Artificial Intelligence

Introduction

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Columbia University - COMS 4701

Instruction Team

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Course logistics

https://courseworks2.columbia.edu/courses/95748

- **Prerequisites**: Students are required to have the following prerequisites: Basics of linear algebra (vectors, matrices, derivatives), calculus, probability theory, and proficiency Python programming.
- **Assignments**:
  - **Homework**: about 6 (conceptual, programming) assignments.
    * Environments, agents and intro to python
    * Search algorithms
    * Adversarial search
    * Machine Learning
    * Constraint Satisfaction Problems (CSPs)
    * HMMS

Academic honesty

Academic integrity will be strictly enforced.

- **Columbia University Guide to Academic Integrity:**
  `https://www.college.columbia.edu/academics/academicintegrity`

- **Department of Computer Science Academic Honesty Policy:**
  `http://www.cs.columbia.edu/education/honesty`

Course materials

- Slides will be posted before every lecture.

- **Suggested readings**:

  - We recommend this book, which is the main reference in the field:
    Artificial Intelligence, A Modern Approach. Stuart Russell and Peter Norvig. Third Edition. Pearson Education.

    http://aima.cs.berkeley.edu/

  - Check out the list of readings, useful links we suggest for this course.

Course logistics

Waitlist students: The list is managed by the CS department.

Piazza: We will use Piazza for discussions.

No website
Gradescope + Canvas : For all HW submissions

Lectures:

- Tuesdays and Thursdays 10:10-11:25

Tell us about You. Why are your taking an AI class?

AI in the movies

Definition of AI

"Intelligence: The ability to learn and solve problems"

Webster's Dictionary.

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

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"The science and engineering of making intelligent machines"

McCarthy.

Definition of AI

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"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."

Russel and Norvig AI book.

Why AI?

AI is a revolution!

"Just as the Industrial Revolution freed up a lot of humanity from physical drudgery, I think AI has the potential to free up humanity from a lot of the mental drudgery."

Andrew Ng.

What is AI?

Four schools of thoughts (Russel & Norvig)

Thinking humanly	**Thinking rationally**
"The exciting new effort to make computers think... *machines with minds*, in the full and literal sense." (Haugeland, 1985)	"The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985
Acting humanly	**Acting rationally**
"The study of how to make computers do things 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)

What is AI?

Thinking humanly: cognitive approach

Requires to determine how humans think!

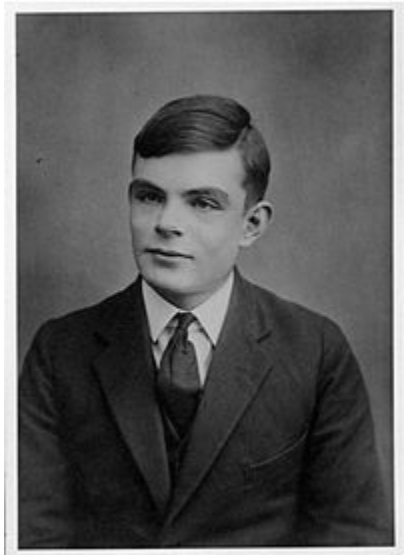
1960's "cognitive revolution".

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.

Turing Test



Alan Turing (1912-1954)

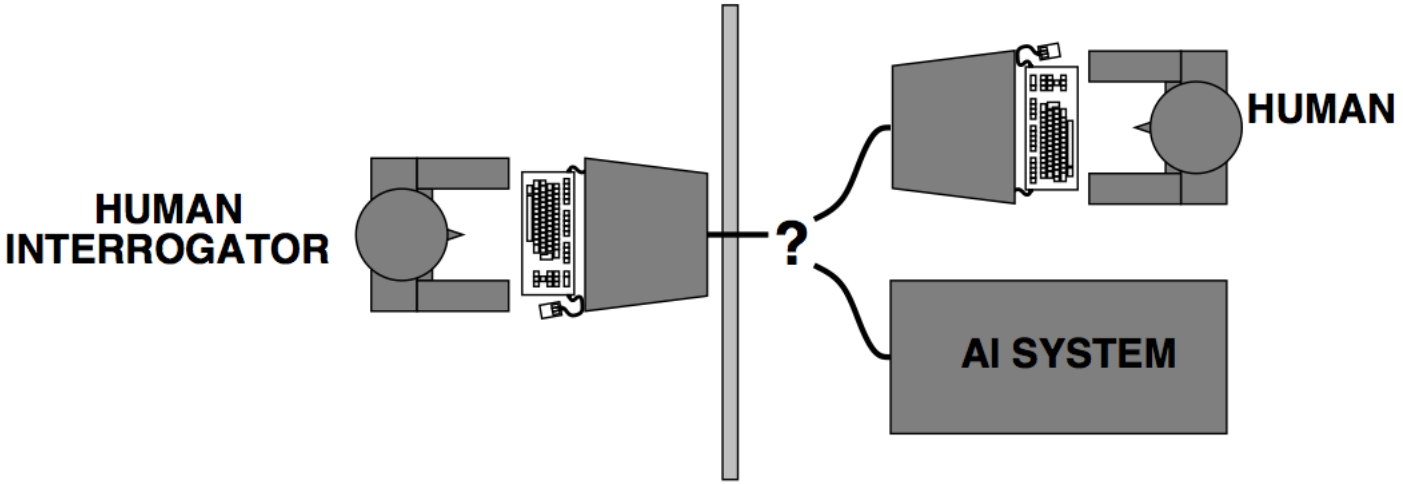
- Famous British mathematician.
- Code breaker during World War II.
- Proposed an operational test for intelligent behavior: The Imitation Game.
- In "Computing machinery and intelligence" (1950), he laid down AI major components:
  (language, reasoning, knowledge, learning, understanding).

http://www.turingarchive.org/browse.php/B/9

Turing Test

Acting humanly:

- **Turing test (Alan Turing 1950)**: A computer passes the test of intelligence, if it can fool a human interrogator.



Credit: From Russel and Norvig slides.

What is AI?

Acting humanly:

What is AI?

Thinking rationally: Laws of thoughts.

- 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.

What is AI?

Acting rationally:

- 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?

Four schools of thoughts (Russel & Norvig)

