Teaching Assistant

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  • Email: canzhezhao@sjtu.edu.cn
  • 1st year PhD student
  • Research interests on bandit algorithms and optimization
  • Office hour: Fri 7-9 PM

• Zhihui Xie (谢知晖)
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  • 1st year Master student
  • Research on causal machine learning and recommendation systems
  • Office hour: Wed 7-9 PM
References (will add more during course)

- Reinforcement Learning: An Introduction by Richard S. Sutton and Andrew G. Barto
- 周志华《机器学习》清华大学出版社，2016.
Goal

• Know what is AI and what it usually covers
• Familiar and understand popular AI problems and algorithms
• Be able to build AI models in applications
  • Know which algorithms to adopt and when to adopt
• Get a touch of latest research
Prerequisites

• Basic computer science principles
  • Big-O notation
  • Comfortably write non-trivial code in Python/numpy

• Probability
  • Random Variables
  • Expectations
  • Distributions

• Linear Algebra & Multivariate/Matrix Calculus
  • Gradients and Hessians
  • Eigenvalue/vector

Slide credit: Anand Avati
Grading

• Attendance and participation: 5%
• Homework (written & programming) 40%
• Project: 25%
• Final exam: 30%
Honor code

• Discussions are encouraged

• Independently write-up homework and code

• Same reports and homework will be reported
Course Outline

• Search
• Constraint satisfaction problems
• Game trees
• Markov decision processes (MDPs)
• Reinforcement learning
• Hidden Markov models (HMMs)
• Bayes nets
• Machine learning basics
• Neural networks
What is AI?
What is AI?
The science of making machines that:

Think like people
Think rationally

Act like people
Act rationally
Acting humanly: The Turing test approach

• In 1950, Turing defined a test of whether a machine could perform

• Practically though, it is a test of whether a machine can ‘act’ like a person

• “A human judge engages in a natural language conversation with one human and one machine, each of which tries to appear human. If judge can’t tell, machine passes the Turing test”

https://en.wikipedia.org/wiki/Turing_test
Acting humanly: The Turing test approach 2

- The computer would need to possess the following capabilities
  - **Natural language processing** to enable it to communicate successfully in English/or other languages
  - **Knowledge representation** to store what it knows or hears
  - **Automated reasoning** to use the stored information to answer questions and to draw
  - **Machine learning** to adapt to new circumstances and to detect and extrapolate patterns

- **Total Turing test includes a video signal, so the computer will need**
  - **Computer vision** to perceive objects
  - **Robotics** to manipulate objects and move about
Thinking humanly: The cognitive modeling approach

• The interdisciplinary field of cognitive science brings together computer models from AI and experimental techniques from psychology to construct precise and testable theories of the human mind

• Real cognitive science is necessarily based on experimental investigation of actual humans or animals

• In the early days of AI, people think that an algorithm performs well on a task ⇔ it is a good model of human performance
What about the Brain?

• Brains (human minds) are very good at making rational decisions, but not perfect

• Brains aren’t as modular as software, so hard to reverse engineer!

• “Brains are to intelligence as wings are to flight”

• Lessons learned from the brain: memory and simulation are key to decision making
Thinking rationally: The “laws of thought” approach

• The Greek philosopher Aristotle, syllogisms (三段论)
• The logicists hope to build on logic systems to create intelligent systems
• The emphasis was on correct inferences
Acting rationally: The rational agent approach

• Making correct inferences is sometimes part of being a rational agent, but not all
• An agent is just something that acts (agent comes from the Latin agere, to do)
• A rational agent is one that acts so as to achieve the best outcome or, when there is uncertainty, the best expected outcome
• This approach has two advantages:
  • It is more general than the “laws of thought” approach because correct inference is just one of several possible mechanisms for achieving Rationality
  • It is more amenable to scientific development than are approaches based on human behavior or human thought
AI Definition by John McCarthy

• What is artificial intelligence
  • It is the science and engineering of making intelligent machines, especially intelligent computer programs

• What is intelligence
  • Intelligence is the computational part of the ability to achieve goals in the world

• John McCarthy (1927-2011)
  • co-authored the document that coined the term "artificial intelligence" (AI), developed the Lisp programming language family

http://www-formal.stanford.edu/jmc/whatisai/whatisai.html
AI and this course

• Describe machines (or computers) that mimic "cognitive" functions that humans associate with the human mind, such as "learning" and "problem solving".

• This course is about:
  • General AI techniques for a variety of problem types
  • Learning to recognize when and how a new problem can be solved with an existing technique
  • Computational Rationality
What is AI?

