CS 15-281:
AI: Representation and Problem Solving

Tuomas Sandholm

Jan 12th, 2026

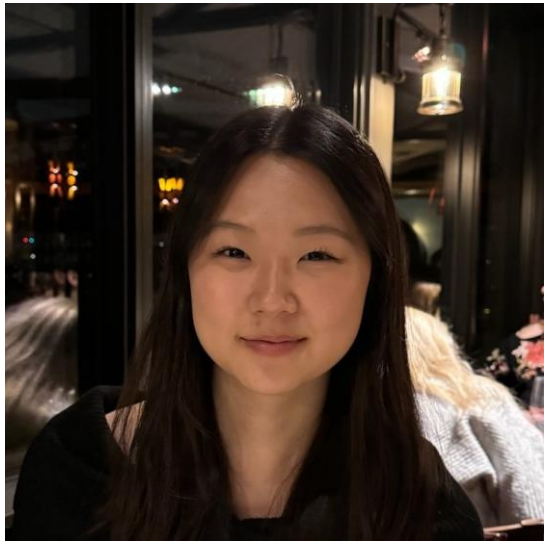
Course team

Professor

Tuomas Sandholm

TAs

Pranav



Sunny

Outline for today

- Course logistics
- What is AI?
- History of AI
- Current applications of AI
- What is an agent?

Course Information

Website: www.cs.cmu.edu/~15281

Canvas: canvas.cmu.edu 

Gradescope: gradescope.com 

Communication: piazza.com/cmu/spring2026/15281/home 

Please check website for: Prerequisites/Corequisites/Course Scope

Course Structure

Course will be taught through pre-recorded lectures from last year's version of this class (links on canvas/course website)

Scheduled class times will be used as office hours for students to ask questions

- Ideally mostly about the corresponding lecture/related assignments
- Please watch the assigned lecture before this!

Friday recitations (in person!) will be a review of lecture topics

Grading policy

- Final scores will be composed of:
  - 15% Midterm 1
  - 15% Midterm 2
  - 30% Final exam
  - 20% Programming homework
  - 10% Written homework
  - 5% Online homework
  - 5% Recitation attendance
    - 5% for 10 or more recitations attended (out of 13)
    - Linear scale between 0 (0%) and 10 (5%) recitations attended

Late Days

Late Days

- Total 6 late days allowed for the semester
  - At most 2 late days for any one homework
  - There will be no questions asked for use of these late days
- No further extensions will be granted unless there are extremely extenuating circumstances

Misc.

In-person office hours!

- Email a TA if scheduled office hour times do not work for you

Lectures, handouts, and course notes will all be available on the website

Use the late days appropriately.

Announcements

Recitation starting this Friday

- Materials are fair game for exams

Assignments:

- P0: Python & Autograder Tutorial (out tonight)
  - Required, but worth zero points
  - Due 1/23
- HW1 (online) – out tonight
  - Due 1/23

Weekly Office hours (details on course website)

- Homework questions should generally be directed to TAs
- Instructors can offer more help in broader and conceptual questions, so their office hours are better used for that

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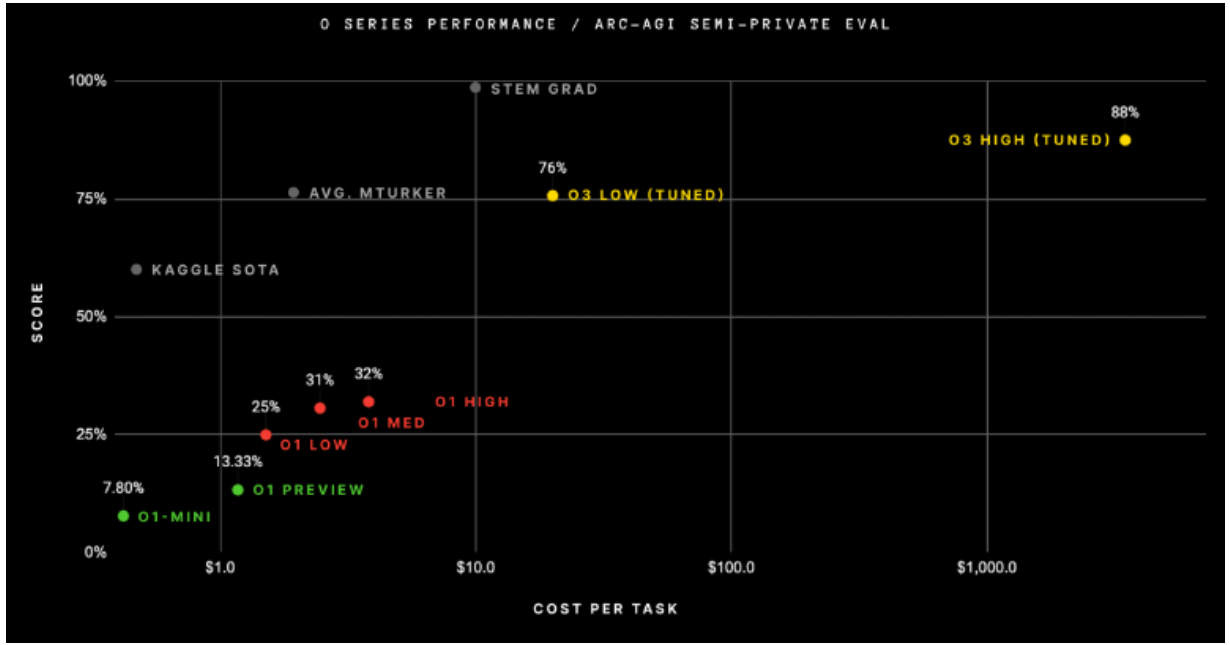
What is AI?

Measurable progress in AI

OpenAI

ChatGPT: Optimizing Language Models for Dialogue



NEWS | 12 January 2023

Abstracts written by ChatGPT fool scientists

Researchers cannot always differentiate between AI-generated and original abstracts.

“Chinese room” argument [Searle 1980]

- Person who knows English but not Chinese sits in room
- Receives notes in Chinese
- Has systematic English rule book for how to write new Chinese characters based on input Chinese characters, returns his notes
  - Person=CPU, rule book=AI program, really also need lots of paper (storage)
  - Has no understanding of what they mean
  - But from the outside, the room gives perfectly reasonable answers in Chinese!
- Searle’s argument: the room has no intelligence in it!

