# CSE5001 高级人工智能
# Advanced Artificial Intelligence

# Basic information

- Instructor: Yu Zhang
- Credits: 3
- Hours: 64
- Languages: Chinese, English

# Course description

- **Outline**: This course introduces some advances in Artificial Intelligence (AI). Topics covered include intelligent optimization and learning, as well as different machine learning algorithms. The assessment in the course will consist of assignments, a project, and a final exam.
- **Learning Outcomes**: Upon finishing this course, students are expected to have a good understanding of challenging optimization and learning problems, and different models and algorithms for tackling these problems.
- **Teaching Methods**: Two-hour lecture + Two-hour lab every week.

# Important notes

We assume the students of this course have a background in computer science or computer engineering. Basic knowledge of programming, data structures and algorithms are assumed.

For every lecture hour, we expect a student with a computer science background to spend 3-6 hours after the lecture to fully digest the content.

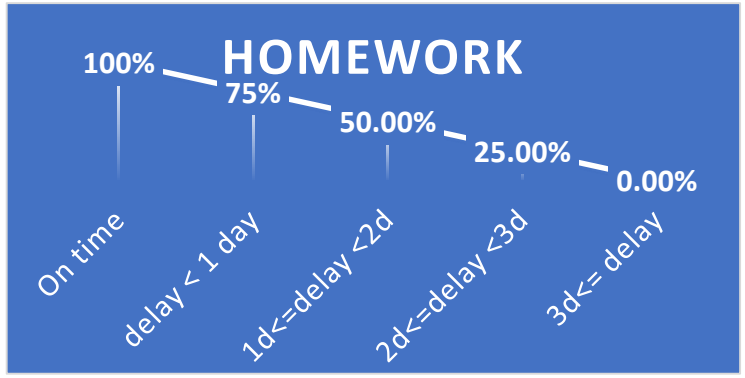
If you do not attend a class, I will assume you know all the contents of that class and information given at the class. I will not repeat any content and information about that class to you outside the class.

# Professional behaviours

- Be polite and cooperative to others.
- Respect each other.
- Follow rules and regulations. There will be **no** exceptions.
- Plagiarism or unethical behaviours will be punished. **Zero** tolerance. *This is stricter than the departmental rules.*
- It's OK to work in teams. It is actually encouraged. However, if you have used code or materials that are not yours, please acknowledge them.
- Do not play mobile phone or talk to each other during classes.

# Course Assessment

- Homework (35%)
  - Late submission will be penalized (25% for each day late)
- Project (20%)
- Final exam (40%)
- Lecture attendance (5%)



# Tentative Course Plan

- 1: Introduction
- 2: Basic Search
- 3: Heuristic Search
- 4: Meta-Heuristic
- 5: Supervised Learning
- 6: Ensemble Learning

# Tentative Course Plan

- 7: Multi-Objective Optimization and Learning
- 8: Unsupervised Learning
- 9: Feature Engineering
- 10: Markov Decision Process
- 11: Reinforcement Learning
- 12: Natural Language Processing

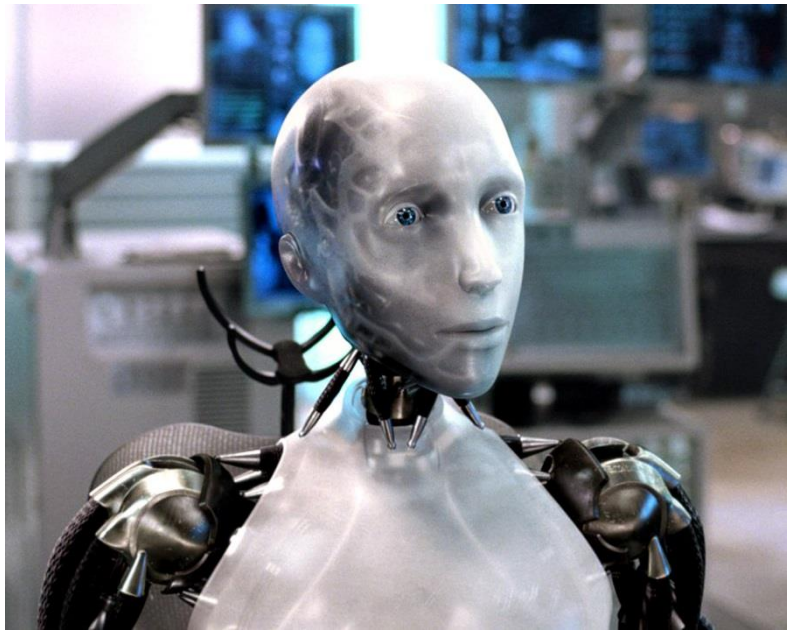
# Recommended Literature

- Books
  - Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach* (3rd edition), Cambridge University Press, 2009.
    - The book resources: http://aima.cs.berkeley.edu/
  - Richard S. Sutton and Andrew G. Barto: *Reinforcement Learning: An Introduction* (2nd edition), MIT Press, 2017
    - The book resources: http://incompleteideas.net/book/the-book-2nd.html
  - Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest and Clifford Stein: *Introduction to Algorithms* (3rd edition), MIT Press, 2009.
    - The book resources: https://mcdtu.files.wordpress.com/2017/03/introduction-to-algorithms-3rd-edition-sep-2010.pdf
- We will refer to these books as *"AI textbook"*, *"RL textbook"* and *"Algorithms textbook"* in the future lectures/labs/assignments.

