Outline

• What has artificial intelligence (AI) achieved so far?
• What has AI missed so far?
• Why we need brain-like intelligence?
• How much we know about brain computation?
• What can brain science offer AI?
• What we will learn in this course?
Artificial Intelligence
What Is Artificial Intelligence?

• AI is a collection of hard problems which can be solved by humans and other living things, but for which we don’t have good algorithms for solving.
  – E.g., understanding spoken natural language, medical diagnosis, circuit design, learning, self-adaptation, reasoning, chess playing, proving math theories, etc.

• Another definition: a program that
  – Acts like human (Turing test)
  – Thinks like human (human-like patterns of thinking steps)
  – Acts or thinks rationally (logically, correctly)

• Some problems used to be thought of as AI but are now considered not
  – e.g., compiling Fortran in 1955, symbolic mathematics in 1965, pattern recognition in 1970
Can Machines Think?

Alan Turing
(1912-1954)

Computing Machinery and Intelligence (1950)
Chess Playing

Deep Blue beat G. Kasparov in 1997

Garry Kasparov and Deep Blue. © 1997
Figure 16-2 An expert system on the job. This expert system helps Ford mechanics track down and fix engine problems.

Figure 16-3 Airline scheduling program produced with the aid of an expert system. This system offers a graphical user interface to help solve a complex airport scheduling problem. (a) This screen illustrates the system’s ability to display multiple views of objects and the relationships between them. (b) Various screen windows show planes circling the airport, the number of planes approaching the airport, gate information, and two concourses with planes at their gates.
Web Intelligence

Preprocessing and Indexing

Text Classification

Information Filtering

Information Filtering System

DB Template Filling & Information Extraction System

Text Data

Classification System

DB

user profile

filtered data

feedback

question

answer

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Mars Rover Sojourner: Mars Pathfinder Mission
Personal Robots

- Movie of PR2 Making Pancakes
Autonomous Driving Cars: DARPA Grand Challenge


Video
DARPA Grand Challenge: Final Part 1
Natural Language Processing

Videos: **ALICE Artificial Intelligence and Nicole**
Talking Robot: **Android Video**

- **Polysemy**
  - I keep the money in the bank.
  - I walk along the bank of the river.

- **Ambiguity**
  - Time flies like an arrow.
  - I saw a man with a telescope.

- **Diversity**
  - She sold him a book for five dollars.
  - He bought a book for five dollars from her.

- **Related Knowledge**
  - Lexical, Grammatical, Situational, Contextual
Watson and Q&A

• Movie of Watson winning “Jeopardy”
History of AI

• Early enthusiasm (1950’s & 1960’s)
  – Turing test (1950)
  – 1956 Dartmouth conference
  – Emphasize on intelligent general problem solving
• Emphasis on knowledge (1970’s)
  – Domain specific knowledge
  – DENDRAL, MYCIN
• AI became an industry (late 1970’s & 1980’s)
  – Knowledge-based systems or expert systems
  – Wide applications in various domains
• Searching for alternative paradigms (late 1980’s - early 1990’s)
  – AI’s Winter: limitations of symbolic/logical approaches
  – New paradigms: neural networks, fuzzy logic, genetic algorithms, artificial life
• Resurge of AI (mid 1990’s – present)
  – Internet, Information retrieval, data mining, bioinformatics
  – Intelligent agents, autonomous robots
• Recent trends:
  – Probabilistic computation
  – Biological basis of intelligence
  – Brain research, cognitive science
Artificial Intelligence (AI)

Symbolic AI
Rule-Based Systems

Connectionist AI
Neural Networks

Evolutionary AI
Genetic Algorithms

Molecular AI:
DNA Computing
Research Areas and Approaches

Artificial Intelligence

- Research
  - Paradigm
    - Rationalism (Logical)
    - Empiricism (Statistical)
    - Connectionism (Neural)
    - Evolutionary (Genetic)
    - Biological (Molecular)

- Application
  - Intelligent Agents
  - Information Retrieval
  - Electronic Commerce
  - Data Mining
  - Bioinformatics
  - Natural Language Proc.
  - Expert Systems

- Learning Algorithms
- Inference Mechanisms
- Knowledge Representation
- Intelligent System Architecture
Intelligent Agents

Autonomous Agents

- Biological Agents
- Robotic Agents
- Computational Agents

  - Software Agents
  - Artificial Life Agents

  - Task-specific Agents
  - Entertainment Agents
  - Viruses
Brain Science
What is the information processing principle underlying human intelligence?
Humans and Computers

The Entire Problem Space

Human Computers

Current Computers

What Kind of Computers?
The Computer and the Brain

- Less than 1 million processors (10^{-9} sec each, neuron: 10^{-3} sec)
- Central processing
- Arithmetic operation (linearity)
- Sequential processing
- Silicon-based (dry)

- 10 billion neurons (100 trillion synapses)
- Distributed processing
- Nonlinear processing
- Parallel processing
- Carbon-based (wet)
Computing Power and Memory Capacity of Computers and Organisms [Moravec, 1988]
Von Neummann’s *The Computer and the Brain* (1958)