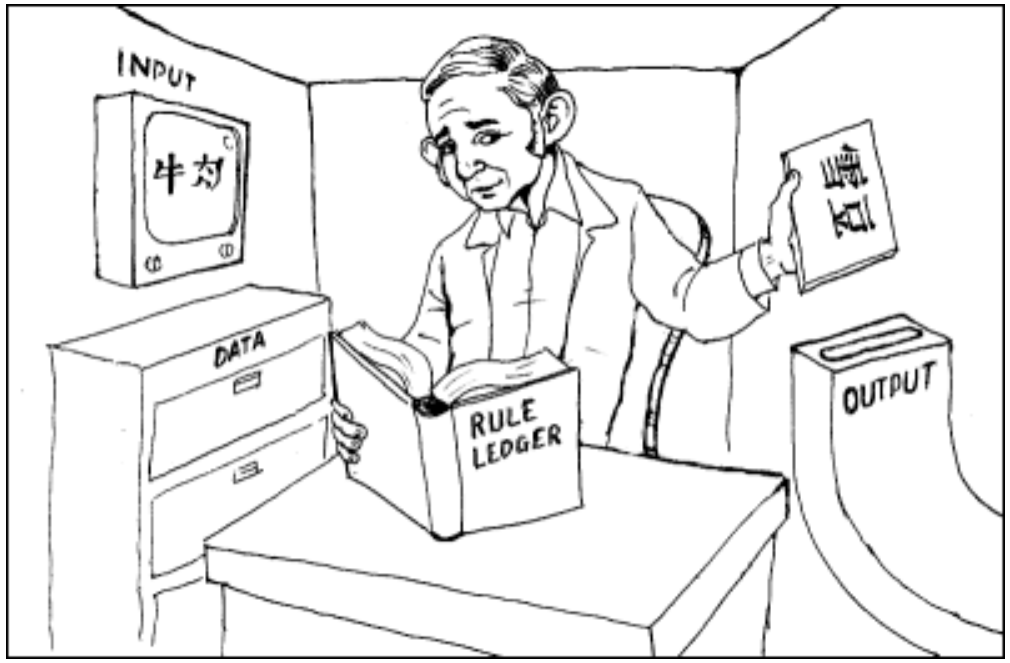
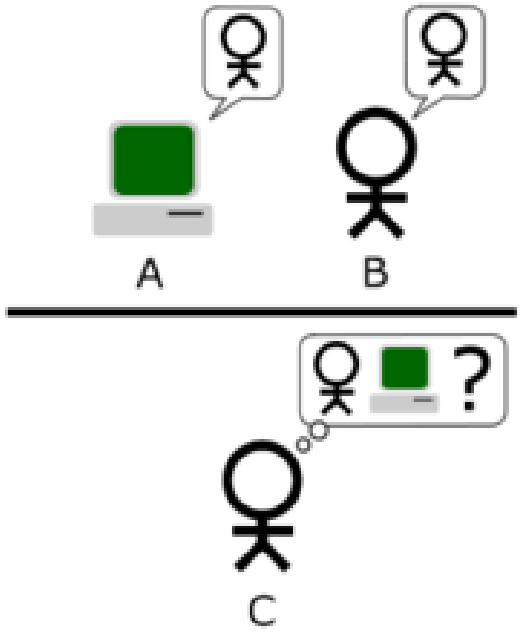


image from http://www.unc.edu/~prinz/pictures/c-room.gif

Turing Test

- In 1950, Turing defined a test of whether a machine could “think”
- “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”



en.wikipedia.org/wiki/Turing_test

Some classic definitions

Think like a human

- Cognitive science / neuroscience
- Does intelligence require biology?

Think rationally

- Logic and automated reasoning
- But, not all problems can be solved just by these techniques

Act like a human

- Turing test
- ELISA, Loebner prize
- “What is 1228 x 5873”? … “I don’t know, I’m just a human

Act rationally

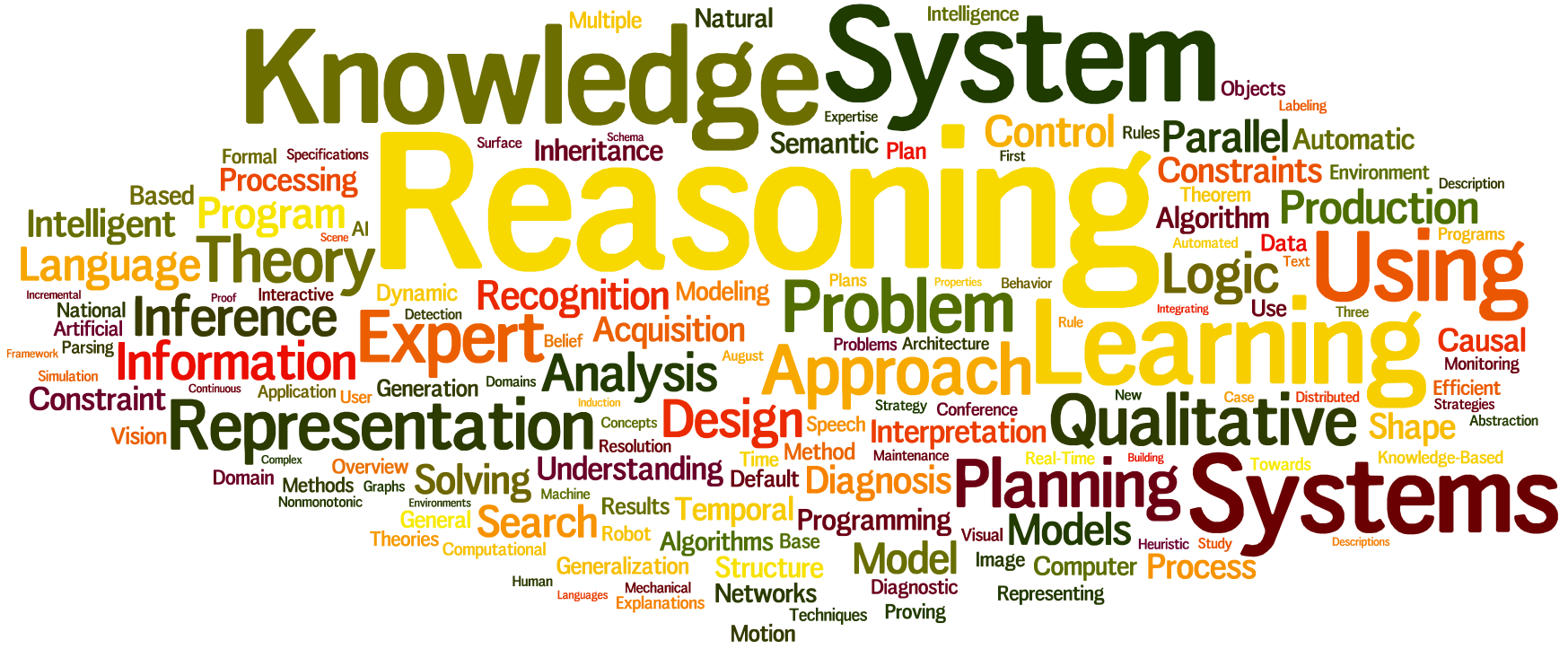
- Basis for intelligent agents framework
- Unclear if this captures the current scope of AI research

The pragmatist view

"AI is that which appears in academic conferences on AI"