- Reading materials
  - Relevant papers/books as handed out at each lecture.

# Introduction

Fall 2019



# Outline

- What is AI?
- Foundations of AI
- History of AI
- Applications of AI
- Summary

# What is AI?

# Definitions of AI

"Intelligence: The ability to learn and solve problems"

Webster's Dictionary.

"Artificial intelligence (AI) is the intelligence exhibited by machines or software'

Wikipedia.

"The science and engineering of making intelligent machines"

McCarthy.

"The study and design of intelligent agents, where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success."

Russell and Norvig's AI book.

# What is AI?

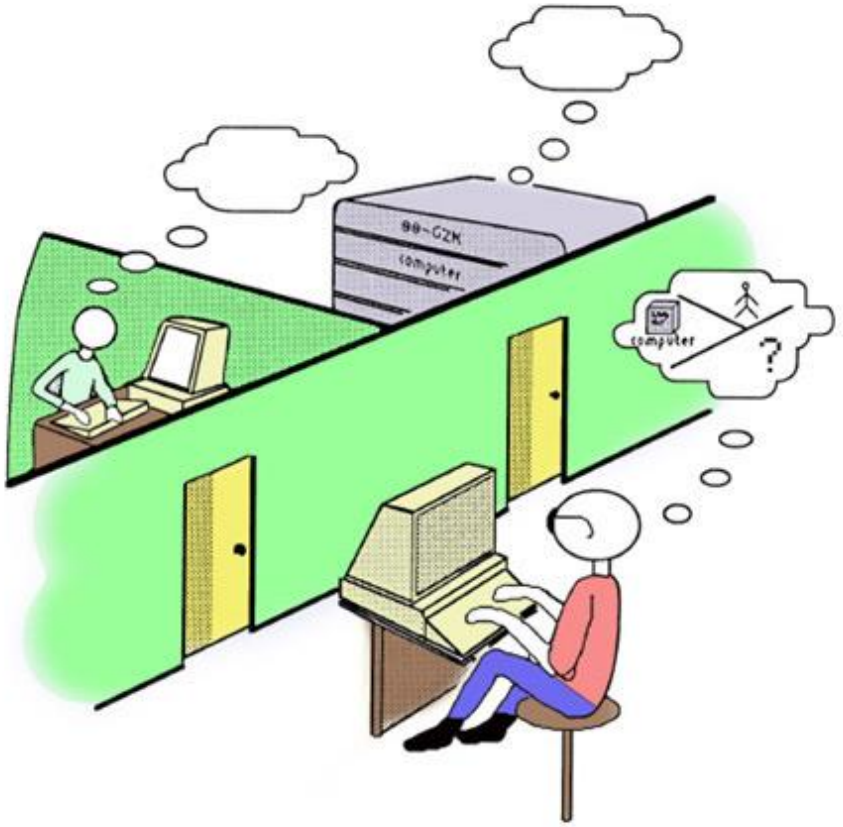
| **Thinking Humanly** | **Thinking Rationally** |
| --- | --- |
| "The exciting new effort to make computers think . . . *machines with minds*, in the full and literal sense." (Haugeland, 1985)<br><br>"[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning . . ." (Bellman, 1978) | "The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985)<br><br>"The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992) |
| **Acting Humanly** | **Acting Rationally** |
| "The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990)<br><br>"The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991) | "Computational Intelligence is the study of the design of intelligent agents." (Poole *et al.*, 1998)<br><br>"AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998) |

# Thinking humanly: cognitive approach

- Requires to determine how humans think!
  1960's "cognitive revolution".
  Requires scientific theories of internal activities of the brain
  - What level of abstraction? "Knowledge" or "circuits"?
  - How to validate?
- Today, Cognitive Science and Artificial Intelligence are distinct disciplines.

# Acting humanly: Turing test

- Turing test (Alan Turing 1950): A computer passes the test of intelligence, if it can fool a human interrogator.
- Major components of AI: knowledge, reasoning, language, understanding, learning.



# AI passes Turing test in 'world first’

- In 2014, a computer program called **Eugene Goostman**, which simulates a 13-year-old Ukrainian boy, is said to have passed the Turing test at an event organized by the University of Reading.


BBC News (http://www.bbc.com/news/technology-27762088)

# Thinking rationally: “laws of thought”

- Codify “right thinking” with **logic**.
- Several Greek schools developed various forms of logic: *notation* and *rules of derivation* for thoughts.
- Problems:
  1. Not all knowledge can be expressed with logical notations.
  2. Computational blow up.

# Acting rationally: rational agent

- The right thing: that which is expected to maximize goal achievement, given the available information.
- A **rational agent** is one that acts so as to achieve the best outcome, or when there is uncertainty, the best expected outcome.
- Aristotle (Nicomachean Ethics):
  "*Every art and every inquiry, and similarly every action and pursuit, is thought to aim at some good*."