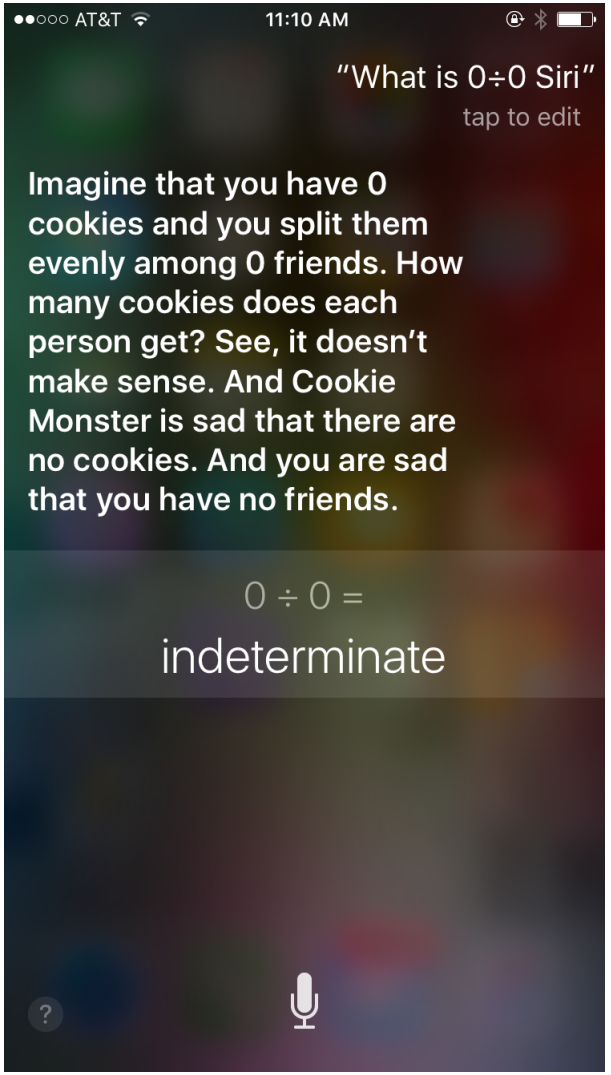
Thinking humanly	**Thinking rationally**
"The exciting new effort to make computers think... *machines with minds*, in the full and literal sense." (Haugeland, 1985)	"The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985
Acting humanly	**Acting rationally: Our approach**
"The study of how to make computers do things 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)

Applications of AI

Applications of AI

Speech recognition

- Virtual assistants: Siri (Apple), Echo (Amazon), Google Now, Cortana (Microsoft).
- "They" helps get things done: send an email, make an appointment, find a restaurant, tell you the weather and more.
- Leverage deep neural networks to handle **speech recognition** and **natural language understanding**.



Applications of AI

Handwriting recognition (check, zipcode)

Applications of AI

Machine translation

- Historical motivation: translate Russian to English.
- First systems using **mechanical translation** (one-to-one correspondence) failed!
- "Out of sight, out of mind" $\Rightarrow$ "Invisible, imbecile".

Applications of AI

Machine translation

- Historical motivation: translate Russian to English.
- First systems using **mechanical translation** (one-to-one correspondence) failed!
- "Out of sight, out of mind" $\Rightarrow$ "Invisible, imbecile".

Oops!

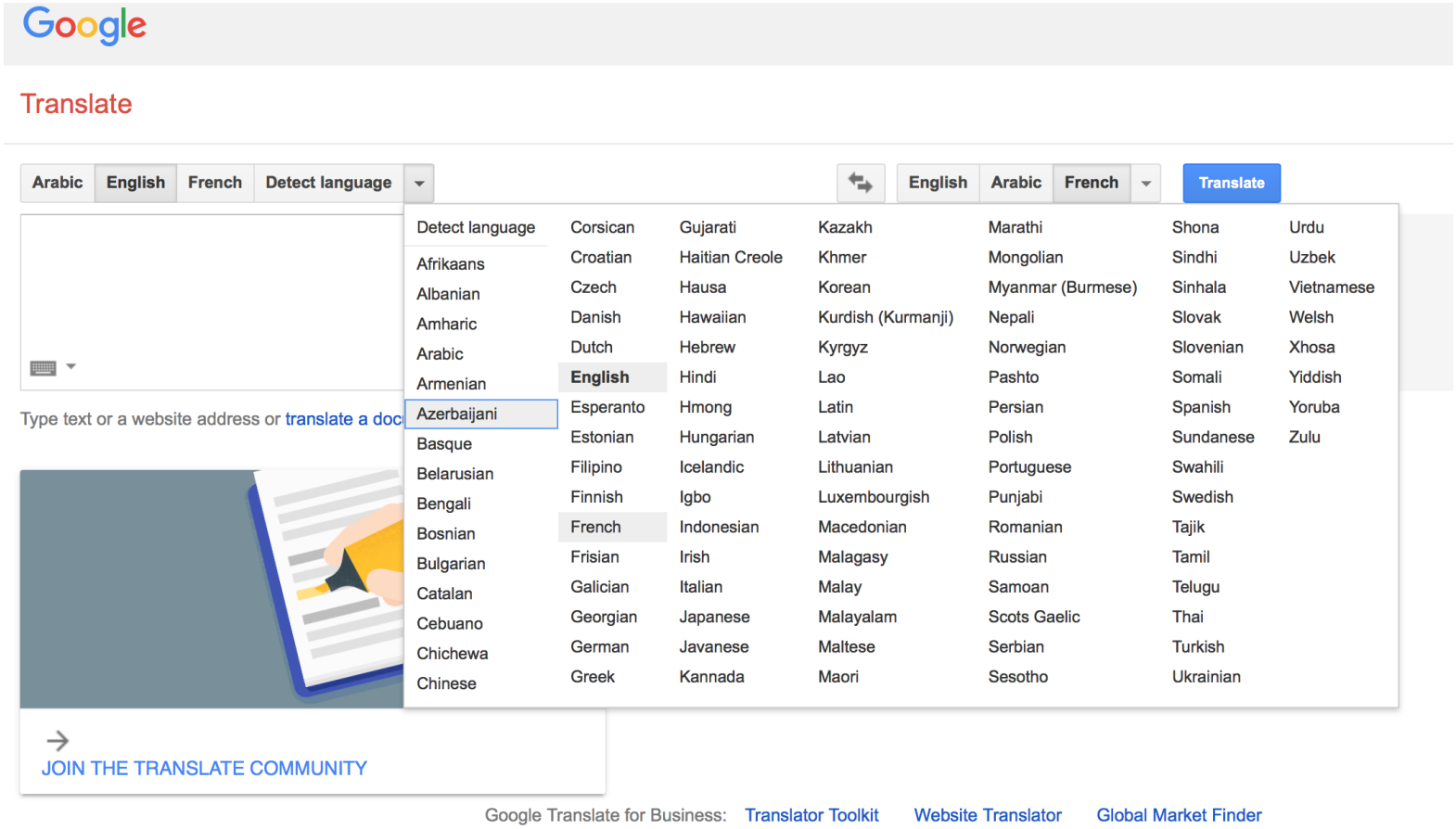
Applications of AI

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.