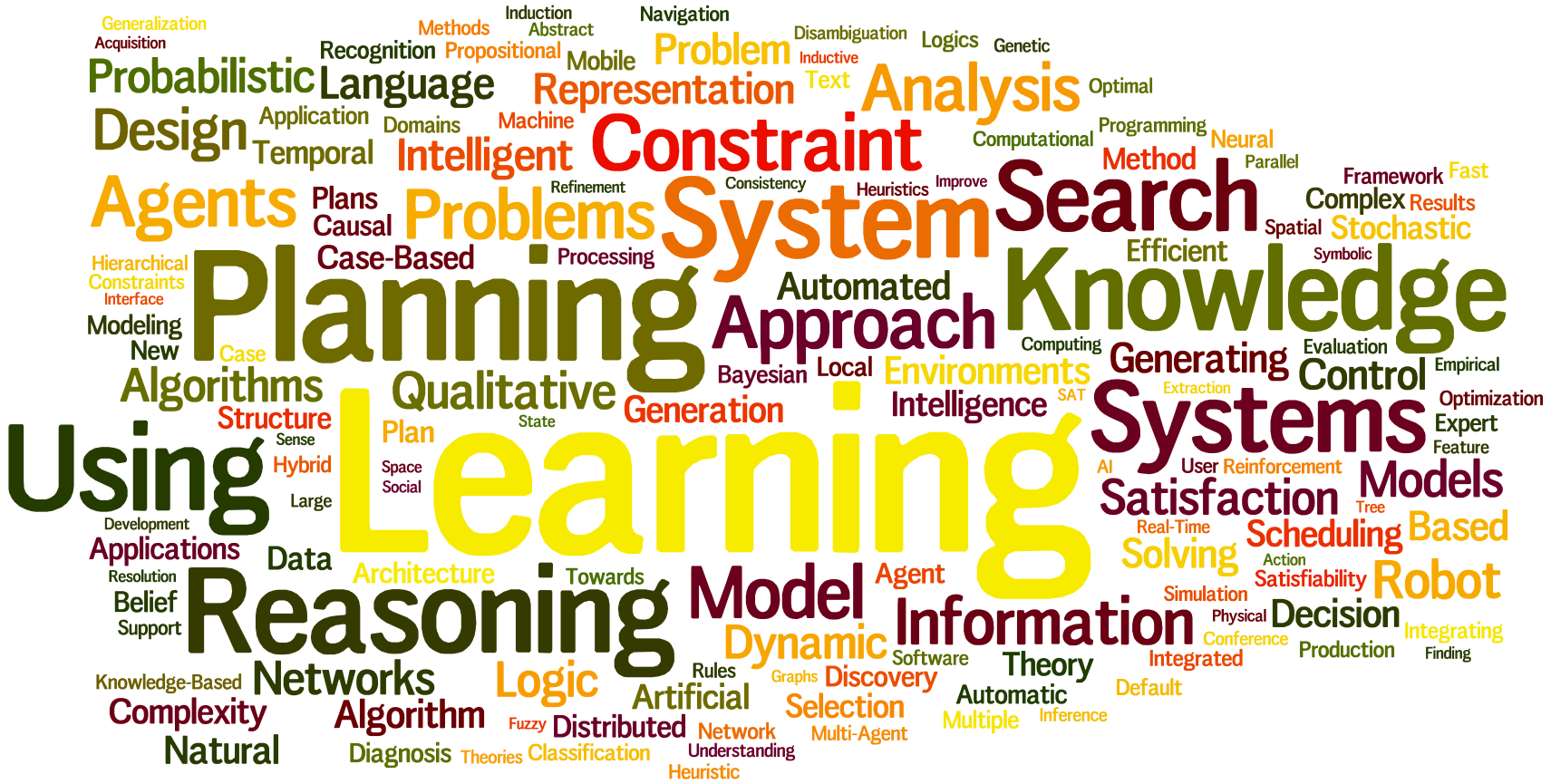
Alternate definition: "AI is that which marketing departments call AI"

Paper titles in AAAI



1980s

Paper titles in AAAI



1990s

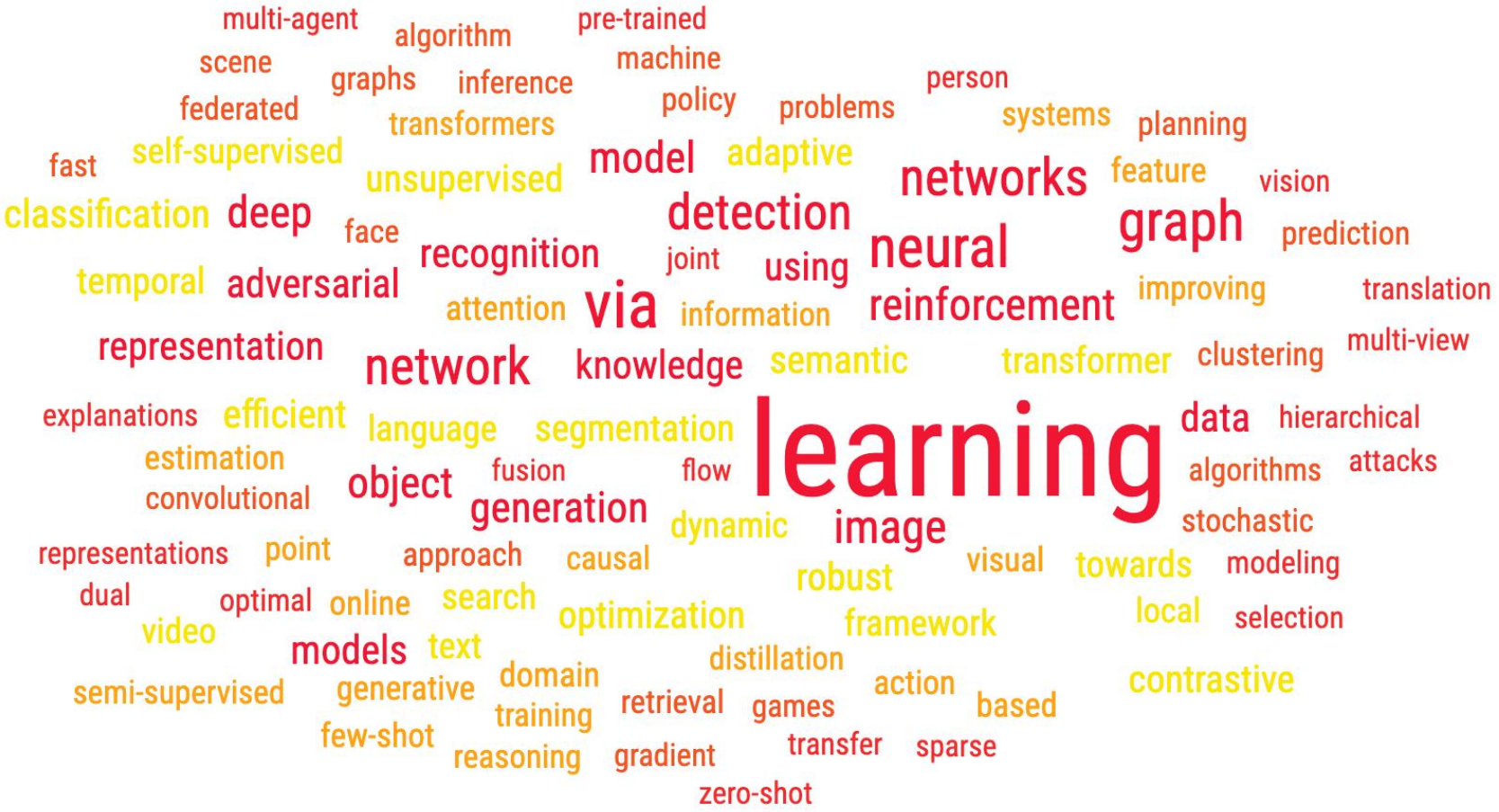
Paper titles in AAAI

2000s

Paper titles in AAAI

2010s

Paper titles in AAAI



2020s

A broader (but vague) definition

Artificial intelligence is the development and study **of computer systems** to address **complex** real-world problems typically associated with some form of intelligence

