Artificial Intelligence
CPSC 470/570

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AI as Game Playing

Checkers: Chinook vs. Tinsley (1994)


Go: Google AlphaGo vs. Lee Sedol (2016)

Poker (No-limit hold’em): CMU Libratus (2017)
AI is also

Source: Boston Dynamics. https://www.youtube.com/watch?v=WcbGRBPkrps
Definitions of AI

**Think like Humans**
“The automation of activities that we associate with human thinking, activities such as decision-making, problem solving, learning…” – Bellman, 1978

**Think Rationally**
“The study of mental faculties through the use of computational models” – Charniak and McDermott, 1985

**Act like Humans**
“The art of creating machines that perform functions that require intelligence when performed by people.” – Kurzweil, 1990

**Act Rationally**
“A field of study that seeks to explain and emulate intelligent behavior in terms of computational processes.” – Schalkoff, 1990

**Defined in terms of Humans**

**Defined in terms of Logic**

Thought

Action
What AI was...

- Spreadsheets
- Graphical interfaces
- Icon-oriented interfaces
- Object-oriented programming languages
- Sketching software
- Automated theorem provers
  and every robotics, vision, natural language, sound processing and reasoning project...

AI is a Moving Target
Hype
AI Headlines from today (1/14/19)

- AI beats expert doctors at finding cervical pre-cancers - Tech News
  The Star Online • today

- IBM's AI Machine Makes A Convincing Case That It's Mastering The Human Art Of Persuasion
  Forbes • today

- The Future of Artificial Intelligence In The Workplace
  Forbes • 2 days ago

- How AI is making business travel better
  CNN • 5 days ago

- Most Kiwi staff see AI as a threat rather than an opportunity: survey
  CIO New Zealand • today

- Remember Elon Musk's Scary Warning Against AI? Here's More Reason to Worry.
  Entrepreneur • 3 days ago

- Commentary: Bad news. Artificial intelligence is biased
  Channel NewsAsia • 2 days ago • Opinion

- Never mind killer robots—here are six real AI dangers to watch out for in 2019
  MIT Technology Review • 6 days ago
The good, the bad, and the ugly

- AI is the new electricity!
  - Andrew Ng, Chief scientist Baidu
- Will robots take our children’s jobs?
  - NYT, Dec 11, 2017
- Bill Gates: AI taking everyone’s jobs will be a good thing
  - Business Insider, Jan 25, 2018
- AI is more dangerous than nuclear weapons
  - Elon Musk at SXSW, Mar 13, 2018
- Stephen Hawking: AI could destroy civilization!
  - Newsweek, Nov 7, 2017
Growth of AI

Growth of Annually Published Papers

Source: Scopus.com, via 2017 AI index (http://aiiindex.org/)
Growth of AI: Large Corporate AI Investments

• Late 2015: Toyota announces $1b USD investment in AI

• Hired leadership:
  – CEO Gil Pratt, former DARPA PM
  – CTO James Kuffner, former Google autonomous vehicle lead

• Feb 2017: two systems announced
  – Chauffeur (level 4/5 autonomy)
  – Guardian (level 1/2 driver assist)

Source:
http://pressroom.toyota.com/releases/tri+autonomous+test+vehicle+sonoma+raceway+prius+challenge.htm
Growth of AI: Startup Funding Soaring

Worldwide Venture Capital Investment in Robotics


Source: FORTUNE MAGAZINE, GRAPHIC: NICOLAS RAPP, SOURCE: CB INSIGHTS
Growth of AI: Unprecedented Hiring

• “Universities’ AI Talent Poached by Tech Giants”
  – WSJ, 11/24/16
• “Giant Corporations are Hoarding the World’s AI Talent”
  – Wired, 11/16/16
• “Over 4,000 Artificial Intelligence job roles vacant on shortage of talent”
  – Forbes, 12/18/18

• Median annual salary (source: NSF)
  – $55,000 post-doc in academia
  – $110,000 in industry labs
Why now?

• Access to massive amounts of data
• Access to powerful computing platforms
  – Multicore chips
  – Ubiquitous cellphones and tablets
  – Cloud computing
• Maturity of robotics hardware
Syllabus

• Approximately one week for each of these topics:
  – Search
  – Game Playing
  – Logical Formalisms
  – Inference
  – Planning
  – Dealing with Uncertainty
  – Machine Learning
  – Communication and Language
  – Perception
  – Robotics
Agents as a Unifying Design

**Environment**

<table>
<thead>
<tr>
<th>Environment</th>
<th>Accessible</th>
<th>Deterministic</th>
<th>Episodic</th>
<th>Static</th>
<th>Discrete</th>
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<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<td>Part-picking robot</td>
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<td>Refinery controller</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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</table>
Basic Search