Applications of AI

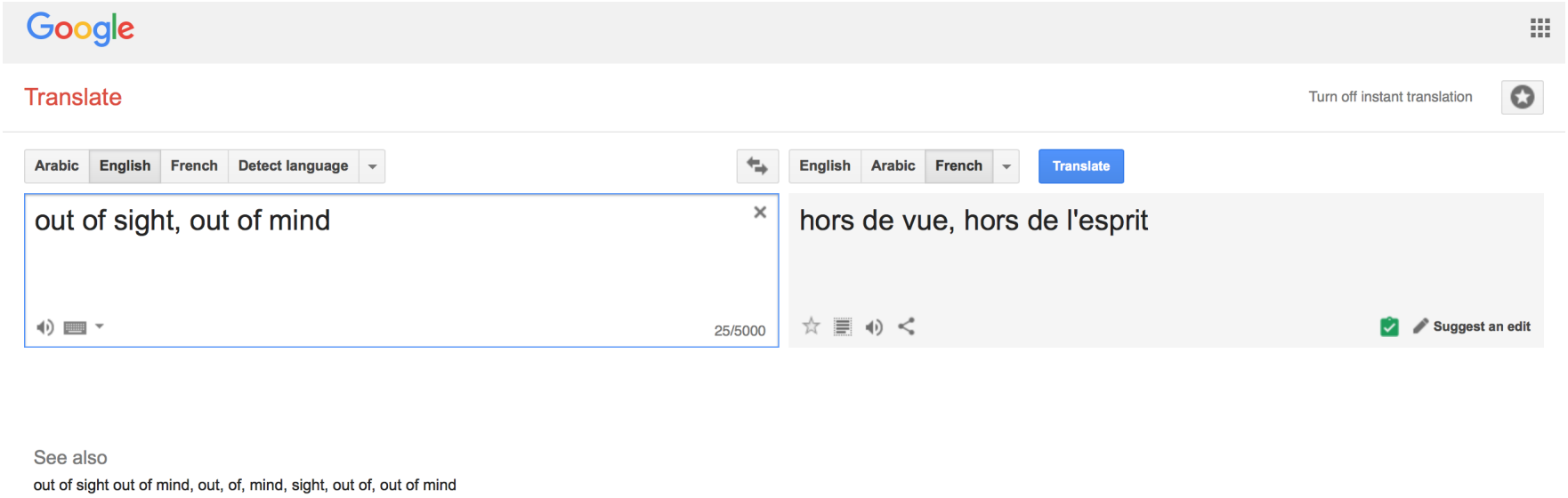
Machine translation



100+ languages

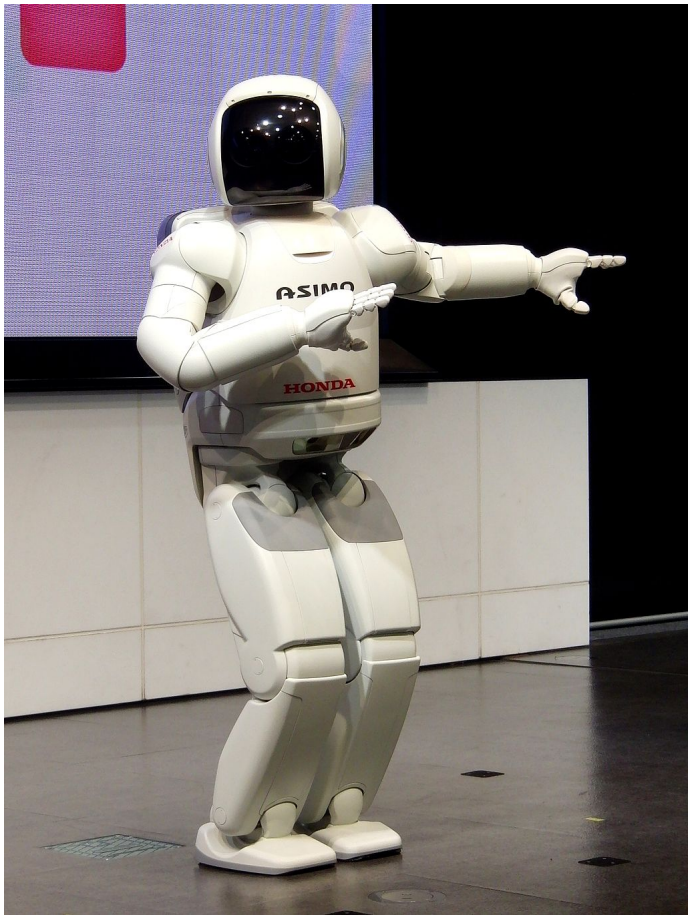
Applications of AI

Machine translation



Applications of AI

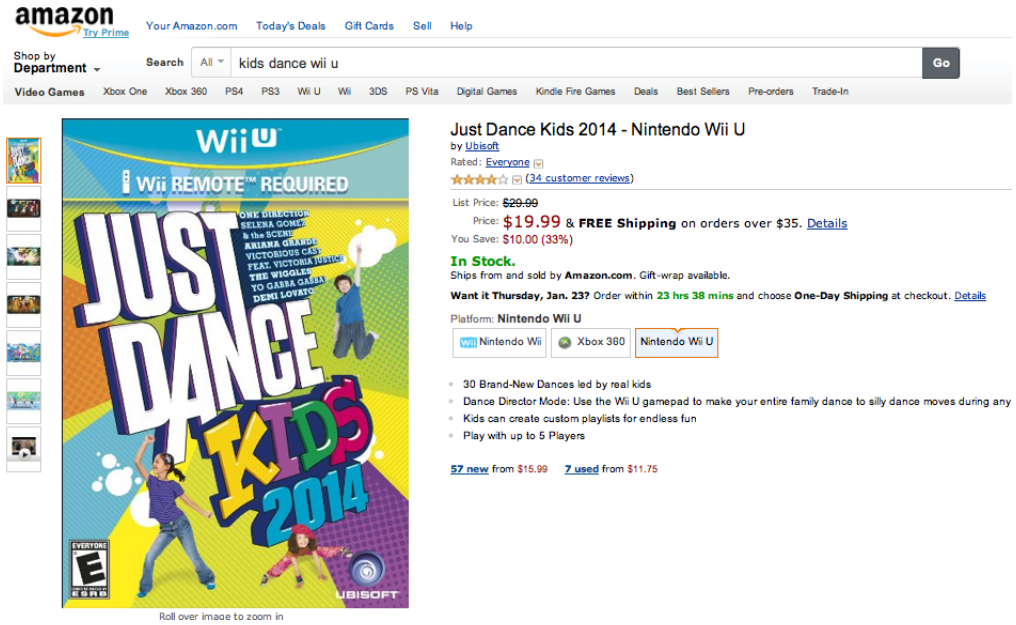
Robotics: Awesome robots today! NAO, ASIMO, and more!



Credit: By Momotarou2012, via Wikimedia Commons.