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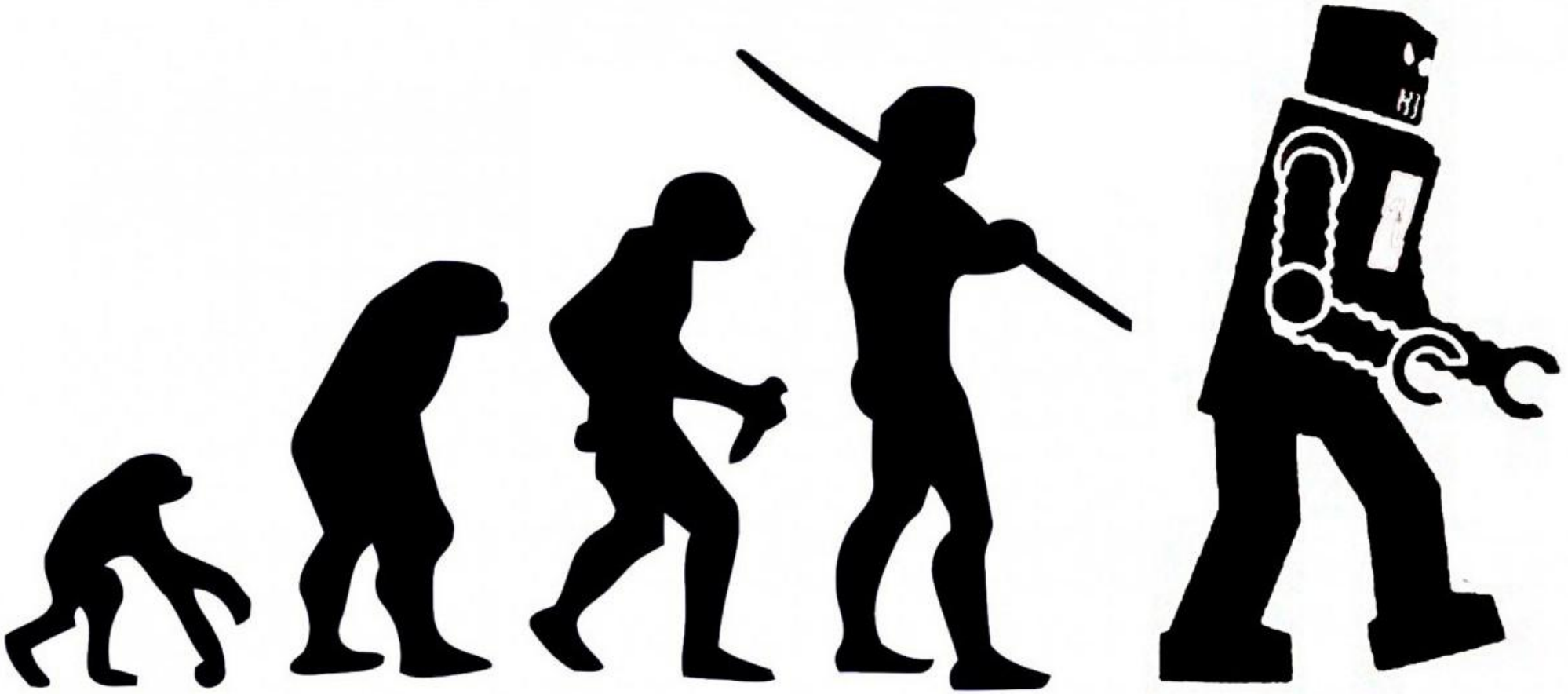
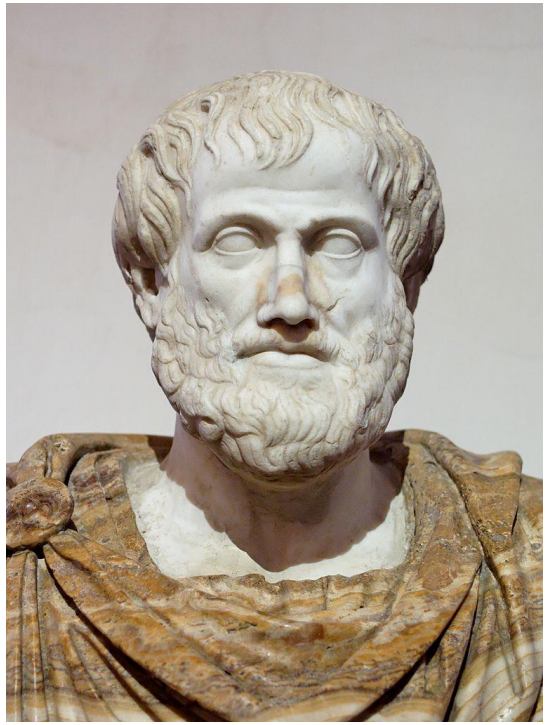
A brief history of AI



Prehistory (400 B.C -)



Aristotle

Philosophy: mind/body dualism, materialism

Mathematics: logic, probability, decision theory, game theory

Cognitive psychology

Computer engineering

Birth of AI (1943 –1956)

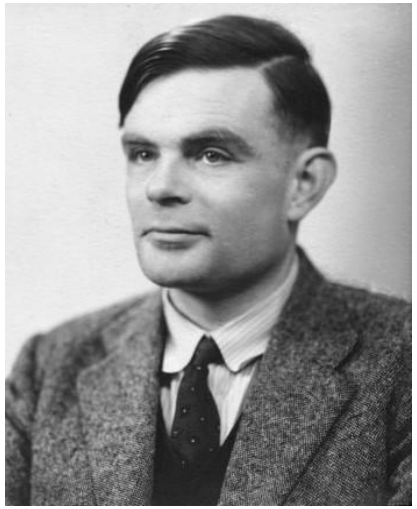
- [1943] McCullogh and Pitts: simple neural networks
  - A computational model inspired by the brain

A LOGICAL CALCULUS OF THE IDEAS IMMANENT IN NERVOUS ACTIVITY*

■ WARREN S. MCCULLOCH AND WALTER PITTS
University of Illinois, College of Medicine,
Department of Psychiatry at the Illinois Neuropsychiatric Institute,
University of Chicago, Chicago, U.S.A.

Birth of AI (1943 –1956)

- [1943] McCullogh and Pitts: simple neural networks
- [1950] Turing test



A. M. Turing (1950) Computing Machinery and Intelligence. *Mind 49:* 433-460.

COMPUTING MACHINERY AND INTELLIGENCE

By A. M. Turing

Birth of AI (1943 –1956)

- [1943] McCullogh and Pitts: simple neural networks
- [1950] Turing test
- [1955-56] Newell and Simon: Logic Theorist

First program deliberately engineered to perform automated reasoning; eventually goes onto being called the first artificial intelligence program

Uses search + heuristics

Birth of AI (1943 –1956)

- [1943] McCullogh and Pitts: simple neural networks
- [1950] Turing test
- [1955-56] Newell and Simon: Logic Theorist
- [1956] Dartmouth workshop (coined the term artificial intelligence)

Birth of AI (1956 Dartmouth workshop)

- 1956: workshop at Dartmouth college; 11 attendees including John McCarthy, Marvin Minsky, Claude Shannon, Allen Newell and Herbert Simon

John McCarthy

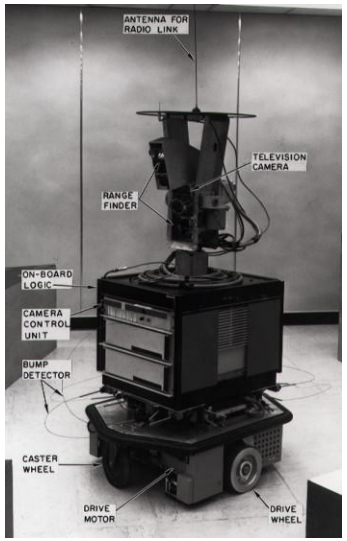
Aim for general principles: Every aspect of learning or any other feature of intelligence can be so precisely described that a machine can be made to simulate it