The science of making machines that:

A: Think like people
B: Act like people
C: Think rationally
D: Act rationally
Maximize Your Expected Utility
What is Machine Learning?

• Term “Machine Learning” coined by Arthur Samuel in 1959
  • Samuel Checkers-playing Program

• Common definition (by Tom Mitchell):
  • *Machine Learning is the study of computer algorithms that improve automatically through experience*

• Subfield of Artificial Intelligence (AI)
  • The hottest subfield - reinvigorated interest in AI due to deep learning!
Difference between AI and ML

- AI is a bigger concept to create intelligent machines that can simulate human thinking capability and behavior, whereas, machine learning is an application or subset of AI that allows machines to learn from data without being programmed explicitly.
An example of AI but is not machine learning

• A* search algorithm
  • Objective: Find the shortest path between two nodes of a weighted graph
  • Use heuristic information

• Compare with Breadth First Searching and Greedy Searching
Breadth First Searching

• Pink: start point, Purple: end point;
• Blue: visited points, the darker the earlier

Each time it visits, or expand the point with least $g(n)$ value
• $g(n)$ is the distance from start point to point n

Short comings: computing burden is too high, it visited too many points before getting the end point.
Greedy Searching

• Each time it visit or expand the point with least $h(n)$ value
  • $h(n)$ is the distance from point n to end point. It works fine when there is no obstacles.

• The cost doubles when there is obstacles
A* algorithm

• It combines the stability of BFS and the heuristics in greedy searching.
• Each time it visits point with the least $f(n) = g(n) + h(n)$ value.
The Foundations of AI

The disciplines that contributed ideas, viewpoints, and techniques to AI
Philosophy

• Can formal rules be used to draw valid conclusions?
• How does the mind arise from a physical brain?
• Where does knowledge come from?
• How does knowledge lead to action?

• Rationalism (理性主义)/materialism (唯物主义)/empiricism (经验主义)
Mathematics

- What are the formal rules to draw valid conclusions?
- What can be computed?
- How do we reason with uncertain information?

- The first nontrivial *algorithm* is thought to be Euclid’s algorithm for computing greatest common divisors

- The word *algorithm* (and the idea of studying them) comes from al-Khowarazmi, a Persian mathematician of the 9th century

- NP-completeness/probability/entropy
Economics

• How should we make decisions so as to maximize payoff?
• How should we do this when others may not go along?
• How should we do this when the payoff may be far in the future?

• The pioneering AI researcher Herbert Simon (1916–2001) won the Nobel Prize in economics in 1978 for his early work showing that models based on satisficing—making decisions that are “good enough,” rather than laboriously calculating an optimal decision—gave a better description of actual human behavior (Simon, 1947).
Neuroscience

• How do brains process information?

<table>
<thead>
<tr>
<th></th>
<th>Supercomputer</th>
<th>Personal Computer</th>
<th>Human Brain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational units</td>
<td>$10^4$ CPUs, $10^{12}$ transistors</td>
<td>$4$ CPUs, $10^9$ transistors</td>
<td>$10^{11}$ neurons</td>
</tr>
<tr>
<td>Storage units</td>
<td>$10^{14}$ bits RAM</td>
<td>$10^{11}$ bits RAM</td>
<td>$10^{11}$ neurons</td>
</tr>
<tr>
<td></td>
<td>$10^{15}$ bits disk</td>
<td>$10^{13}$ bits disk</td>
<td>$10^{14}$ synapses</td>
</tr>
<tr>
<td></td>
<td>$10^{-9}$ sec</td>
<td>$10^{-9}$ sec</td>
<td>$10^{-3}$ sec</td>
</tr>
<tr>
<td>Cycle time</td>
<td>$10^4$</td>
<td>$10^5$</td>
<td>$10^{17}$</td>
</tr>
<tr>
<td>Operations/sec</td>
<td>$10^{-9}$ sec</td>
<td>$10^{10}$</td>
<td>$10^{14}$</td>
</tr>
<tr>
<td>Memory updates/sec</td>
<td>$10^4$</td>
<td>$10^{10}$</td>
<td></td>
</tr>
</tbody>
</table>
Psychology

• How do humans and animals think and act?

• **Cognitive psychology** views the brain as an information-processing device

• **Developmental psychology** is the scientific study of how and why human beings change over the course of their life, especially concerned with infants and children
Computer engineering

• How can we build an efficient computer?