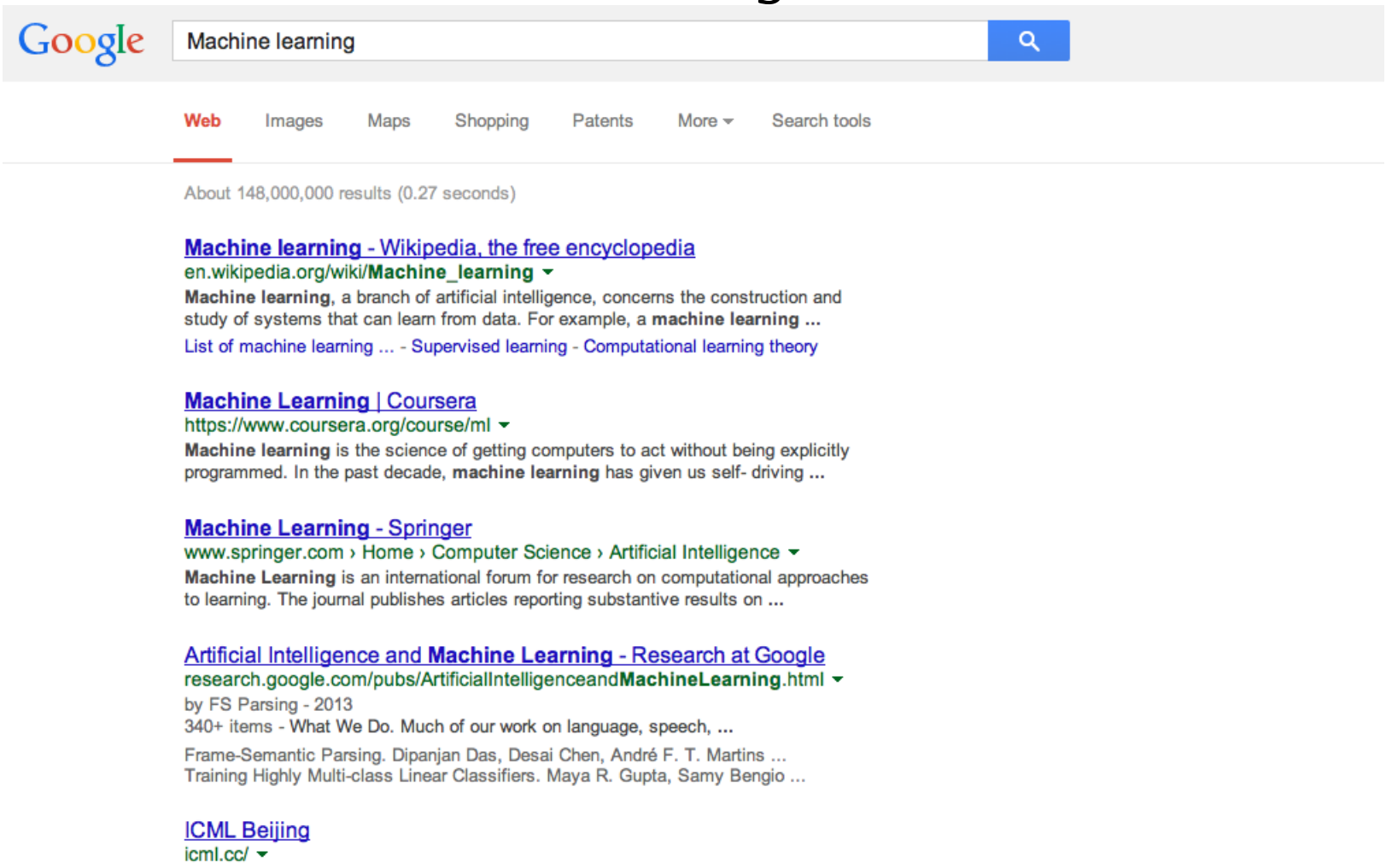
Applications of AI

Recommendation systems (collaborative filtering)



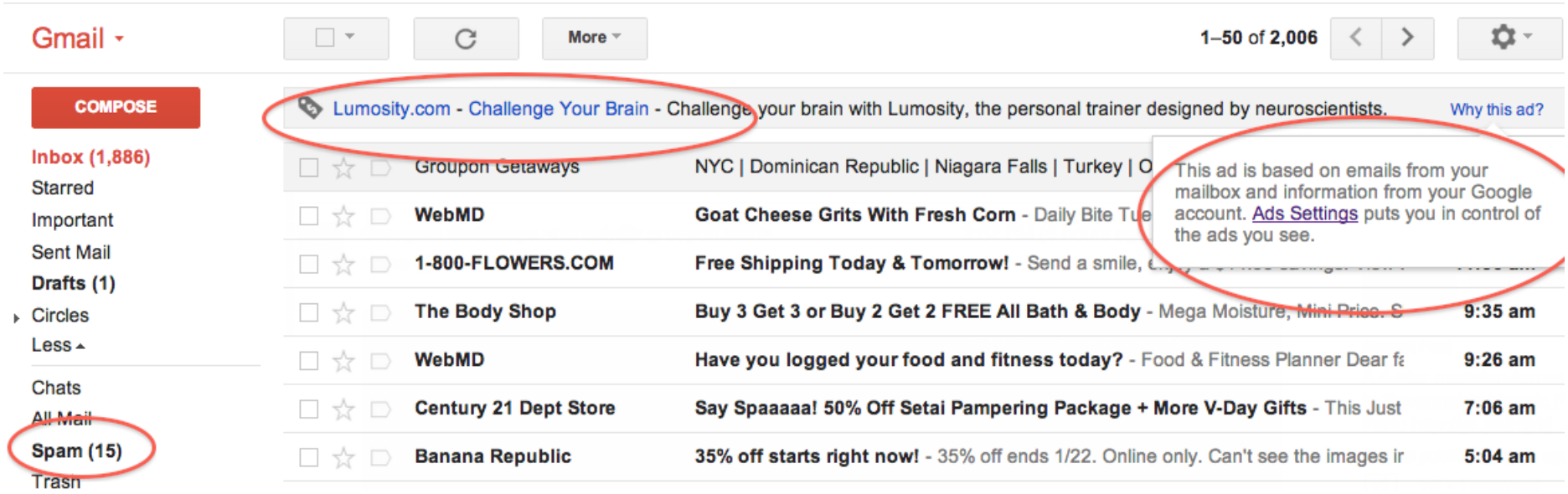
Applications of AI

Search engines



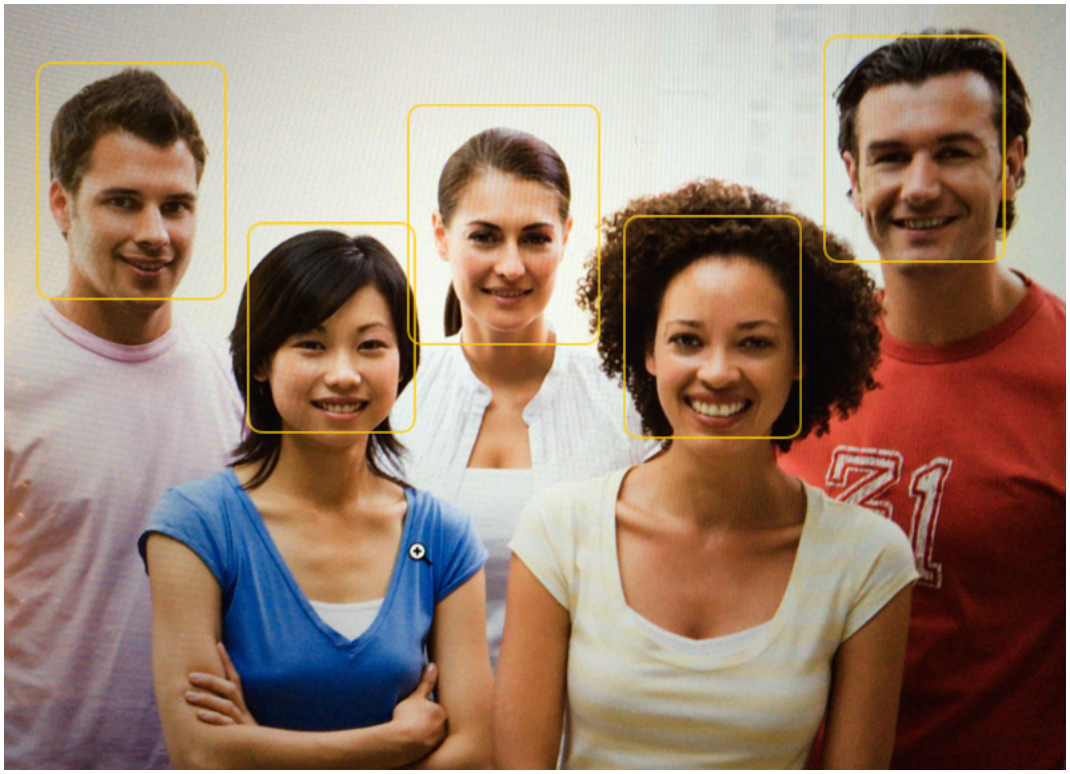
Applications of AI

Email



Applications of AI

Face detection



Viola-Jones method.