Branching Factor $b=3$
Heuristic Search

**A* Search**
Minimize the total path cost \( f = g + h \)

**Greedy Search**
Heuristic function gives an estimate of the distance to the goal

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<table>
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<tr>
<th></th>
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<td><strong>Boston</strong></td>
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<tr>
<td><strong>Nashville</strong></td>
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<td><strong>Key West</strong></td>
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<td><strong>Austin</strong></td>
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<tr>
<td><strong>San Francisco</strong></td>
<td>658</td>
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</table>
Search and Game Playing

Minimax Search with Alpha-Beta Pruning

Kasparov vs. Deep Blue
Knowledge Representation

Propositional Logic Syntax

Sentence → AtomicSentence | ComplexSentence
AtomicSentence → True | False | P | Q | ...
ComplexSentence → (Sentence) |
Sentence Connective Sentence |
¬Sentence
Connective → ∧ | ∨ | ⇒ | ⇔

Inference Rules

\[
\frac{\alpha \Rightarrow \beta , \alpha}{\beta}
\quad
\frac{\neg \alpha}{\alpha}
\quad
\frac{\alpha_1, \alpha_2, \alpha_3, ..., \alpha_n}{\alpha_1 \land \alpha_2 \land ... \land \alpha_n}
\quad
\frac{\alpha_1 \land \alpha_2 \land \alpha_3 \land ... \land \alpha_n}{\alpha_i}
\quad
\frac{\alpha \lor \beta , \neg \beta}{\alpha}
\quad
\frac{\alpha_i}{\alpha_1 \lor \alpha_2 \lor ... \lor \alpha_n}
\]

\[
\frac{\neg \alpha \Rightarrow \beta , \beta \Rightarrow \gamma}{\neg \alpha \Rightarrow \gamma}
\quad
\frac{\alpha \lor \beta , \neg \beta \lor \gamma}{\alpha \lor \gamma}
\]
First-Order Logic

• **Existential and Universal Quantifiers**

\[ \text{Sentence} \to \text{AtomicSentence} \]
\[ \quad | \text{Sentence} \text{ Connective} \text{ Sentence} \]
\[ \quad | \text{Quantifier Variable,..Sentence} \]
\[ \quad | \neg \text{Sentence} \]
\[ \quad | (\text{Sentence}) \]

\[ \text{AtomicSentence} \to \text{Predicate}(\text{Term,..}) \]
\[ \quad | \text{Term} = \text{Term} \]

\[ \text{Term} \to \text{Function}(\text{Term,..}) \]
\[ \quad | \text{Constant} \]
\[ \quad | \text{Variable} \]

\[ \text{Connective} \to \Rightarrow | \land | \lor | \leftrightarrow \]

\[ \text{Quantifier} \to \forall | \exists \]

\[ \text{Variable} \to a | b | c | ... \]

\[ \text{Function} \to \text{Mother} | \text{LeftLegOf} | ... \]

\[ \text{Predicate} \to \text{Before} | \text{HasColor} | \text{Raining} | ... \]

\[ \text{Constant} \to A | X_1 | \text{John} | ... \]

• **Situation Calculus**

\[ \text{At(Agent,[1,1], S_0)} \land \]
\[ \text{At(Agent,[1 2], S_1)} \]

• **Changes from one situation to the next**

\[ \text{Result(Forward, S_0) \Rightarrow S_1} \]
Building a Knowledge Base

- Decide what to talk about
- Decide on a vocabulary of predicates, functions, and constants
  - Ontology
- Encode general knowledge within the domain
  - Limiting errors
- Encode a description of the specific problem
- Pose queries and get answers
Inference

Resolution

- American(x) ∧ Alcohol(y) ∧ Minor(z) ∧ Sells(x,y,z) ⇒ Criminal(x)
- Minor(Jimmy)
- Owns(Jimmy,B1)
- Beer(B1)
- Owns(Jimmy,x) ∧ Beer(x) ⇒ Sells(Nathan,x,Jimmy)
- American(Nathan)
- Beer(x)⇒Alcohol(x)
- Using 4, 7 and modus ponens Alcohol(B1)
- Using 5, 3, 4 and modus ponens Sells(Nathan,B1,Jimmy)
- Using 1, 6, 8, 2, 9 and modus ponens Criminal(Nathan)

Proof by Refutation

\[ P(w) \Rightarrow Q(w) \]
\[ Q(y) \Rightarrow S(y) \]
\[ P(w) \Rightarrow S(w) \]
\[ True \Rightarrow P(x) \lor R(x) \]
\[ True \Rightarrow S(x) \lor R(x) \]
\[ R(z) \Rightarrow S(z) \]
\[ True \Rightarrow S(A) \]

\[ \{y/w\} \]
\[ \{w/x\} \]
\[ \{x/A,z/A\} \]
Expert Systems

\[ \int \frac{x^4}{(1 - x^2)^{\frac{5}{3}}} \, dx \]