We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer

Early successes in AI (1950s – 60s)

[1952] Checkers: Arthur Samuel's program learned weights via self-play and played at a strong amateur level

[1958] McCarthy LISP, advice taker, time sharing



[1968-72] Shakey the robot

[1971-74] Blocksworld planning and reasoning domain

Early success in AI (1950s – 60s)

Overwhelming optimism

Machines will be capable of doing any work a man can do – Herbert Simon [1965]

Within a generation, I am convinced, few compartments of intellect will remain outside the machine's realm — the problems of creating "artificial intelligence" will be substantially solved – Marvin Minsky [1960s]

I visualize a time when we will be to robots what dogs are to humans. And I am rooting for the machines – Claude Shannon

First AI winter (Later 1970s)

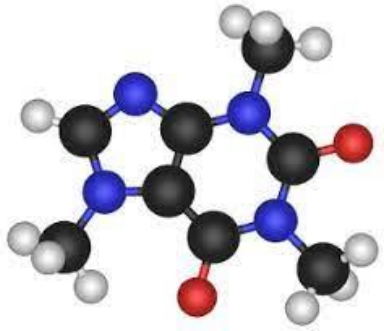
AI did not live up to the promise

- 1966 ALPAC report cut off funding for machine translation
  - *we will not suddenly or at least quickly attain machine translation*
- 1973 LightHill report
  - In no part of the field have the discoveries made so far produced the major impact that was then promised
- 1970s DARPA cut funding

What went wrong?

- Limited compute: search space grows exponentially
- Limited information about the complex world
- How to address this? The answer at the time was knowledge-based systems or expert systems that encode prior knowledge
  - Moved away from the optimism of generality…

Knowledge based systems (1970s-80s)



- [1971-74] Feigenbaum's DENRAL to infer molecular structure from mass spectrometry
- MYCIN: diagnose blood infections, recommend antibiotics
- 1981–Japan's "fifth generation" computer project, intelligence computers running Prolog
- [1982] XCON or R1 expert system to configure customer orders; deployed at DEC and saved $40 million a year

Second AI winter (late 1980s to early 1990s)

- Knowledge based systems also failed to deliver at the time
  - Required considerable manual effort to develop and maintain
  - "Knowledge acquisition bottleneck"
  - Deterministic rules could not handle uncertainty
- [1987] DARPA cuts AI funding for expert systems
- [1991] Japan's fifth generation project fails to meet goals

Splintering & changing of AI, and cross-fertilization with other fields (mid 1990s-)

- Many subfields and ideas: machine learning, computer vision, robotics, language processing, multiagent systems, ...
- Ideas from different fields
  - Bayes rule from probability
  - Cross-fertilization between search in AI and integer programming in operations research
  - Game theory from mathematics and economics
  - Stochastic gradient descent from statistics
  - Value iteration from control theory
  - Artificial neural networks from neuroscience
- AI becomes more mathematical
- Statistical rigor starts to be required in experimental results

Beyond symbolic AI

- Symbolic AI: top-down approach with a vision
- Neural AI: bottoms-up approach inspired by the human mind
- Neural AI had its own story with promise, successes, and winters

Phase one of neural AI

- [1943] McCulloch/Pitts model for computation
- [1958] Rosenblatt's perceptron algorithm for binary classification
- [1969] Perceptrons book showed that linear networks could not solve XOR <> part of the AI winter that killed neural net research

Phase two of neural AI

- [1986] Popularization of the backpropagation algorithm (originally invented by Seppo Linnainmaa in 1972) for training multi-layer networks by Rumelhardt, Hinton, Williams

- [1989] LeCun applied CNNs (pioneered previously by CMU's Alex Waibel) for handwriting recognition

- Was still hard to train very deep networks successfully---hence successes limited to simple tasks

Phase three of neural AI

- "AlexNet moment" [2012]: huge gains on a real-world image classification task by successfully training deep networks
  - Large scale data (ImageNet) + GPUs + training heuristics

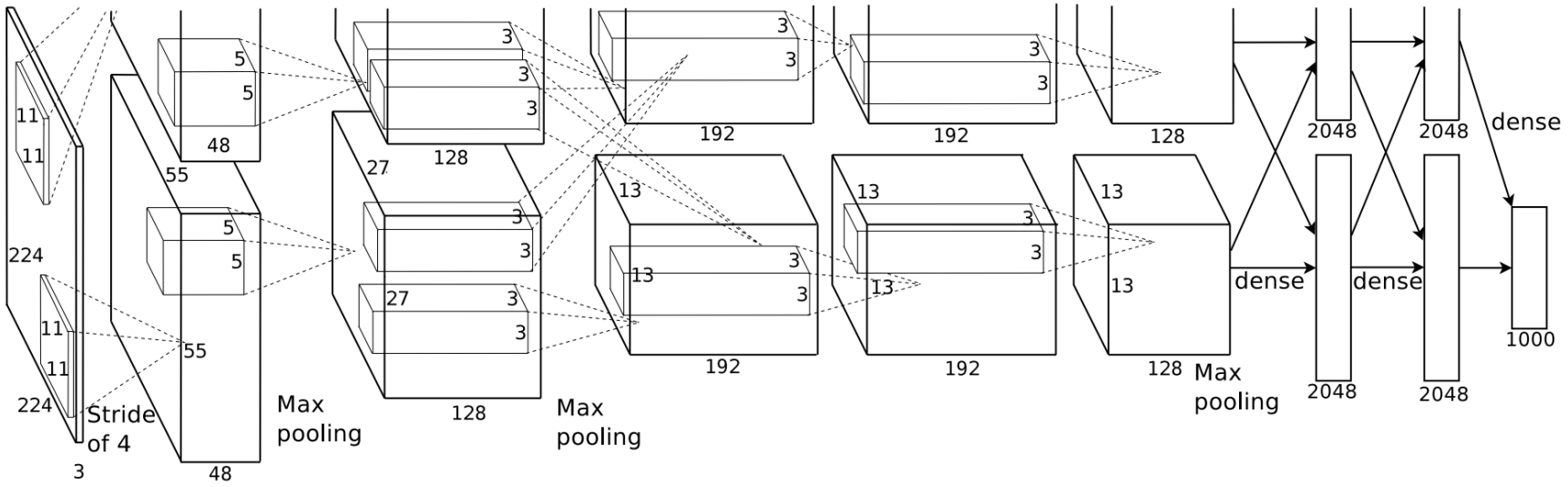


Figure 2: An illustration of the architecture of our CNN, explicitly showing the delineation of responsibilities between the two GPUs. One GPU runs the layer-parts at the top of the figure while the other runs the layer-parts at the bottom. The GPUs communicate only at certain layers. The network's input is 150,528-dimensional, and the number of neurons in the network's remaining layers is given by 253,440–186,624–64,896–64,896–43,264–4096–4096–1000.