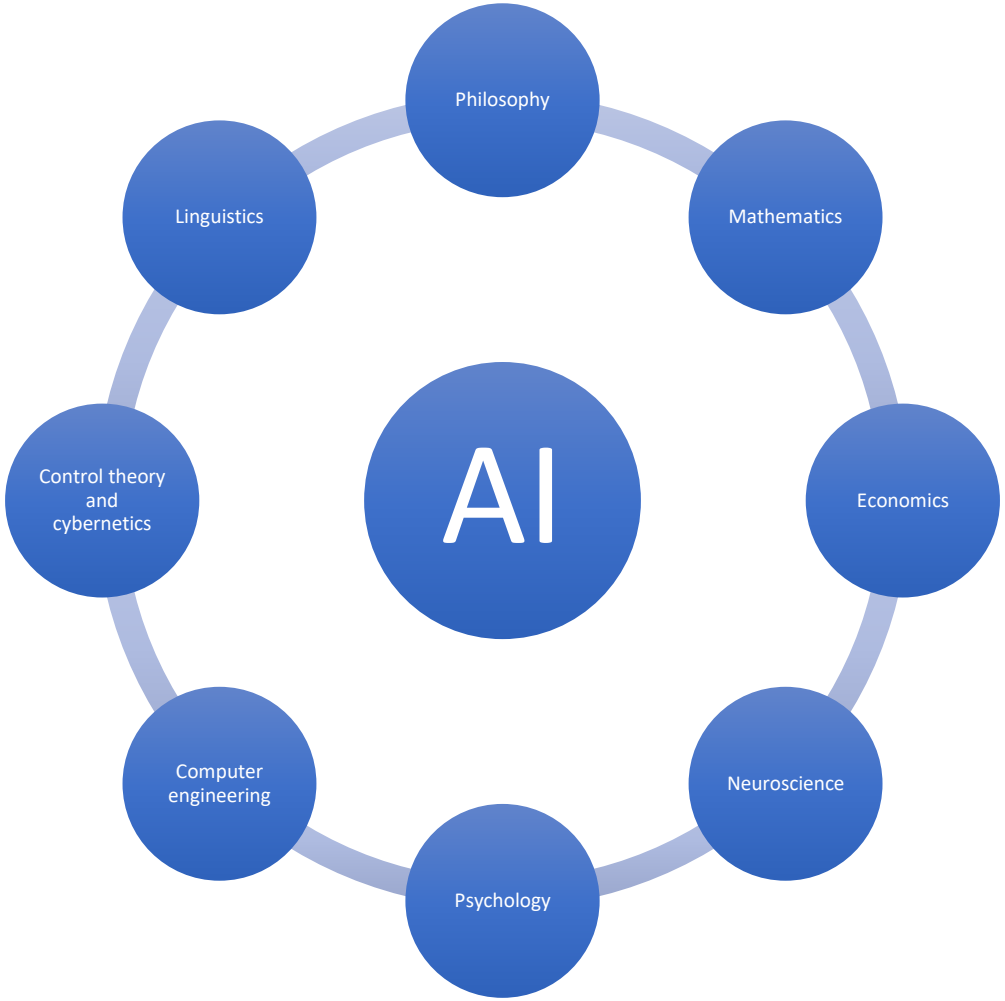
# What is AI? Our Approach

| **Thinking Humanly** | **Thinking Rationally** |
|---|---|
| "The exciting new effort to make computers think . . . *machines with minds*, in the full and literal sense." (Haugeland, 1985)<br><br>"[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning . . ." (Bellman, 1978) | "The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985)<br><br>"The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992) |
| **Acting Humanly** | **Acting Rationally: Our approach** |
| "The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990)<br><br>"The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991) | "Computational Intelligence is the study of the design of intelligent agents." (Poole *et al.*, 1998)<br><br>"AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998) |

# Foundations of AI

# The Foundation of AI

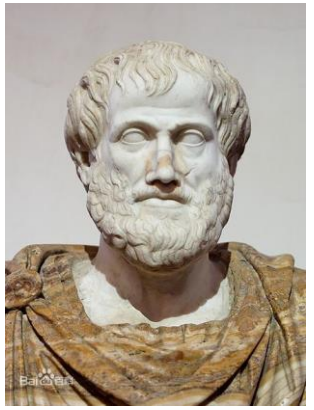
- Philosophy
- Mathematics
- Economics
- Neuroscience
- Psychology
- Computer engineering
- Control theory and cybernetics
- Linguistics



# 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?

✓Logic, methods of reasoning.
✓Mind as physical system that operates as a set of rules.
✓Foundations of learning, language, rationality.



Aristotle
(384–322 B.C.)

René Descartes
(1596–1650)

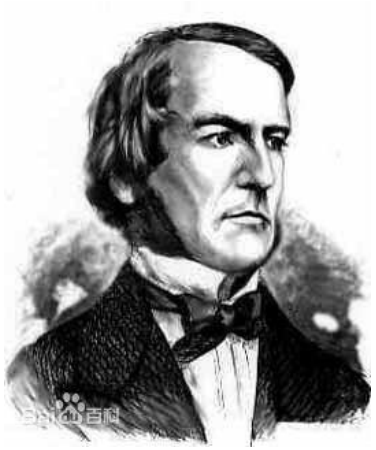
# Mathematics

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

✓Logic: Formal representation and proof.

✓Computation, algorithms.

✓Probability.