Try \( y = \arcsin x \), yielding:

\[ \int \frac{\sin^4 y}{\cos^4 y} \, dy \]

SAINT

DENDRAL

Mass spectrogram for \( \text{C}_8\text{H}_{10}\text{O} \)

XCON (R1)

CYC

\[
\text{Collection} \\
\text{StuffType} \\
\text{TemporalStuffType} \\
\text{ExistingStuffType} \\
\text{ObjectType} \\
\text{TemporalObjectType} \\
\text{ExistingObjectType}
\]
Planning

Representing World State and Change in a Logical Language

Partial-Order Planning

Start

At(Home)

Go(SM)

At(SM)

Sells(SM,Banana)

Buy(Banana)

At(SM)

Go(HWS)

Sells(HWS,Drill)

At(HWS)

Buy(Drill)

At(SM)

Sells(SM,Milk)

Buy(Milk)

At(SM)

Have(Drill)

Have(Milk)

Have(Banana)

Finish

Pickup(B), Stack(B,C)
Pickup(A), Stack(A,B)
Planning in the Real World: Robot path planning

- Configuration Spaces
- Probabilistic Roadmap
- Cell Decomposition
- Visibility Graphs
- Potential Fields
Planning in Real-World Systems

Conditional Planning

Execution Monitoring

Start

On(Tire1)
Flat(Tire1)
Inflated(Spare)

Intact(Tire1)

On(Tire1)
Inflated(Tire1)

Interact(Tire1)

Intact(Tire1)

Flat(Tire1)

Intact(Spare)

On(Spare)
Inflated(Spare)

Finish

 ¬ Intact(Tire1)

¬ Intact(Tire1)

¬ Intact(Tire1)

¬ Intact(Tire1)

¬ Intact(Tire1)

¬ Intact(Tire1)

Start State

Current State

Finish State

Mistake!
Dealing with Uncertainty

Belief Networks

Incremental Construction

A conditional probability table gives the likelihood of a particular combination of values
Learning from Observations

Learning Optimal Decision Trees

Decision Tree for deciding whether to wait for a table

\[
\text{Remainder}(A) = \sum_{i=1}^{V} \frac{p_i + n_i}{p + n} I \left( \frac{p_i}{p_i + n_i}, \frac{n_i}{p_i + n_i} \right)
\]

\[
\text{Remainder}(\text{Patrons}) = \frac{2}{12} I(0,1) + \frac{4}{12} I(1,0) + \frac{6}{12} I \left( \frac{\frac{2}{6}}{\frac{2}{6} + \frac{4}{6}}, \frac{\frac{4}{6}}{\frac{2}{6} + \frac{4}{6}} \right)
\]

\[
\text{Remainder}(\text{Patrons}) \approx 0 + 0 + \frac{6}{12} \left( -\frac{2}{6} \log_6 \frac{2}{6} - \frac{4}{6} \log_6 \frac{4}{6} \right)
\]

\[
\text{Remainder}(\text{Patrons}) \approx 0.459 \text{ bits}
\]
Supervised Learning
Using Version Spaces

Most general boundaries (G)

Most specific boundaries (S)

(a) consistent
(b) false negative
(c) generalization includes the false negative example
(d) false positive
(e) specialization removes the false positive example
Genetic Algorithms

Evolving physical morphology and control: Karl Sims

- **Genotype**
  - Interaction with environment
  - Development

- **Phenotype**
  - Interaction with environment + competition
  - Selection

- **“New” Population**
  - Reproduction

Following
Learning Using Neural Nets

Perceptrons

Multi-Layer Networks

Backprop and Linear Separability
Deep Learning

Patterns of Local Contrast

Input Layer

Hidden Layer 1

Hidden Layer 2

Face Features

Face

Output Layer
Reinforcement Learning
(Rewarded at the end of an action sequence)

Utility Learning
(Temporal Difference)

• Learn a utility function that maps states to utilities and select an action by maximizing expected value
• Needs a model of the environment (needs to know the results of actions)
• Predictive

Action-Value Learning
(Q-Learning)

• Learn an action-value function that gives the expected utility of taking a given action in a given state
• No need for an environment model
• Do not know where actions lead, so it cannot look ahead

\[ Q(a,i) \leftarrow Q(a,i) + \alpha (R(i) + \max_{a'} Q(a',j) - Q(a,i)) \]
Communication: Grammars, Syntax, and Semantics

Intention
Know(H, ¬Alive(Wumpus, S3))

Incorporation
Tell(H, ¬Alive(Wumpus, S3))

Disambiguation
¬Alive(Wumpus, S3)

Generation
The wumpus is dead.

Analysis
The wumpus is dead.