Phase three of neural AI

- Ever larger amounts of data and compute (both offline and real time)

- [2020] GPT-3 with 175B parameters, trained on about 45TB of text data from different datasets
- [2024] Llama-3.1 was released on July 23, 2024, with three sizes: 8B, 70B, and 405B parameters

The AI renaissance

- [1997] DeepBlue defeats Garry Kasparov

- [1995] NavLab5 automobile drives across country 98% autonomously

- [2005, 2007] Stanford and CMU win DARPA grand challenges in autonomous driving

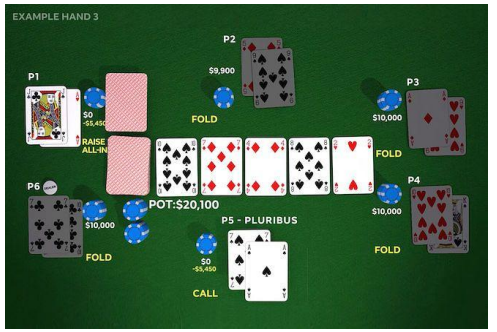
- [2011] IBM's Watson defeats human Jeopardy opponents

The AI renaissance

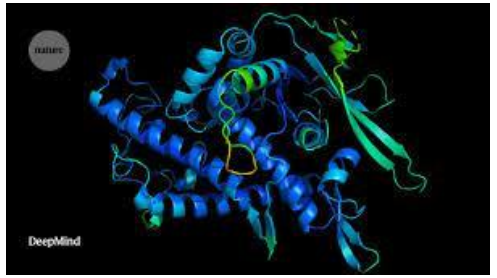
- [2016] DeepMind's AlphaGo beats top human player Lee Sodol

- [2017] CMU's Libratus defeats world's best players at two-player no-limit Texas Hold'em

- [2019] CMU's Pluribus defeats world's best players at multi-player no-limit Texas Hold'em



- [2021] DeepMind's AlphaFold offers highly accurate protein structure prediction



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AI in the real world

Translation

Spam detection

Voice assistant

Stock market

Facial recognition

Hiring systems

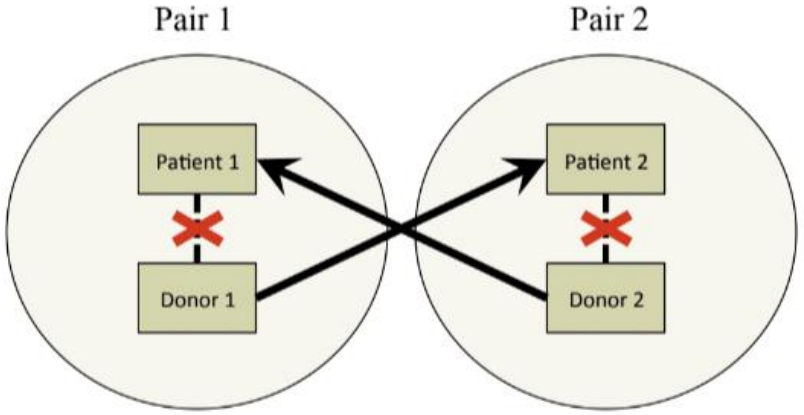
Autonomous driving

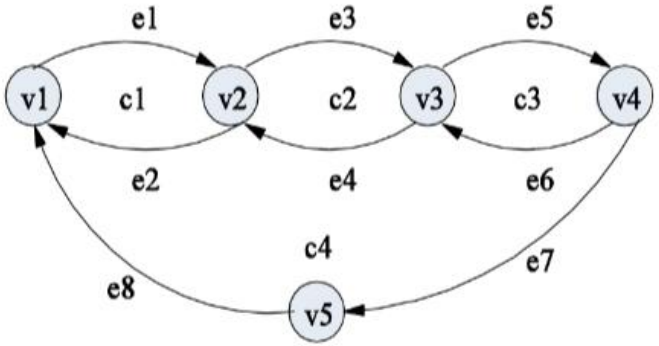
Large-scale combinatorial multi-attribute sourcing auctions 2001-2010 [Sandholm, Handbook of Market Design, Ch. 16, 2013]

- One of the first SaaS analytics companies
- Over 800 auctions, totaling over $60 Billion
  - The most *expressive* auctions ever conducted
- Created 12.6% savings for buy side
- Suppliers also benefited
- Grew to 130 employees, operations on 4 continents
- Acquired in 2010
- Key AI technologies:
  - Winner determination algorithms
  - Bidding languages
  - Preference elicitation from multiple agents
  - Automated mechanism design

Kidney exchange

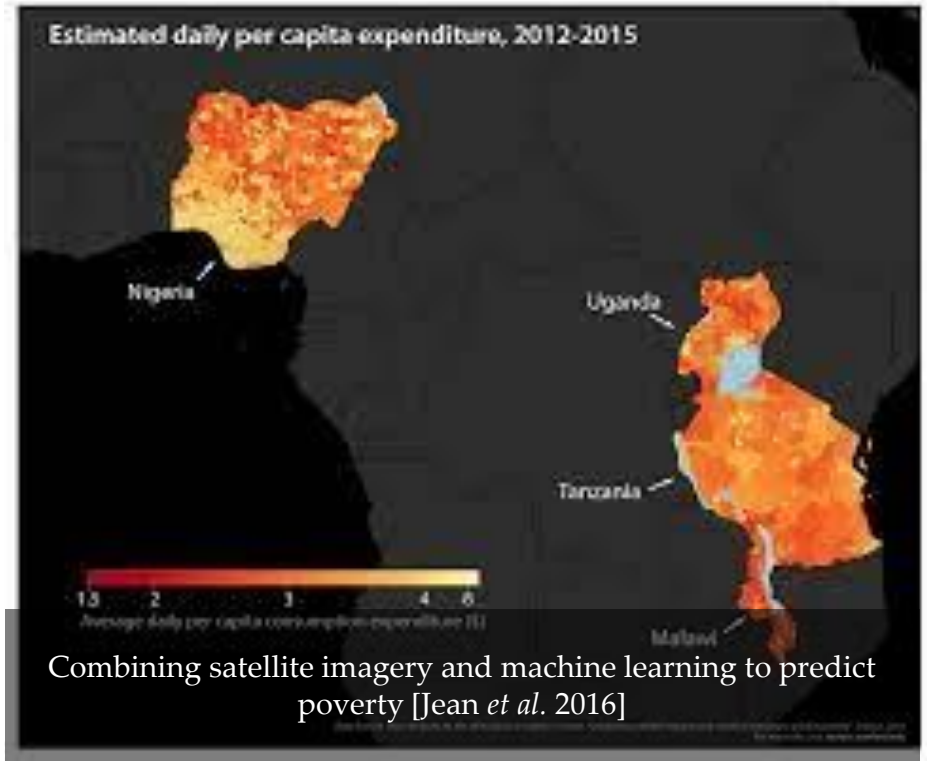
AI from Prof. Sandholm's lab has been running the national kidney exchange for UNOS since 2010.





AI and sustainability

Deepmind's AI reduces Google Data Center's energy consumption



Combining satellite imagery and machine learning to predict poverty [Jean *et al.* 2016]

ARTIFICIAL INTELLIGENCE

AI Discovers First New Antibiotic in Over 60 Years

A landmark study discovers a new antibiotic using AI deep learning technology.

Posted December 24, 2023 | Reviewed by Abigail Fagan

KEY POINTS

- Antimicrobial resistance poses a major threat to public health.
- Researchers used AI to discover a new class of antibiotics to treat drug-resistant staph infections.
- The study used graph-based searches for chemical substructure options.

In Prof. Sandholm's August 2021 IJCAI John McCarthy Award talk, he predicted there will be ***human-only categories*** *in future art competitions*

An A.I.-Generated Picture Won an Art Prize. Artists Aren't Happy.