George Boole
(1815–1864)

Thomas Bayes
(1702–1761)

# Economics

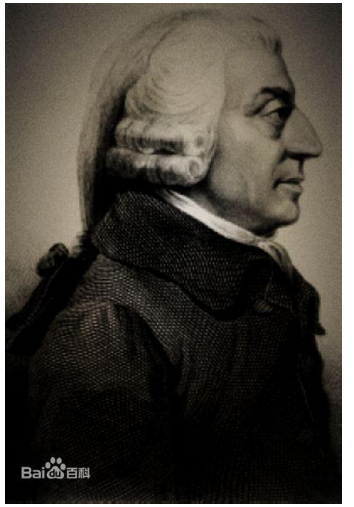
- How should we make decisions so as to maximize payoff?
- How should we do this when others may not go along?
- How should we do this when the payoff may be far in the future?

✓Formal theory of rational decisions.

✓Combined decision theory and probability theory for decision making under uncertainty.

✓Game theory.

✓Markov decision processes.



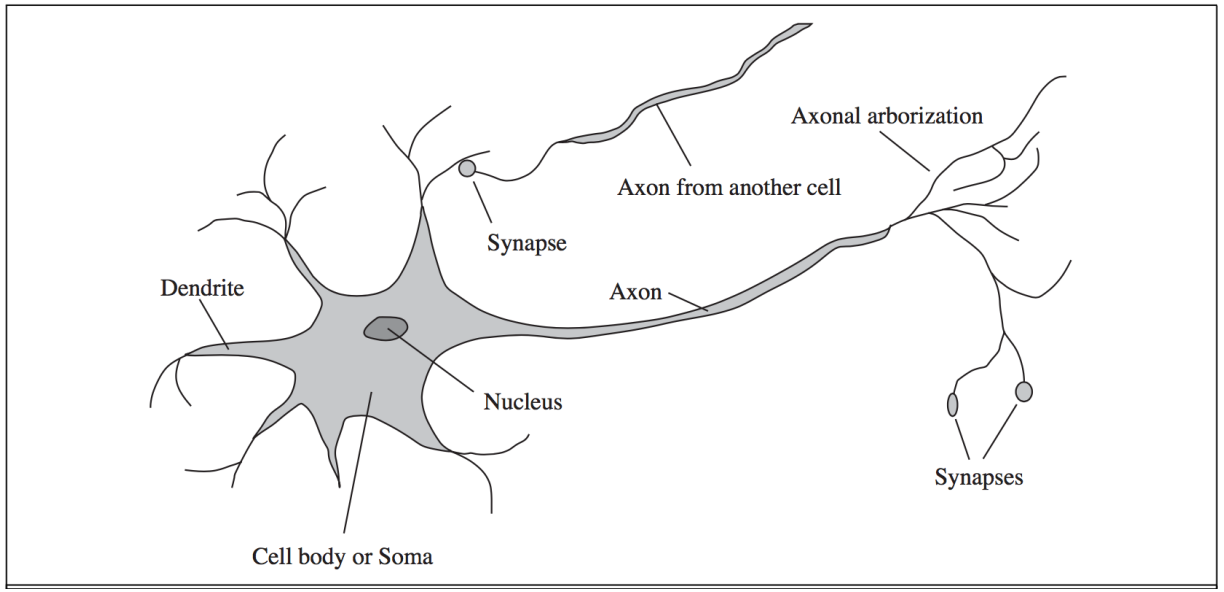
Adam Smith
(1723–1790)

Herbert Simon
(1916–2001)

# Neuroscience

- How do brains process information?

✓How brains and computers are (dis)similar.



# Psychology

- How do humans and animals think and act?

✓Cognitive psychology perceives the brain as an information processing machine.

✓Led to the development of the field *cognitive science*: how could computer models be used to study *language*, *memory*, and *thinking* from a psychological perspective.

# Computer engineering

- How can we build an efficient computer?

✓E.g., Self-driving cars are possible today thanks to advances in computer engineering.

# Control theory and cybernetics

- How can artifacts operate under their own control?

✓Design simple optimal agents receiving feedback from the environment.

✓Modern control theory design systems that maximize an objective function over time.

# Linguistics

- How does language relate to thought?

✓Modern linguistics + AI = Computational linguistics (Natural language processing).

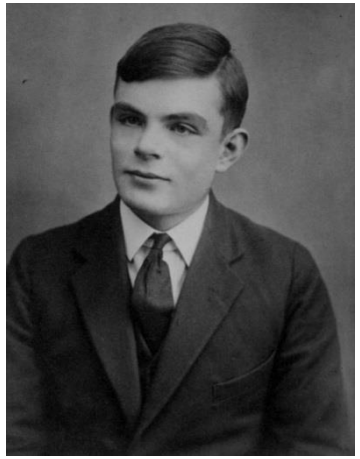
# History of AI

# The History of AI

- The gestation of artificial intelligence (1943–1955)
- The birth of artificial intelligence (1956)
- Early enthusiasm, great expectations (1952–1969)
- A dose of reality (1966–1973)
- Knowledge-based systems: The key to power? (1969–1979)
- AI becomes an industry (1980–present)
- The return of neural networks (1986–present)
- AI adopts the scientific method (1987–present)
- The emergence of intelligent agents (1995–present)
- The availability of very large data sets (2001–present)

# The gestation of AI (1943–1955)

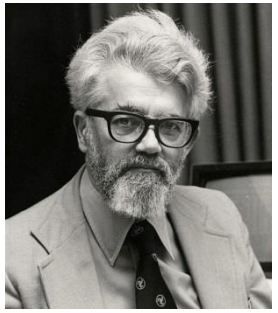
- McCulloch and Walter Pitts, model of artificial neurons, 1943.
- Donald Hebb, **Hebbian learning**, 1949.
- Marvin Minsky and Dean Edmonds, neural network computer, 1950.
- Alan Turing, *Computing Machinery and Intelligence*, 1950.