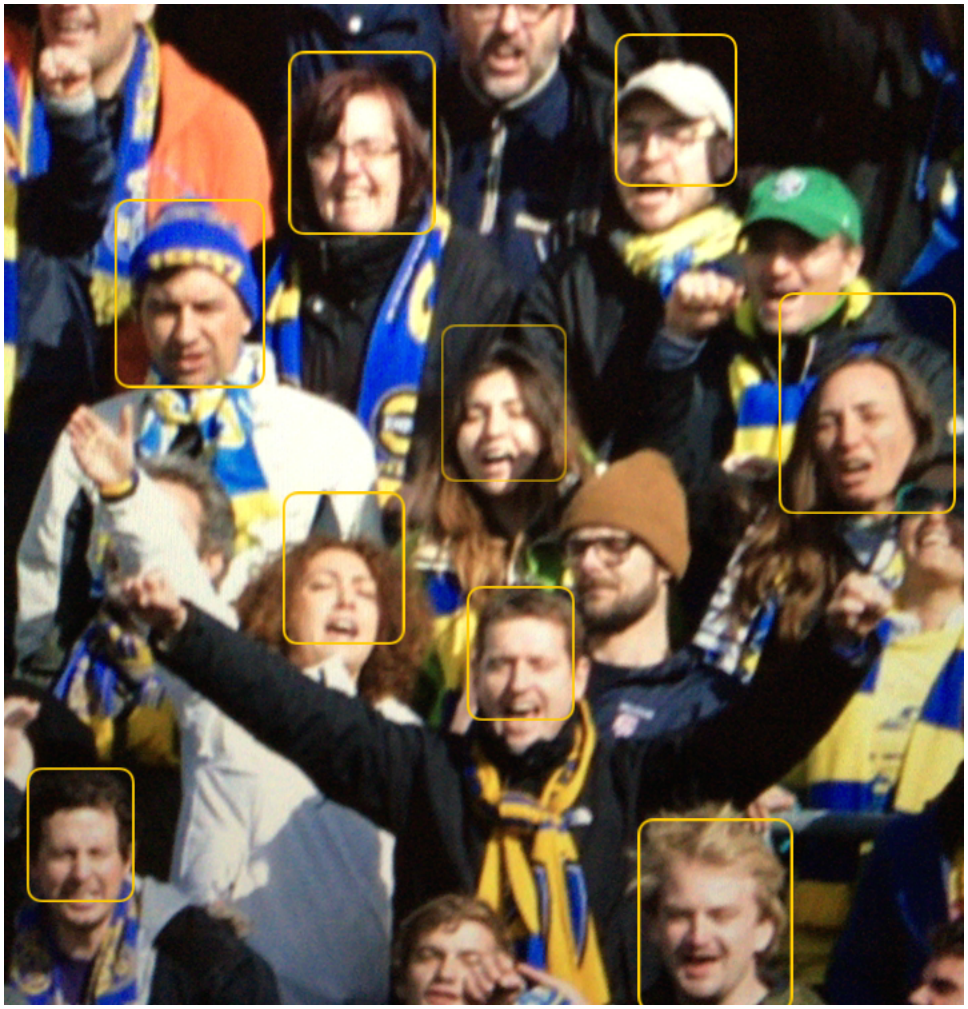
Applications of AI

Face detection

Viola-Jones method.

Applications of AI

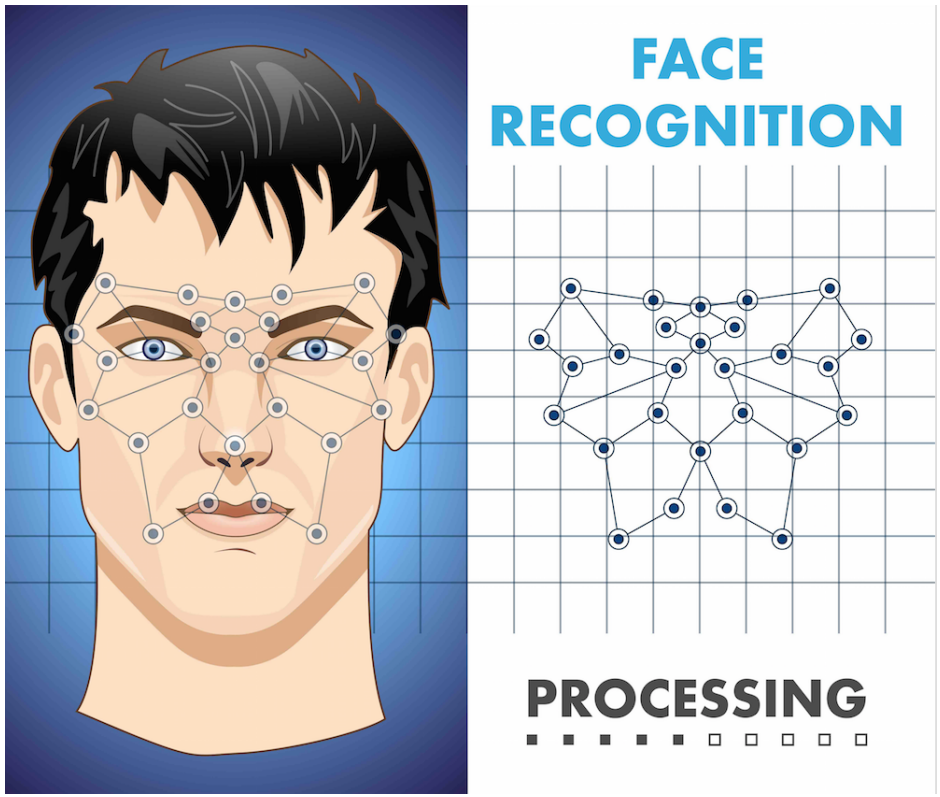
Face detection



Viola-Jones method.