• Designing algorithms is not enough

• Hardware
  • modern digital electronic computer

• Software
  • operating systems, programming languages, and tools needed to write modern programs (and papers about them)

• Work in AI has also pioneered many ideas that have made their way back to mainstream computer science
  • time sharing, interactive interpreters, personal computers with windows and mice
Control theory and cybernetics

• How can artifacts operate under their own control?

• Goal of modern control theory, especially the branch known as stochastic optimal control, is to
  • Design systems that maximize an objective function over time
  • Roughly match our view of AI: designing systems that behave optimally

• Differences of control theory and AI:
  • Control theory more care about continuous variables with calculus and matrix algebra as tools
  • AI uses logical inference and computation to escape these limitations and consider problems such as language, vision, and planning that fell completely outside the control theorist’s purview
Linguistics

• How does language relate to thought?

• Understanding language requires an understanding of the subject matter and context, not just an understanding of the structure of sentences

• Knowledge representation (the study of how to put knowledge into a form that a computer can reason with)
  • decades of work on the philosophical analysis of language
The History of AI
1950s

- Turing’s test
- Dartmouth Conference 1956: the birth of AI
Chess as the First Killer App for AI

- Claude Shannon proposed the first chess playing program in 1950
  - It included adversarial search and minimax (later lecture)
  - It also included many heuristics for faster searching
<table>
<thead>
<tr>
<th></th>
<th>Turing</th>
<th>Kister, Stein, Ulam, Walden, Wells (Los Alamos)</th>
<th>Bernstein, Roberts, Arbuckle, Belaky (Bernstein)</th>
<th>Newell, Shaw, Simon (NSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vital statistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Date</strong></td>
<td>1951</td>
<td>1956</td>
<td>1957</td>
<td>1958</td>
</tr>
<tr>
<td><strong>Board</strong></td>
<td>8 x 8</td>
<td>6 x 6</td>
<td>8 x 8</td>
<td>8 x 8</td>
</tr>
<tr>
<td><strong>Computer</strong></td>
<td>Hand simulation</td>
<td>MANIAC-I 11,000 ops./sec</td>
<td>IBM 704 42,000 ops./sec</td>
<td>RAND JOHNNIAC 20,000 ops./sec</td>
</tr>
<tr>
<td><strong>Chess program Alternatives</strong></td>
<td>All moves</td>
<td>All moves</td>
<td>7 plausible moves</td>
<td>Sequence of move generators</td>
</tr>
<tr>
<td><strong>Depth of analysis</strong></td>
<td>Until dead (exchanges only)</td>
<td>All moves deep Material, mobility</td>
<td>Area control</td>
<td>Acceptance by goals</td>
</tr>
<tr>
<td><strong>Static evaluation</strong></td>
<td>Numerical Many factors</td>
<td>Numerical</td>
<td>Minimax</td>
<td>Minimax</td>
</tr>
<tr>
<td><strong>Integration of values</strong></td>
<td>Minimax Material dominates</td>
<td>Minimax (modified) Best value</td>
<td>Minimax</td>
<td>Minimax</td>
</tr>
<tr>
<td><strong>Final choice</strong></td>
<td>Material dominates</td>
<td>Best value</td>
<td>Best value</td>
<td>1. First acceptable 2. Double function</td>
</tr>
<tr>
<td><strong>Programming Language</strong></td>
<td>Machine code</td>
<td>Machine code</td>
<td>Single board</td>
<td>Single board</td>
</tr>
<tr>
<td><strong>Data scheme</strong></td>
<td>Single board No records</td>
<td>Centralized tables Recompute</td>
<td>Recompute</td>
<td>Recompute</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>Minutes</td>
<td>12 min/move 600 words</td>
<td>8 min/move 7000 words</td>
<td>1-10 hr/move (est.) Now 6000 words, est. 10,000</td>
</tr>
<tr>
<td><strong>Space</strong></td>
<td>1 game</td>
<td>3 games (no longer exists)</td>
<td>2 games</td>
<td>0 games</td>
</tr>
<tr>
<td><strong>Results Experience</strong></td>
<td>Lose to weak player</td>
<td>Beats weak player</td>
<td>Passable amateur</td>
<td>Some hand simulation</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>Aimless Subtweets of evaluation lost</td>
<td>Equivalent to human with 20 games experience</td>
<td>Blind spots</td>
<td>Good in spots (opening)</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

Chess-Playing Programs and the Problem of Complexity

Allen Newell
J. C. Shaw
H. A. Simon
The Promise of AI

• In 1965, Herbert Simon predicted that “machines will be capable, within 20 years, of doing any work a man can do”

• In 1967, AI pioneer Marvin Minsky predicted “in from three to eight years we will have a machine with the general intelligence of an average human being.”