"I won, and I didn't break any rules," the artwork's creator says.

Jason Allen's A.I.-generated work, "Théâtre D'opéra Spatial," took first place in the digital category at the Colorado State Fair. via Jason Allen

By Kevin Roose

Sept. 2, 2022

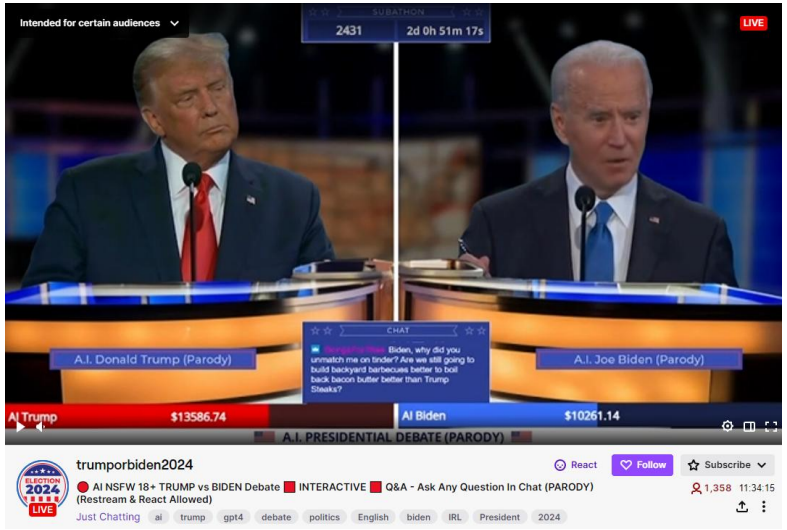
New York Times

Deepfakes of Prof. Sandholm Spring 2023-

Some harmful applications of deepfakes

A recent video from Republican presidential candidate and Florida Gov. Ron DeSantis includes an image with three fake photos of former President Donald Trump and Dr. Anthony Fauci hugging. These three images appear to be AI-generated.

DeSantis War Room/Screenshot and annotation by NPR



https://www.twitch.tv/trumporbiden2024

An A.I. Hit of Fake 'Drake' and 'The Weeknd' Rattles the Music World

A track like "Heart on My Sleeve," which went viral before being taken down by streaming services this week, may be a novelty for now. But the legal and creative questions it raises are here to stay.

Labels hope that fans will continue to prize the work of artists, including the real Drake, above that of A.I.-generated imitations. Adam Riding for The New York Times

By Joe Coscarelli New York Times

Published April 19, 2023 Updated April 24, 2023


THE
BEATLES
NOW AND THEN
MUSIC VIDEO
vevo

Large language models (LLMs) 2018-

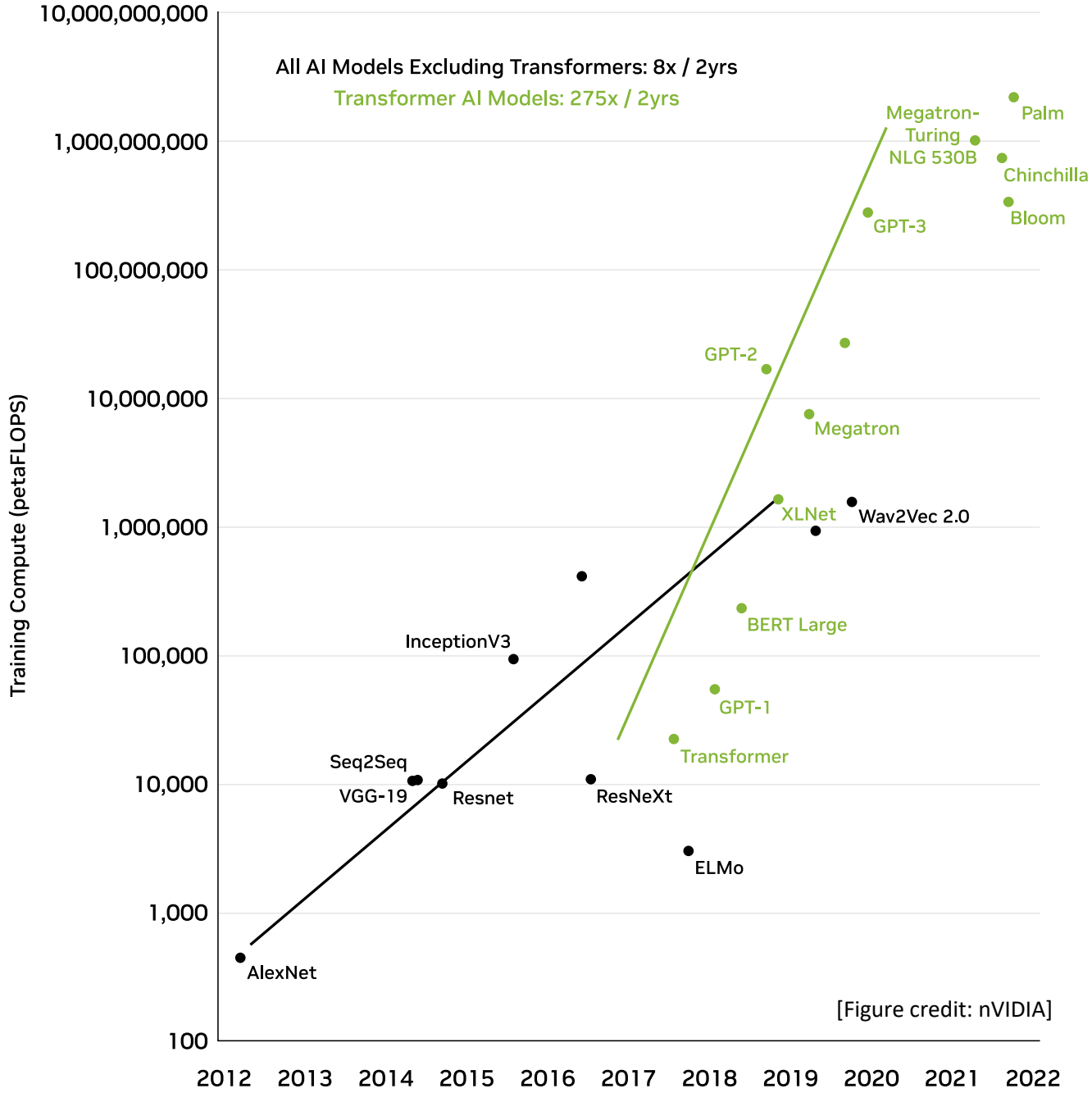
1. Generation (e.g., story writing, marketing content creation)
   - Tim Boucher wrote 97 books in 9 months using ChatGPT from OpenAI and Claude from Anthropic. He used Midjourney to generate images to match the story. Word count 2,000 - 83,000. Price $1.99 - $5.99
   - Non-AI-assisted record, by Barbara Cartland, is 191 books per year
2. Summarization (e.g., web search, legal paraphrasing, meeting notes summarization)
   - E.g., Bing co-pilot, Bard
   - In the future also question answering from specific corpora
3. Translation (e.g., between languages, text-to-code, text-to-database)
4. Classification (e.g., toxicity classification, sentiment analysis)
5. Chatbot (e.g., open-domain Q+A, virtual assistants)
   - E.g., Bing co-pilot, Bard

Downsides of LLMs

- Hallucination
  - May be impossible to fully get rid of
    - But code writing & external calls help
  - In important applications, getting sensical answers most of the time isn't good enough (cf. self-driving in 2015)
- Limited reasoning. Thus poor at
  - strategies against adversaries
    - Can't play tic-tac-toe, much less no-limit Texas hold'em poker
  - logic
  - collaborative filtering
  - …

Downsides of LLMs …

- Training cost
  - Open AI's GPT-4 took "more than $100M" [OpenAI CEO 4/17/2023] (Microsoft invested $1B+$10B in OpenAI)
  - "Really good large language models take $ Billions to train" [Amazon CEO 4/13/2023]



Downsides of LLMs …

- Proliferation of content
- Privacy loss & copyright issues
- Biases & inclusivity
- Explainability
- No “understanding” (?) but LLMs are used as if they understand in consulting, medicine, customer service, etc.