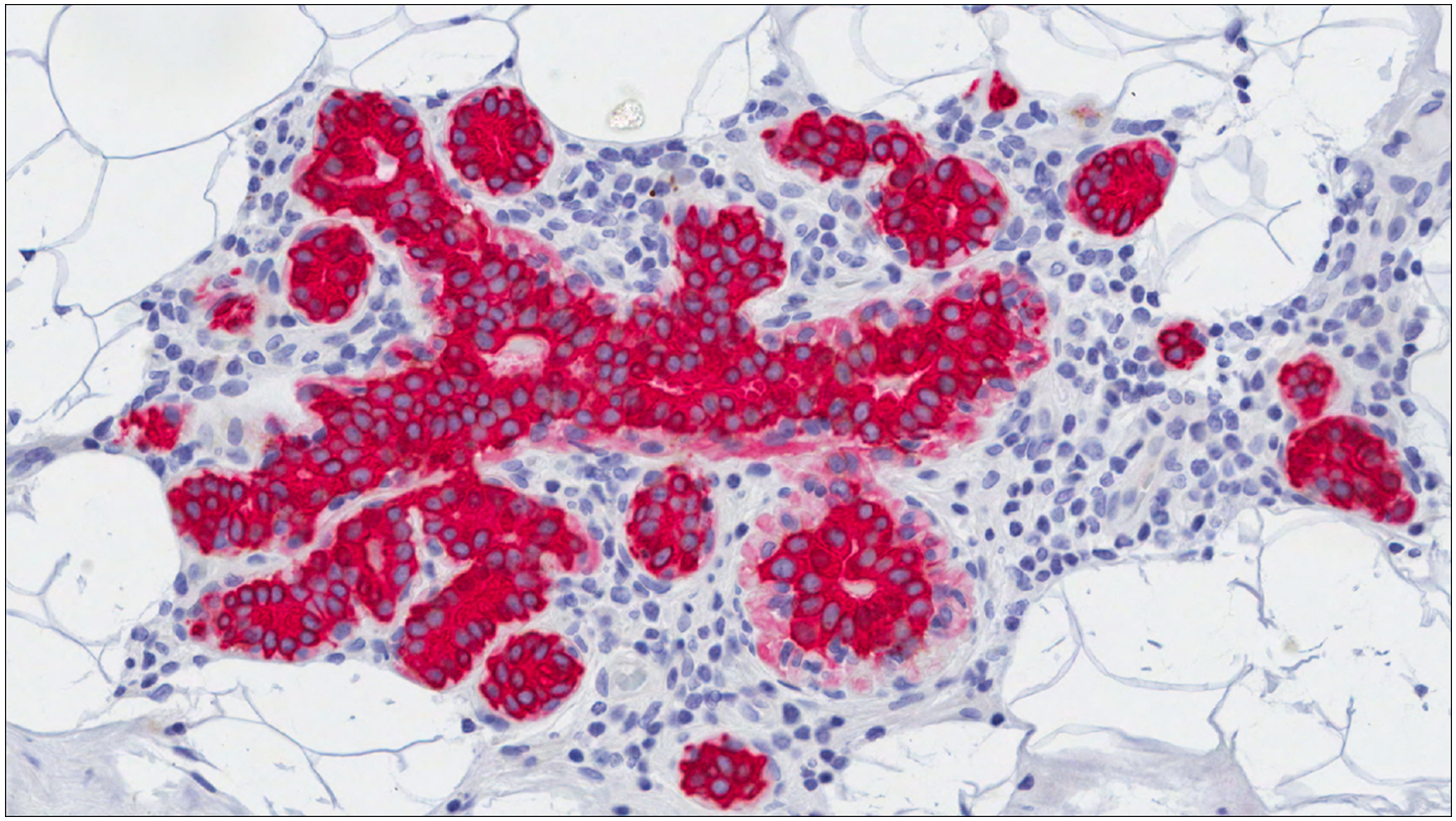
Applications of AI

Face recognition



Applications of AI

Detection of breast cancer in mammography images



Applications of AI

Chess (1997): Kasparov vs. IBM Deep Blue

(Left) Copyright 2007, S.M.S.I., Inc. - Owen Williams, The Kasparov Agency, via Wikimedia Commons (Right) By James the photographer, via Wikimedia Commons

Powerful search algorithms!

Applications of AI

Jeopardy! (2011): Humans vs. IBM Watson

By Rosemaryetoufee (Own work), via Wikimedia Commons

Natural Language Understanding and information extraction!

Applications of AI

Go (2016): Lee Sedol versus Google AlphaGo

AlphaGo

(Left) By LG Electronics, via Wikimedia Commons (Right) By Google DeepMind, via Wikimedia Commons

Deep Learning, reinforcement learning, and search algorithms!

Applications of AI

Autonomous driving

By User Spaceape on en.wikipedia, via Wikimedia Commons

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

Applications of AI

Amazon Go

https://www.youtube.com/watch?v=NrmMk1Myrxc

State-of-the-art applications

- Speech recognition
- Autonomous planning and scheduling
- Financial forecasting
- Game playing, video games
- 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 cars
- Energy optimization
- Question answering systems
- Social network analysis
- Medical diagnosis, imaging
- Route finding
- Traveling salesperson
- Protein design
- Document summarization
- Transportation/scheduling
- Computer animation

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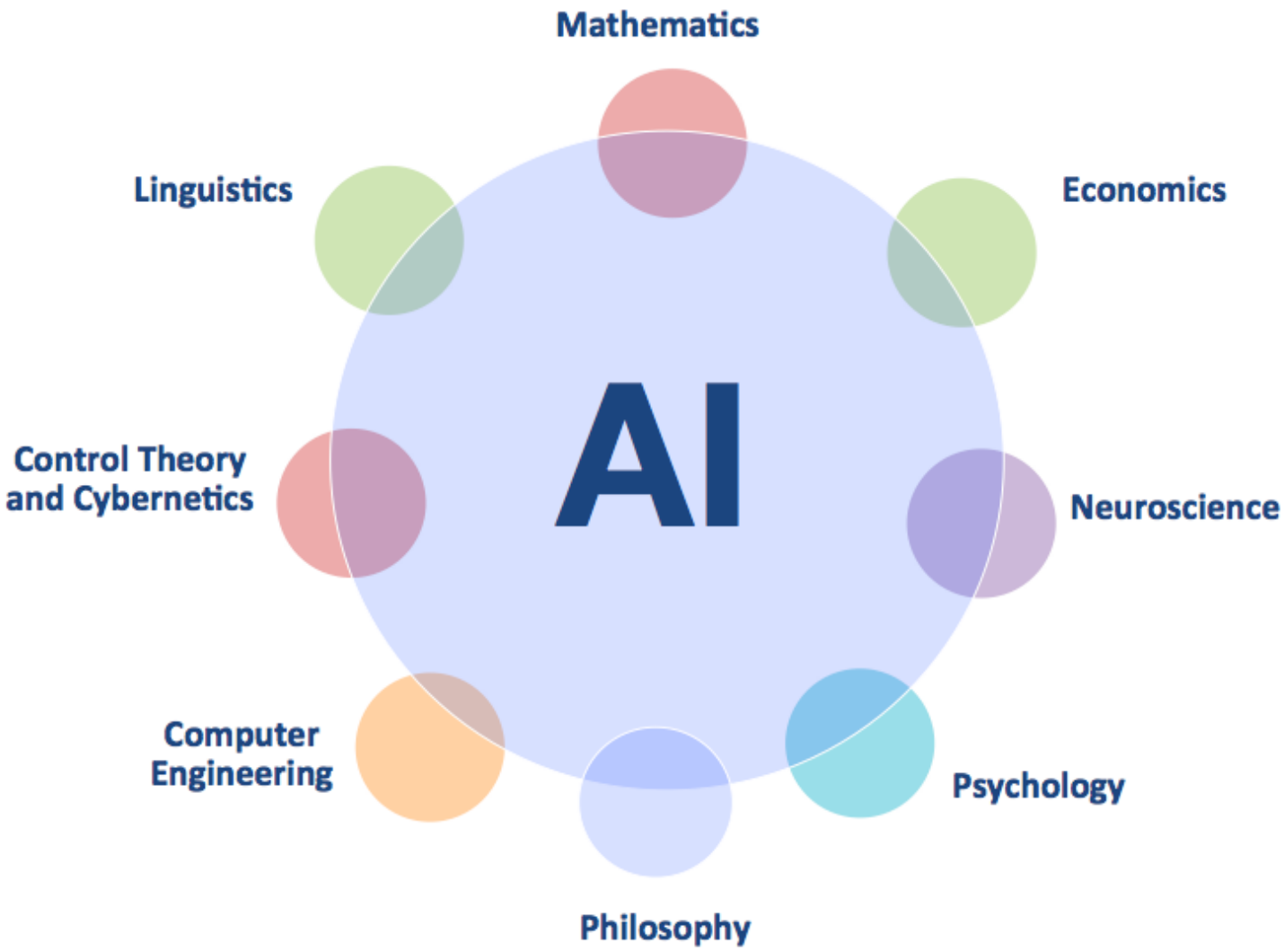
- Computer animation

Many more!