• In 1967, John McCarthy told the U.S. government that it would be possible to build “a fully intelligent machine” in the space of a decade
1970s - first AI winter

• Limited computer power
• Intractability and the combinatorial explosion
• Commonsense knowledge and reasoning
  • Hard to encode so many concepts and rules
  • Didn’t know how to teach computers to learn these
Evolution of AI Research: 1970s and 1980s

- Focus on:
  - Searching for a solution using general search algorithms
  - Encoding knowledge that humans have and using logic to solve
Computer Vision, Blocks World, Natural Language

Larry Roberts 1963 Thesis

Terry Winograd’s 1971 Thesis on SHRDLU for natural language understanding
Early Robots

1983 – mobile robots by Hans Moravec

Dean Pomerleau (CMU) 1986
NAVLAB controlled by NNs

https://www.youtube.com/watch?v=ntlczNQfjQ
Deep Blue

• Started in the mid-1980s at CMU, didn’t win until 1997
• Project moved to IBM
• “Good Old-Fashioned” Brute Force Search using custom hardware
• Win Garry Kasparov by 3.5:2.5 on Chess
• Search over 12 following steps

• https://www.youtube.com/watch?v=KF6sLCeBj0s
Rise of Statistical Approaches: 1990s – 2000s

• Knowledge-based:
  • Search for a solution using general search algorithms
  • Encode knowledge that humans have and use logic to solve

• Statistical:
  • Learning patterns and choosing solutions based on observed likelihood
Evolution of AI Research: 1990s
Evolution of AI Research: 2000s
Evolution of AI Research: 2010s
2010s-now

• Deep learning
  • The return of neural networks
• Big data
  • Large datasets, like ImageNet
• Computational power
• Artificial general intelligence (AGI)
Computer Vision (CV) -- ImageNet, AlexNet

**ImageNet**

22K categories and 15M images

- Animals
- Bird
- Fish
- Mammal
- Invertebrate
- Plants
- Tree
- Flower
- Food
- Materials
- Structures
- Artifact
- Tools
- Appliances
- Sport Activities


AlexNet, CNN

CV (Detection) -- R-CNN, Fast R-CNN, Faster R-CNN


Speech recognition (Unsupervised, ICA)

Mixed

Separated
Speech recognition (Unsupervised, ICA, cont.)

Mixed

Separated
Speech recognition

• Previous works use
  • Hidden Markov models (HMMs)
    • Deal with the temporal variability of speech
  • Gaussian mixture models (GMMs)
    • Determine how well each state of each HMM fits a frame or a short window of frames of coefficients that represents the acoustic input

• New
  • Feed-forward neural network
    • Takes several frames of coefficients as input and produces posterior probabilities over HMM states as output

Speech recognition

Deep Learning: From GMM-HMM to DNN-HMM

Natural Language Processing (NLP) -- Word2Vec

Image and audio processing systems work with rich, high-dimensional datasets encoded as vectors.

Natural Language Processing (NLP) -- Word2Vec (cont.)

Word Analogies

Test for linear relationships, examined by Mikolov et al. (2014)

\[ d = \arg \max_x \frac{(w_b - w_a + w_c)^T w_x}{\|w_b - w_a + w_c\|} \]

man:woman :: king:?

+ king [0.30 0.70]
- man [0.20 0.20]
+ woman [0.60 0.30]

queen [0.70 0.80]
NLP -- BERT

• BERT
  • Bidirectional Encoder Representations from Transformers
  • The pre-train deep bidirectional representations from unlabeled text by jointly conditioning on both left and right context in all layers
  • The pre-trained BERT model can be finetuned with just one additional output layer to create state-of-the-art models for a wide range of tasks, such as question answering and language inference, without substantial task specific architecture modifications
  • It obtains new state-of-the-art results on eleven natural language processing tasks

Figure 1: Differences in pre-training model architectures. BERT uses a bidirectional Transformer. OpenAI GPT uses a left-to-right Transformer. ELMo uses the concatenation of independently trained left-to-right and right-to-left LSTM to generate features for downstream tasks. Among three, only BERT representations are jointly conditioned on both left and right context in all layers.
AlphaGo 2016

• Win Lee Sedol by 4:1 on Go
• Efficient search on large solution space

Texas hold’em 2017

DeepStack
• In a study involving 44,000 hands of poker, DeepStack defeated with statistical significance professional poker players in heads-up no-limit Texas hold’em
• Imperfect information setting

History of Game AI

1956 checkers
1992 backgammon
1994 checkers
1997 chess
2016 Go
2017 Texas hold’em
2019 Majiang
Game playing – state of the art
Recent popularity of AI and ML
AI and Machine Learning Together: 2010s and 2020s

How to Teach Artificial Intelligence Some Common Sense

We've spent years feeding neural nets vast amounts of data, teaching them to think like human brains. They're crazy-smart, but they have absolutely no common sense. What if we've been doing it all wrong?