Synthesis
[thawahmpahsihzdeyd]
Communication

Speech Generation

- Klatt Synthesizer
  - DECTalk Demo

Source Model
- Voicing
- Hiss
- Friction

Control Parameters
- Cascade Branch
- Parallel Branch

Filter Model

Speech Recognition

- Hidden Markov Models
- Phone HMM for [m]:
  - Onset: 0.3
  - Mid: 0.7
  - End: 0.9
  - Final: 0.6

Output probabilities for the phone HMM:
- Onset: 0.5
- C1: 0.2
- C2: 0.7
- C3: 0.1
- C4: 0.3
- C5: 0.1
- C6: 0.5
- C7: 0.4

- Demo of Dragon NaturallySpeaking

DECTalk Demo

Readme.txt

April 2001
For DECTalk[R] demos for:
- Wce2.08
- Wce2.11 (Palm Size PC and MS HPC Pro)
- Wce3.00 (Pocket PC)
After double clicking on self extracting executable downloaded from we the following files will appear.

For Windows:

Speaking 1 2 3 4 5 6 7 8 9 10 WPM
Perception

Mathematical Tools: Convolution

\[ h(x) = \int_{-\infty}^{+\infty} f(u)g(x-u)du \]

\[ h(x) = \sum_{u=-\infty}^{+\infty} f(u)g(x-u) \]

Applications: Edge Detection

Pre-attentive and Post-attentive
Higher-Level Perception

Finding Similar Images

Motion Identification

Region Segmentation

Object Detection and Recognition
Robotics: Kinematics

Basic Joint Types

Forward Kinematics
(from joints to positions)
Given Y1, Y2 find x,y

Inverse Kinematics
(from positions to joints)
Given x,y find Y1, Y2

Problems with
ambiguous solutions
(or no solutions)
Robot Control Architectures
Social Robotics and HRI
The Future of AI
Course Information

• Official prerequisites:
  – After CPSC 201 and 202 (or by permission of the instructor)

• Description:
  – Introduction to artificial intelligence research, focusing on reasoning and perception. Topics include knowledge representation, predicate calculus, temporal reasoning, vision, robotics, planning, and learning.

• Skills
  – Quantitative Reasoning
Grading

• Grading will be determined as follows:
  – Final Exam : 30%
  – Midterm Exam : 20%
  – Problem Sets : 50%

• These weights are subject to minor variations.

• Each problem on the problem sets and exams will be worth a specified number of points, which will be shown with the problem.
<table>
<thead>
<tr>
<th>Date</th>
<th>Lecture Topic</th>
<th>Date</th>
<th>Lecture Topic</th>
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<tbody>
<tr>
<td>01/14/19</td>
<td>Course Overview</td>
<td>03/25/19</td>
<td>Neural Networks</td>
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<tr>
<td>01/16/19</td>
<td>Intelligent Agents</td>
<td>03/27/19</td>
<td>Deep Learning</td>
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<td>01/18/19</td>
<td>Python Intro</td>
<td>03/29/19</td>
<td>Reinforcement Learning I (utility functions)</td>
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<td>Natural Language Processing</td>
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<td>04/05/19</td>
<td>Communication</td>
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<td>04/08/19</td>
<td>Introduction to Machine Perception</td>
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<td><em>Guest– Dragomir Radev – NLP</em></td>
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<td>Constraint satisfaction problems</td>
<td>04/12/19</td>
<td>Vision and Robotics</td>
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<td>Propositional Logic</td>
<td>04/15/19</td>
<td>Robotics: Kinematics, Sensors and Actuators</td>
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<td>03/08/19</td>
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Assignments (draft list)

- HW 0: Introduction to the Course Environment
- HW 1: Search (Pacman)
- HW 2: Game Playing (Othello)
- HW 3: Logic and Representations
- HW 4: Planning (Blocks world)
- HW 5: Supervised Learning (Muir Trail)
- HW 6: Deep learning (Autonomous vehicles)
- HW 7: Reinforcement learning (Pacman revisited)
- HW 8: Vision
- HW 9: Robotics Control
Collaboration Policy

• Homework assignments are your individual responsibility, and plagiarism will not be tolerated.

• You are encouraged to discuss assignments with the instructor, with the TAs, and with other students.

• However, each student is required to implement and write any assignment on their own.

• You will not copy, nor will you allow your work to be copied.
Specifics

• Coding and write up should be done independently
• Do not show your work to anyone
• Do not look at anyone’s work
• Do not use existing code (e.g., github)
Attendance Policy

- Attendance at lectures is critical to success in this course.
- Lectures **will** contain material that is not covered by the text (and may not appear on the lecture slides).
- You are responsible for all material presented in lectures, material contained in the assigned reading, and material covered by the homework assignments.
How to Get Help

• Use the right channels for communication
  – Piazza (not canvas)
  – Email (always include CPSC 470 in the subject line)
  – TAs and ULA staff listed on each assignment