Foundation of AI



Foundation of AI

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

- **Mathematics**
  - Logic: Formal representation and proof.
  - Computation, algorithms.
  - Probability.

- **Economics**
  - Formal theory of rational decisions.
  - Combined decision theory and probability theory for decision making under uncertainty.
  - Game theory.
  - Markov decision processes.

Foundation of AI

- **Neuroscience**
  - Study of brain functioning.
  - How brains and computers are (dis)similar.
- **Psychology**
  - How do we 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**
  - Cares about how to build powerful machines to make AI possible.
  - E.g., Self-driving cars are possible today thanks to advances in computer engineering.

Foundation of AI

- **Control theory and cybernetics**
  - Design simple optimal agents receiving feedback from the environment.
  - Modern control theory design systems that maximize an objective function over time.

- **Linguistics**
  - How are language and thinking related.
  - Modern linguistics + AI = Computational linguistics (Natural language processing).

AI founders

- Aristotle
- Alan Turing
- John Mc Carthy
- Warren McCulloh
- Walter Pitts
- Claude Shannon
- Marvin Minsky
- Dean Edmonds
- Herbert Simon
- Allen Newell
- David Waltz
- Tom Mitchell
- Stuart J. Russell
- Peter Norvig
- etc.

AI Resources

- Major journals/conferences: JAIR, TPAMI, JMLR, IJCAI, AAAI, IAAI, CVPR, ECAI, ICML, NIPS, etc.

- Video lectures:

  http://videolectures.net/Top/Computer_Science/Artificial_Intelligence/

History of AI

- **1940-1950**: Gestation of AI
  - McCulloch & Pitts: Boolean circuit to model of brain
  - Turing's Computing Machinery and Intelligence
    http://www.turingarchive.org/browse.php/B/9

- **1950-1970**: Early enthusiasm, great expectations
  - Early AI programs, Samuel's checkers program
  - Birth of AI @ Dartmouth meeting 1956.
  - Check out the MIT video "The thinking Machine" on youtube
    https://www.youtube.com/watch?v=aygSMgK3BEM

- **1970-1990**: Knowledge-based AI
  - Expert systems, AI becomes an industry
  - AI winter

History of AI

- **1990-present**: Scientific approaches
  - Neural Networks: le retour
  - The emergence of intelligent agents
  - AI becomes "scientific", use of probability to model uncertainty
  - AI Spring!
  - The availability of very large datasets.
    * Data will drive future discoveries and alleviate the complexity in AI.

What you will learn

- **Introduction** to artificial intelligence, **history** of Artificial Intelligence.
- **Building intelligent agents** (search, games, logic, constraint satisfaction problems).
- **Machine Learning** algorithms.
- **Applications** of AI (Natural Language Processing)
- Solving real AI problems through **programming Python**.

Course roadmap

1. Rational intelligent agents
2. Search agents (uninformed search, informed search)
3. Adversarial search/games
4. Machine Learning (ML)
5. Constraint satisfaction problems (CSPs)
6. Logic (propositional logic, first order logic)
7. Markov Decision Processes (MDPs) and Reinforcement Learning (RL)
8. Application to Natural language Processing (NLP)

Rational intelligent agents

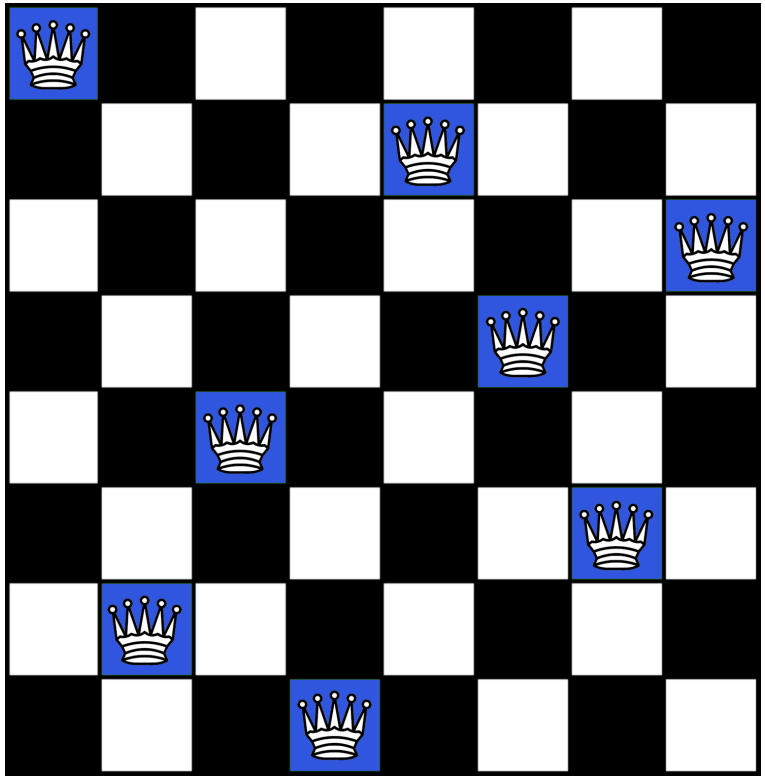
- This course is about designing **intelligent agents**.
- An agent perceives the environment and act upon that environment to achieve some task.
- An agent is function from percepts to actions.
- We care specifically about **rational agents**.
- Rationality is relative to how to act to maximize a **performance measure**.
- AI aims to design the best agents (programs) that achieve the best performance given the computational limitations.

$$\textbf{Agent} = \textbf{Architecture} + \textbf{Program}$$

Search agents

- Agents that work towards a **goal**.
- Agents consider the impact of **actions** on future **states**.
- Agent's job is to identify the action or series of actions that lead to the goal.
- Paths come with different costs and depths.
- Two kinds of search:
  - **Uninformed Search** (use no domain knowledge): BFS, DFS, UCS, etc.
  - **Informed Search** (use heuristic to reach the goal faster): Greedy search, A*, etc.