Alan Turing (1912-1954)
(Turing test, machine learning, genetic algorithms,
and reinforcement learning )

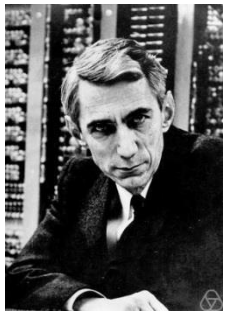
# The birth of AI (1956)

**Dartmouth Workshop**

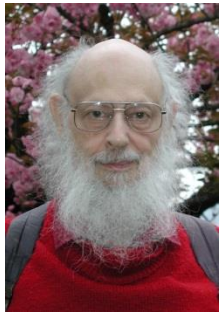


John McCarthy
(Lisp language)

Marvin Minsky
(SNARC)

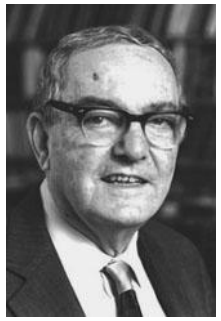


Claude Shannon
(Information theory)



Ray Solomonoff
(Algorithmic probability)

Allen Newell
(General Problem Solver)



Herbert Simon
(Satisficing)

Arthur Samuel
(Computer checkers)

And three others…
Oliver Selfridge (Pandemonium theory)
Nathaniel Rochester (Designed IBM 701)
Trenchard More (Natural deduction)

# Early enthusiasm (1952–1969)

- Newell and Simon, General Problem Solver, 1961, **physical symbol system,** 1976.
- Herbert Gelernter, Geometry Theorem Prover, 1959.
- Arthur Samuel, checker programs , 1952.
- John McCarthy (MIT AI Lab), **Lisp** language, time sharing, Advice Taker, 1958.
- Marvin Minsky (Stanford AI Lab), Microworlds, 1963.
- Neural networks.

# A dose of reality (1966–1973)

- Most early programs knew nothing of their subject matter; they succeeded by means of simple syntactic manipulations.
- The intractability of many of the problems that AI was attempting to solve.
- Some fundamental limitations on the basic structures being used to generate intelligent behavior.

# Knowledge-based systems (1969-1979)

- General vs. Domain-specific knowledge.
- Buchanan *et al.*, infer molecular structure, 1969.
- Feigenbaum, Buchanan, and Dr. Edward Shortliffe, diagnose blood infections, 1970s.
- Understanding natural language.
- Representation and reasoning languages.

# AI becomes an industry (1980–present)

- McDermott, R1, 1982.
- “Fifth Generation” project, Japan, 1981.
- Microelectronics and Computer Technology Corporation, United States, 1982.
- Overall, the AI industry boomed from a few million dollars in 1980 to billions of dollars in 1988, including hundreds of companies.

# Neural networks (1986–present)

- Reinvention of  the **back-propagation** (Bryson & Ho, 1969) learning algorithm in mid-1980s.
- Modern neural network
  - creating effective network architectures and algorithms and understanding their mathematical properties, or
  - modeling of the empirical properties of actual neurons and ensembles of neurons.

# AI becomes “scientific” (1987–present)

- Speech recognition, hidden Markov models.
- Machine translation, sequences of words.
- Neural networks, data mining.
- Uncertain reasoning and expert systems, Bayesian network.
- Robotics
- Computer vision
- Knowledge representation

# Intelligent agents (1995–present)

- Building complete agents (Newell, 1990; Laird *et al.*, 1987)
  - the isolated subfields of AI might need to be reorganized.
  - AI has been drawn into much closer contact with other fields.
- Human-level AI (Minsky *et al.*, 2004)
  - “machines that think, that learn and that create.”
- Artificial General Intelligence (Goertzel and Pennachin, 2007)
  - a universal algorithm for learning and acting in any environment

# Applications of AI

# State-of-the-art applications

- Speech recognition
- Autonomous planning and scheduling
- Financial forecasting
- Game playing, game design
- Spam fighting
- Logistics planning
- Robotics (household, surgery, navigation)
- Machine translation
- Information extraction
- VLSI layout
- Automatic assembly
- Sentiment analysis
- Fraud detection
- Recommendation systems
- Web search engines
- Autonomous car
- Energy optimization
- Question answering systems
- Social network analysis
- Medical diagnosis, imaging
- Route finding
- Traveling sales person
- Protein design
- Document summarization
- Transportation/scheduling
- Computer animation

**Many more!**

# Speech recognition

- Virtual assistants: Siri (Apple), Echo (Amazon), Google Now, Cortana (Microsoft).
- Leverage **deep neural networks** to handle speech recognition and natural language understanding.
- Other technologies:
  - Hidden Markov models
  - Dynamic time warping

# Handwriting recognition

- State-of-the-art key technologies :
  - recurrent neural networks and deep feedforward neural networks
  - bi-directional and multi-dimensional long short-term memory

# Machine translation

- Historical motivation: translate Russian to English.
- First systems using **mechanical translation** (one-to-one correspondence) failed!

