on quad-CPU
Beobot;

Layout & saliency very robust;

Object recognition often confused by background clutter.
Major issues

- How to represent knowledge about the world?
- How to react to new perceived events?
- How to integrate new percepts to past experience?
- How to understand the user?
- How to optimize balance between user goals & environment constraints?
- How to use reasoning to decide on the best course of action?
- How to communicate back with the user?
- How to plan ahead?
- How to learn from experience?
General architecture
Ontology
The task-relevance map

Scalar topographic map, with higher values at more relevant locations
More formally: how do we do it?

- Use ontology to describe categories, objects and relationships:
  Either with unary predicates, e.g., Human(John),
  Or with reified categories, e.g., John ∈ Humans,
  And with rules that express relationships or properties,
  e.g., ∀x Human(x) ⇒ SinglePiece(x) ∧ Mobile(x) ∧ Deformable(x)

- Use ontology to expand concepts to related concepts:
  E.g., parsing question yields “LookFor(catching)”
  Assume a category HandActions and a taxonomy defined by
  catching ∈ HandActions, grasping ∈ HandActions, etc.
  We can expand “LookFor(catching)” to looking for other actions in the
  category where catching belongs through a simple expansion rule:
  ∀a,b,c a ∈ c ∧ b ∈ c ∧ LookFor(a) ⇒ LookFor(b)
Outlook

- AI is a very exciting area right now.

- This course will teach you the foundations.

- In addition, we will use the Beobot example to reflect on how this foundation could be put to work in a large-scale, real system.