John von Neumann (1903-1957)
Some Facts about the Brain

• Volume and mass: 1.35 liter & 1.35 kg
• Processors: $10^{11}$ neurons
• Communication: $10^{14}$ synapses
• Speed: $10^{-3}$ sec
  – Computer: 1 GHz = $10^{-9}$ sec
• Memory: $2.8 \times 10^{21}$ bits
  – = 14 bits/sec $\times 10^{11}$ neurons $\times (2 \times 10^9)$ sec
    (2 x $10^9$ sec = 60 years of life time)
  – Computer disk: tera bits = $10^{12}$ bits
• Reliability: $10^4$ neurons dying everyday
• Plasticity: biochemical learning
Principles of Information Processing in the Brain

• The Principle of Uncertainty
  – Precision vs. prediction

• The Principle of Nonseparability
  – Processor vs. memory

• The Principle of Infinity
  – Limited matter vs. unbounded memory

• The Principle of “Big Numbers Count”
  – Hyperinteraction of $10^{11}$ neurons (or $> 10^{17}$ molecules)

• The Principle of “Matter Matters”
  – Material basis of “consciousness”

[Zhang, 2005]
Human Brain: Functional Architecture

Brodmann's areas & functions
Cortex: Perception, Action, and Cognition

Fig 3-18 Primary sensory and motor cortex & association cortex
Mind, Brain, Cell, Molecule

Mind

Brain

Cell

Molecule

10^{11} \text{ cells} \quad \leftrightarrow \quad 10^{10} \text{ mol.}

memory

∞ memory
From Molecules to the Whole Brain
Computational Neuroscience

- Quantitative models (mathematical)
- Nonlinear dynamics
- Information theory

Refinement feedback

Psychology
Neurophysiology
Neurobiology

Experimental facts
Computational neuroscience
Experimental predictions
Applications
Towards Brain-Like Intelligence
or Biointelligence
To achieve a true human-level intelligence, brain-like information processing is required.
Challenges for Machine Learners

- Incremental learning
- Online learning
- Fast update
- One-shot learning
- Predictive learning
- Memory capacity
- Selective attention
- Active learning
- Context-awareness

- Persistency
- Concept drift
- Multisensory integration

[Zhang, AAAI SSS, 2009]
Neural Representations and Processing

• “Chemical” and “molecular” basis of synapses
• Distributed representation
• Multiple overlapping representations
• Hierarchical representation
• Population coding
• Assembly coding
• Sparse coding
• Temporal coding
• Synfire chain
• Dynamic coordination
• Correlation coding
Fuster’s Theory of Perception-Action Memory

• The brain network is made of associations between dispersed neuronal assemblies representing the perceptual and executive components of a LTM gestalt (cognit) of goal-directed action.
Damasio’s Theory of Convergence Zones

“Meaning is reached by time-locked multiregional reactivation of widespread fragment records” [Damasio, 1989]

- Multiple neuron ensembles
- Local convergence zones
- Global convergence zones
- Feed-forward and feedback projections
- Recall as time-locked activation
- Synchronous activation
- Reactivation

H: human, M: monkey, E: elephant, C: chair
Barsalou’s Theory of Perceptual Symbol Systems

[Barsalou et al., TRENDS in Cognitive Sciences, 2003]
## Paradigms in AI and Cognitive Science

<table>
<thead>
<tr>
<th></th>
<th><strong>Symbolism</strong></th>
<th><strong>Connectionism</strong></th>
<th><strong>Dynamicism</strong></th>
<th><strong>Hyperinter-actionism</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metaphor</strong></td>
<td>symbol system</td>
<td>neural system</td>
<td>dynamical system</td>
<td>biomolecular system</td>
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<tr>
<td><strong>Mechanism</strong></td>
<td>logical</td>
<td>electrical</td>
<td>mechanical</td>
<td>chemical</td>
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<tr>
<td><strong>Description</strong></td>
<td>syntactic</td>
<td>functional</td>
<td>behavioral</td>
<td>relational</td>
</tr>
<tr>
<td><strong>Representation</strong></td>
<td>localist</td>
<td>distributed</td>
<td>continuous</td>
<td>collective</td>
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<tr>
<td><strong>Organization</strong></td>
<td>structural</td>
<td>connectionist</td>
<td>differential</td>
<td>combinatorial</td>
</tr>
<tr>
<td><strong>Adaptation</strong></td>
<td>substitution</td>
<td>tuning</td>
<td>rate change</td>
<td>self-assembly</td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td>sequential</td>
<td>parallel</td>
<td>dynamical</td>
<td>massively parallel</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td>procedure</td>
<td>network</td>
<td>equation</td>
<td>hypergraph</td>
</tr>
<tr>
<td><strong>Mathematics</strong></td>
<td>logic, formal language</td>
<td>linear algebra, statistics</td>
<td>geometry, calculus</td>
<td>graph theory, probabilistic logic</td>
</tr>
<tr>
<td><strong>Space/time</strong></td>
<td>formal</td>
<td>spatial</td>
<td>temporal</td>
<td>spatiotemporal</td>
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</tbody>
</table>

[Zhang, *IEEE Computational Intelligence Magazine*, August 2008]
Plan of the Course
Course Overview

- Brain and Computation
  - Basics of Neuroscience
  - Mathematical models of neurons and synapses
  - Computational models of brain circuits
- Neural Networks
  - Hetero-association networks
  - Auto-association networks
  - Self-organizing maps
- Machine Learning
  - Support vector machines
  - Probabilistic graphical models
  - Reinforcement learning