# Machine translation

- MT has gone through ups and downs.
- Today, **Statistical Machine Translation** leverages the vast amounts of available **translated corpuses**.
- While there is room for improvement, machine translation has made significant progress.

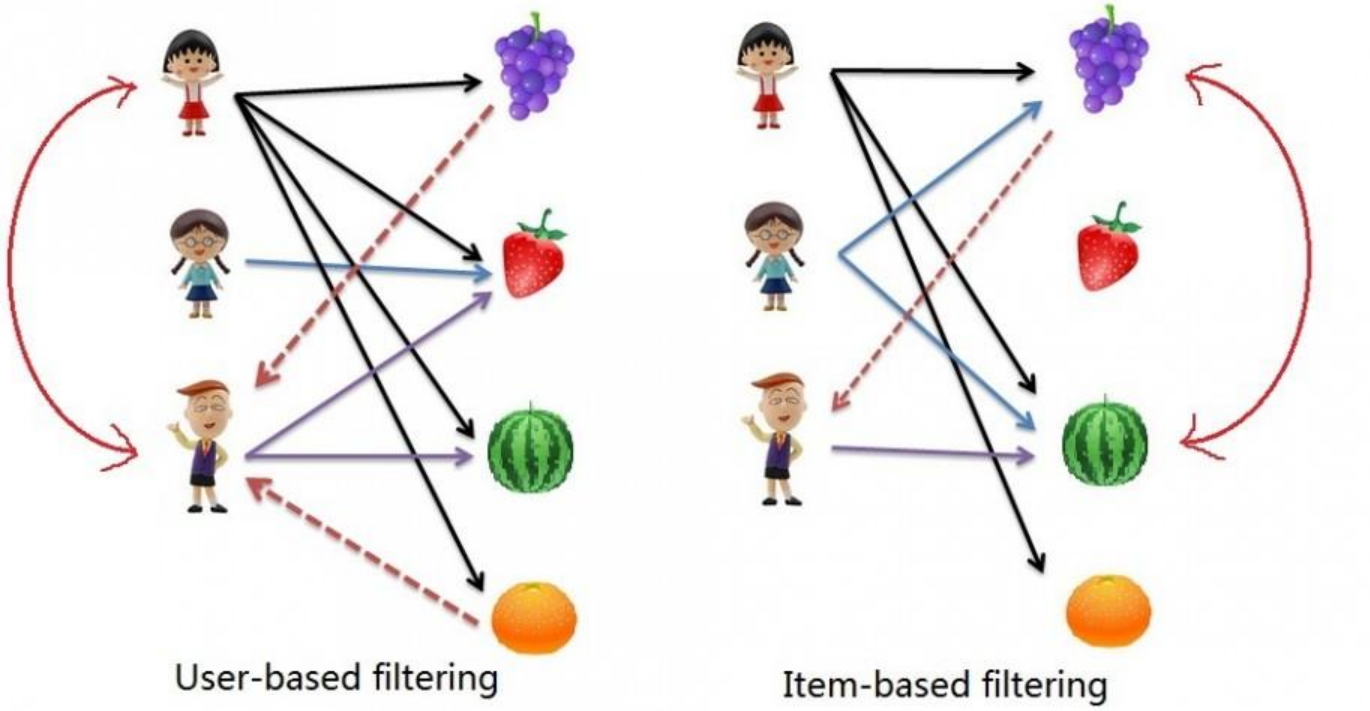

**Google Translate: 100+ languages**

# Robotics

- Awesome robots today! NAO, ASIMO, and more!
- Robotics is an interdisciplinary branch of engineering and science
  - Power source
  - Actuation
  - Sensing
  - Manipulation
  - Locomotion


# Recommendation systems

- Key technology: collaborative filtering



# Search engines

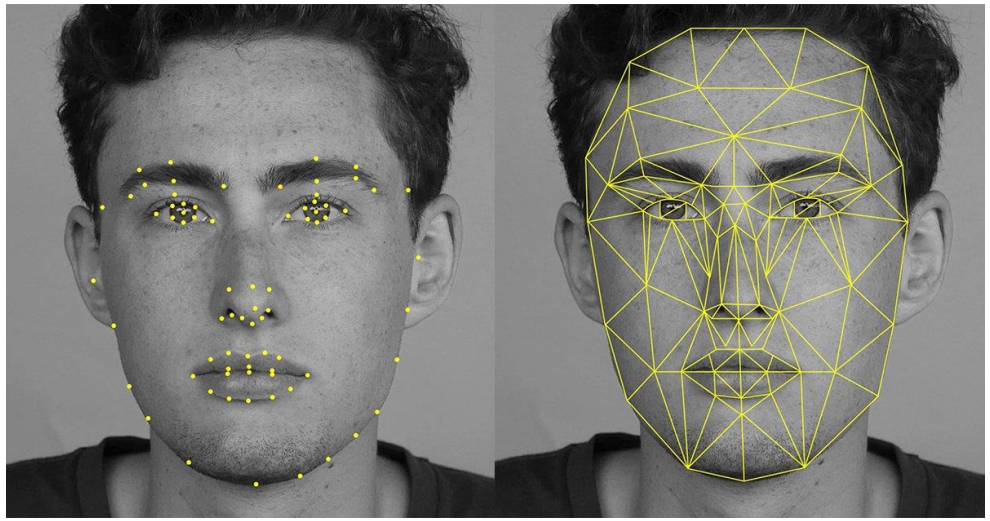
- Key technologies (near real time):
  1. Web crawling
  2. Indexing
  3. Searching