Regulation?

The AI Renaissance

Symbolic AI + Neural AI + tools and ideas from other fields…

Optimization,
algorithms,
probabilistic inference,
statistics,
game theory, etc.

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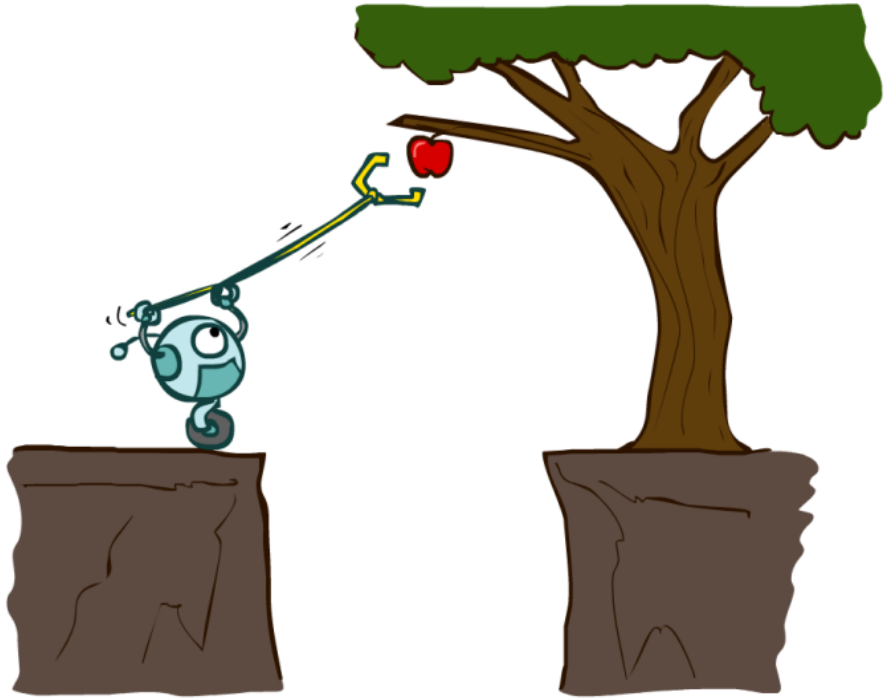
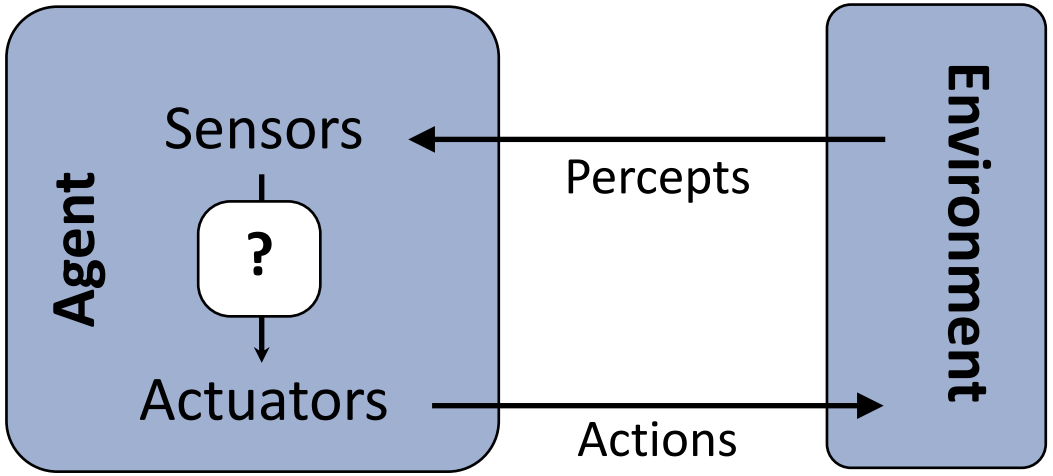
Designing Agents

An **agent** is an entity that *perceives* and *acts*.

Characteristics of the **percepts and state, environment,** and **action space** dictate techniques for selecting actions

How can we design an AI agent to solve our problems given their task environments?





Rational Decisions

We'll use the term **rational** in a very specific, technical way:

- Rational: maximally achieving pre-defined goals
- Rationality only concerns what decisions are made

  (not the thought process behind them)
- Goals are expressed in terms of the **utility** of outcomes
- Being rational means **maximizing your expected utility**

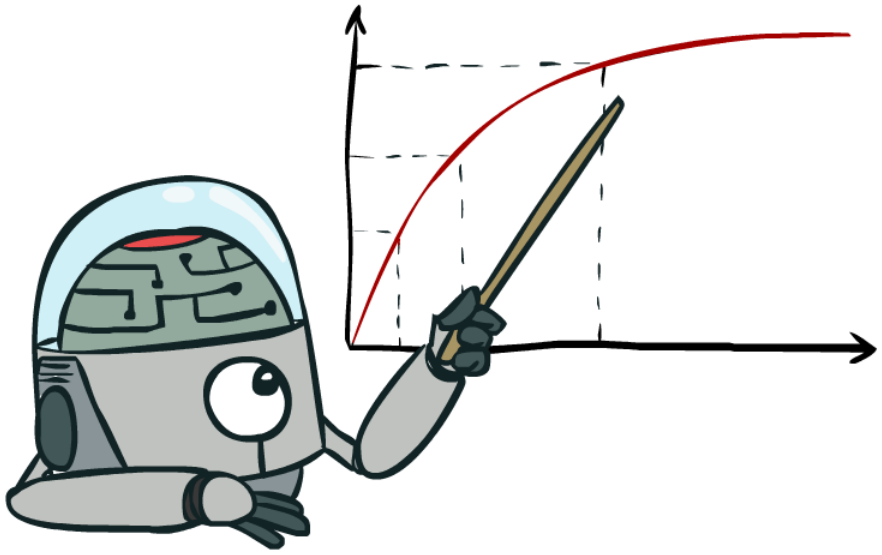
Another title for this course could be:

Introduction to Computational Rationality

Rationality, contd.

What is rational depends on:

- Performance measure
- Agent's prior knowledge of environment
- Actions available to agent
- Percept sequence to date



Being rational means **maximizing your expected utility**

Rational Agents

Are rational agents ***omniscient***?

- No – they are limited by the available percepts and state

Are rational agents ***clairvoyant***?

- No – they may lack knowledge of the environment dynamics

Do rational agents ***explore*** and ***learn***?

- Yes – in unknown environments these are essential

So, rational agents are not necessarily successful, but they are ***autonomous*** (i.e., make decisions on their own to achieve their goals)

- Don’t have to be used as autonomous but rather as recommenders of actions or in some settings as collaborators

Artificial Intelligence (AI) vs Machine Learning (ML)?