AI Requires More Than Machine Learning

Researchers: Are we on the cusp of an ‘AI winter’?

By Sam Shead
Technology reporter

12 January 2020 | Technology
What Can AI Do?
Sci-Fi AI
Face recognition, real-time detection

https://bitrefine.group/home/transportation/face-recognition-support-system
https://cdn-images-1.medium.com/max/1600/1*q1uVc-MU-tC-WwFp2yXJow.gif
Medical image analysis

- Segmentation results on ISBI cells and DIC - HeLa cells


- Breast Cancer Diagnoses

Voice assistants: Google AI 2018
Web app: search, recommendation, ad
Alleviate traffic congestion

- Ride sharing
- Disperse traffic
Exoskeletons
Agriculture: Crop-dusting

- DJI drones (unmanned aerial vehicles)
Transportation: Sorting parcels
EXPLORER
$74,500.00

The Spot Explorer kit puts the power of robotics into your hands and makes robotics easy, so you can focus on building your application.
SMART CITY COMPONENTS

- Smart government
- Mobility/Wi-Fi
- Open data
- Smart health
- Smart farming/agriculture
- Smart buildings
- Smart grid/energy/utilities
- Smart manufacturing
- Smart digital citizens
- Smart transportation

Illustration: Smart City Components
What Can AI Do?

Quiz: Which of the following can be done at present?

- Play a decent game of table tennis?
- Play a decent game of Jeopardy?
- Drive safely along a curving mountain road?
- Drive safely across Pittsburgh?
- Buy a week's worth of groceries on the web?
- Buy a week's worth of groceries at a local market?
- Discover and prove a new mathematical theorem?
- Converse successfully with another person for an hour?
- Perform a surgical operation?
- Put away the dishes and fold the laundry?
- Translate spoken Chinese into spoken English in real time?
- Write an intentionally funny story?
Intelligent Agents
Agents and environments

- Agents interact with environments through sensors and actuators
- An **agent** is an entity that perceives and acts
- A **rational agent** selects actions that maximize its (expected) utility
- Characteristics of the percepts, environment, and action space dictate techniques for selecting rational actions
Pac-Man as an Agent

Agent

Sensors

Actuators

Environment

Percepts

Actions

SCORE: 18

Pac-Man is a registered trademark of Namco-Bandai Games, used here for educational purposes

Demo1: pacman-l1.mp4
Environment 1: Pac-Man

- **Performance measure**
  - -1 per step; +10 food; +500 win; -500 die; +200 hit scared ghost

- **Environment**
  - Pacman dynamics (incl ghost behavior)

- **Actuators**
  - North, South, East, West, (Stop)

- **Sensors**
  - Entire state is visible

Score: 18
Environment 2: Automated taxi

- Performance measure
  - Income, happy customer, vehicle costs, fines, insurance premiums
- Environment
  - streets, other drivers, customers
- Actuators
  - Steering, brake, gas, display/speaker
- Sensors
  - Camera, radar, accelerometer, engine sensors, microphone

## Environment Types

<table>
<thead>
<tr>
<th>Fully or partially observable</th>
<th>Pacman</th>
<th>Taxi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single agent or multi-agent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deterministic or stochastic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static or dynamic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discrete or continuous</td>
<td></td>
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</tbody>
</table>
Simple reflex agents

• Reflex agents:
  • Choose action based on current percept (and maybe memory)
  • May have memory or a model of the world’s current state
  • Do not consider the future consequences of their actions
  • Consider how the world IS

• Can a reflex agent be rational?
Video of Demo Reflex Optimal
Video of Demo Reflex Odd
Summary

• What is AI and ML
• An example of AI but not ML
  • A* algorithm
• Foundation of AI
• History of AI
• What can AI do
  • Many applications in different industries/many aspects of life
• Intelligent agents
  • reflex agents

Questions?

Shuai Li
https://shuaili8.github.io