# Spam filtering

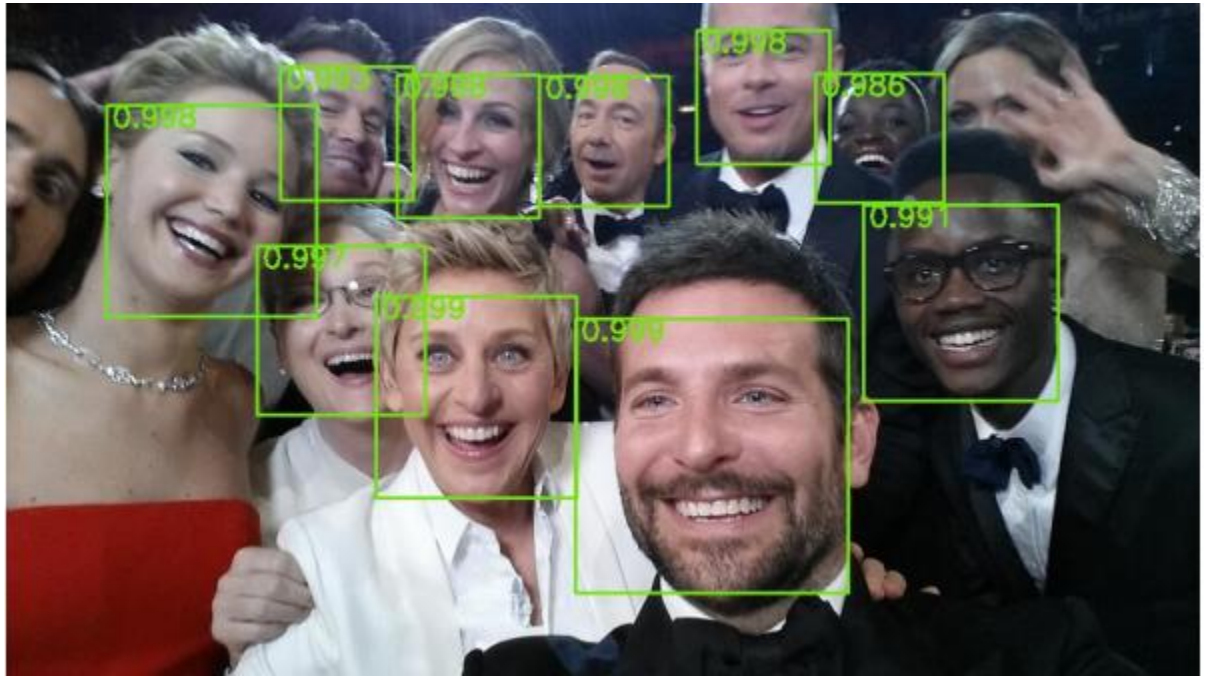
- The baseline technology: Naive Bayes classifiers

# Face recognition

- Popular and relevant technologies:
  - principal component analysis using eigenfaces
  - linear discriminant analysis
  - elastic bunch graph matching using the Fisherface algorithm
  - the hidden Markov model
  - the multilinear subspace learning using tensor representation
  - and the neuronal motivated dynamic link matching.



# Face detection



# Cancer detection

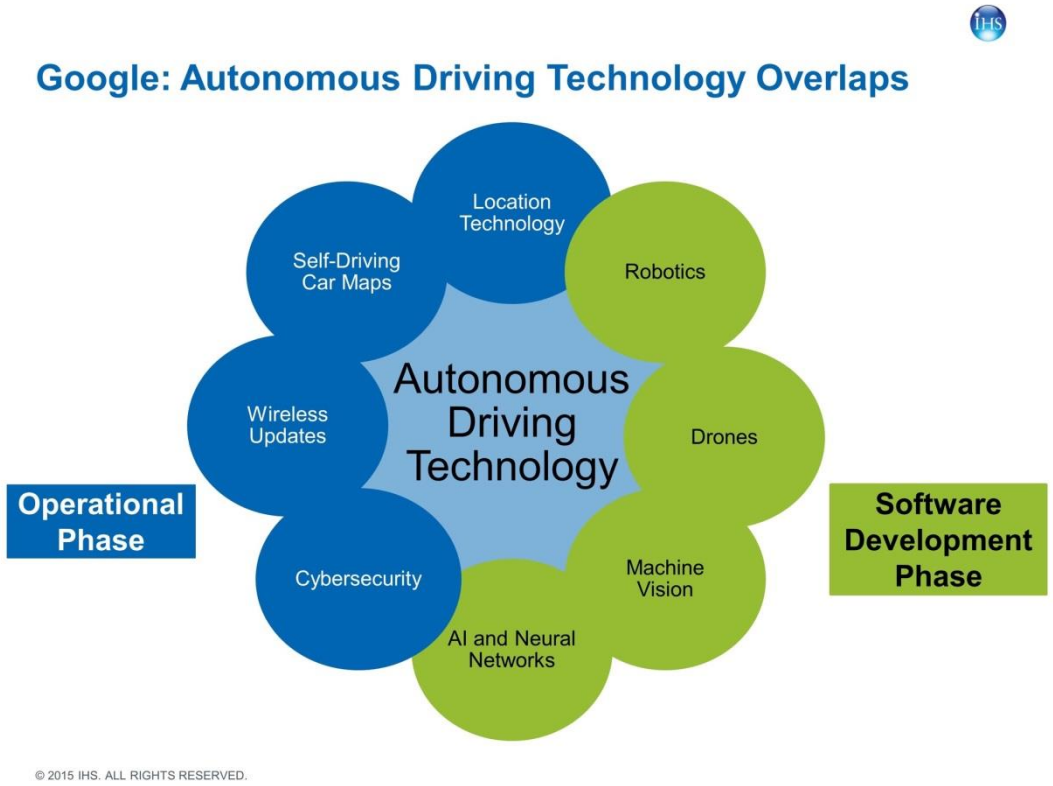
- Skin Cancer Detection & Tracking using **Deep Learning**

# Logistics planning

- Key technologies
  - heuristic search
  - meta-heuristic search

# Autonomous driving

- DARPA Grand Challenge
  - 2005: 132 miles
  - 2007: Urban challenge
  - 2009: Google self-driving car

# Autonomous planning and scheduling

- NASA's Remote Agent program (Jonsson *et al.*, 2000).
- NASA's Mars Exploration Rovers (Al-Chang *et al.*, 2004)
- European Space Agency's Mars Express (Cesta *et al.*, 2007)
- Key technologies
  - dynamic programming
  - reinforcement learning
  - combinatorial optimization

# Chess (1997)

- Garry Kasparov vs. IBM Deep Blue


**Powerful search algorithms!**

# Jeopardy! (2011)

- Ken Jennings vs. IBM Watson


**Natural Language Understanding and information extraction!**

# Go (2016)

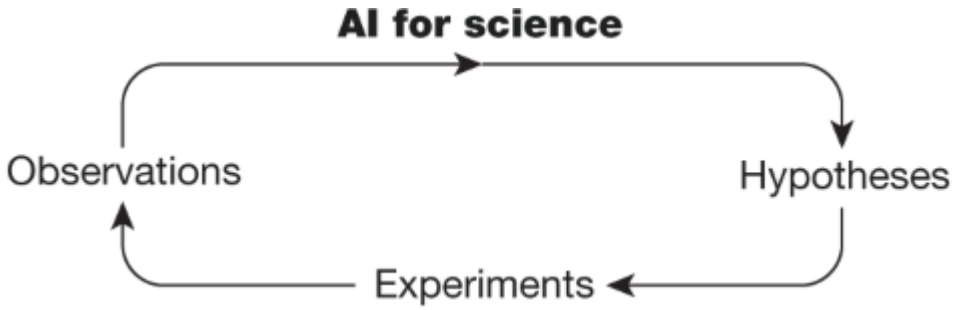
- Lee Sedol versus Google AlphaGo


**Deep Learning, reinforcement learning, and search algorithms!**

# AIGC


资料来源：36氪研究院根据公开资料整理

# AI for Science




Weather forecasting

Battery design optimization

Magnetic control of nuclear fusion reactors

Planning chemical synthesis pathway

Neural solvers of differential equations

Hydropower station location planning

Synthetic electronic health record generation

Rare event selection in particle collisions

Language modelling for biomedical sequences

High-throughput virtual screening

Navigation in the hypothesis space

Super-resolution 3D live-cell imaging

Symbolic regression

# Summary

- AI is a broad field with high impact on humanity and society.
- What can AI do for us is already amazing!
- AI systems do not have to model human/nature but can act like or be inspired by human/nature.
- How human think is beyond the scope of this course.
- Rational (do the right thing) agents are central to our approach of AI.
- Note that rationality is not always possible in complicated environment but we will still aim to build rational agents.

# Reading materials for this lecture

- Book:
  - Stuart J. Russell and Peter Norvig. Artificial Intelligence: A Modern Approach (3rd edition)
    - Chapter I.1: Introduction (pages 1-29)
- Articles
  - A. M. Turing (1950). *Computing Machinery and Intelligence*. Mind 49: 433-460.
    - Read on webpage: http://cogprints.org/499/1/turing.html
  - Artificial intelligence (Wikipedia)
    - https://en.wikipedia.org/wiki/Artificial_intelligence
- Ted talks:
  - *"How AI can enhance our memory, work and social lives"* by Tom Gruber (co-creator of Siri): https://www.ted.com/talks/tom_gruber_how_ai_can_enhance_our_memory_work_and_social_lives
  - *"Don't fear superintelligent AI"* by Grady Booch (IBM): https://www.ted.com/talks/grady_booch_don_t_fear_superintelligence