Search agents

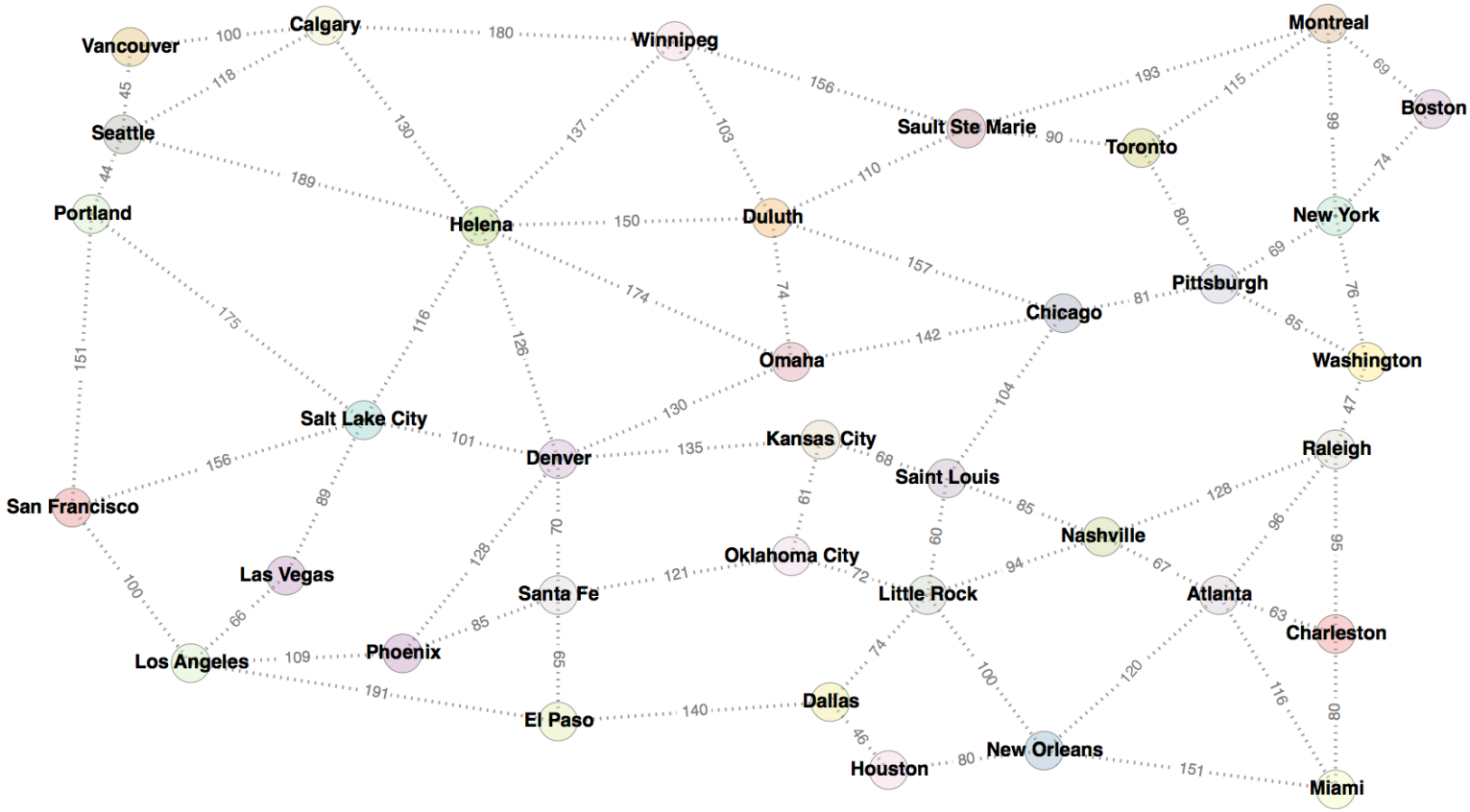


The 8-queen problem: on a chess board, place 8 queens so that no queen is attacking any other horizontally, vertically or diagonally.

Search agents

Start: Las Vegas

Goal: Calgary



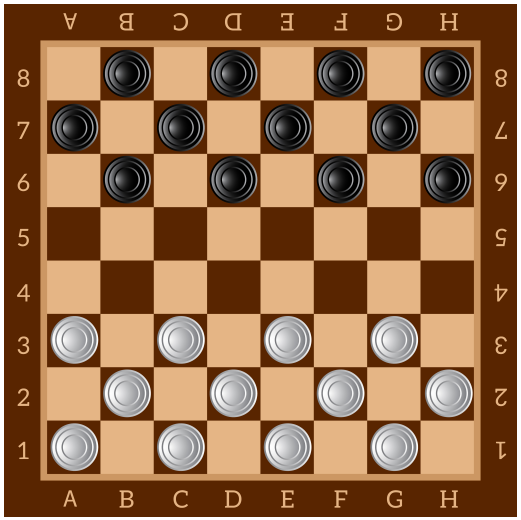
Explore + Execute

Adversarial Search: games

Solved games!

Checkers:

- Chinook ended 40-year-reign of human world champion Marion Tinsley in 1994.
- Used an endgame database defining perfect play for all positions involving 8 or fewer pieces on the board, a total of 443,748,401,247 positions.



Adversarial search: games

- Adversarial search problems $\equiv$ game
- Adversarial $\equiv$ There is an **opponent** we can't control!
- Game vs. search: optimal solution is not a sequence of actions but a **strategy** (policy). If opponent does a, agent does b, else if opponent does c, agent does d, etc.
- Tedious and fragile if hard-coded (i.e., implemented with rules).
- **Concepts/methods**: Minimax algorithm, $\alpha - \beta$ pruning, stochastic games.

Constraint satisfaction

- A search problem too!
- We don't care about the path but about the **goal itself**.
- All paths are of same depth.
- Problem is formulated using variables, domains and constraints.
- Solving the CSP: **finding the assignment(s)** that **satisfy all constraints**.
- **Concepts/methods**: problem formalization, backtracking search, arc consistency, etc.

Constraint satisfaction

8		9	5		1	7	3	6
2		7		6	3			
1	6							
				9		4		7
	9		3		7		2	
7		6		8				
							6	3
			9	3		5		2
5	3	2	6		4	8		9

Variables: $X_{l,c}$ for $1 \leq l \leq 9$ and $1 \leq c \leq 9$.

Constraints: All 3x3 grid, row, column, must contain digits 1..9 and all of them!

Solution: Find the assignments to the variables that satisfy the constraints.

Constraint satisfaction

8	4	9	5	2	1	7	3	6
2	5	7	8	6	3	9	1	4
1	6	3	7	4	9	2	5	8
3	2	5	1	9	6	4	8	7
4	9	8	3	5	7	6	2	1
7	1	6	4	8	2	3	9	5
9	8	4	2	7	5	1	6	3
6	7	1	9	3	8	5	4	2
5	3	2	6	1	4	8	7	9

Variables: $X_{l,c}$ for $1 \leq l \leq 9$ and $1 \leq c \leq 9$.

Constraints: All 3x3 grid, row, column, must contain digits 1..9 and all of them!

Solution: Find the assignments to the variables that satisfy the constraints.

Logical Agents

- Logic can be used by an agent to model the world.
- Sentences in PL and FOL have a fixed **syntax**.
- With symbols and connectives we can form logical sentences: Example: $hot \wedge sunny \Rightarrow beach \vee pool$
- Syntax and **Semantic** represent two important and distinct aspects in logic.
- **Inference:** Given a Knowledge Base (KB) (set of sentences in logic), given a query α, output whether KB entails α, noted: $KB \models \alpha$
- **Concepts/methods**: Modus Ponens, sound and complete inference, horn clauses, etc.

Machine learning

"How do we create computer programs that improve with experience?"

Tom Mitchell

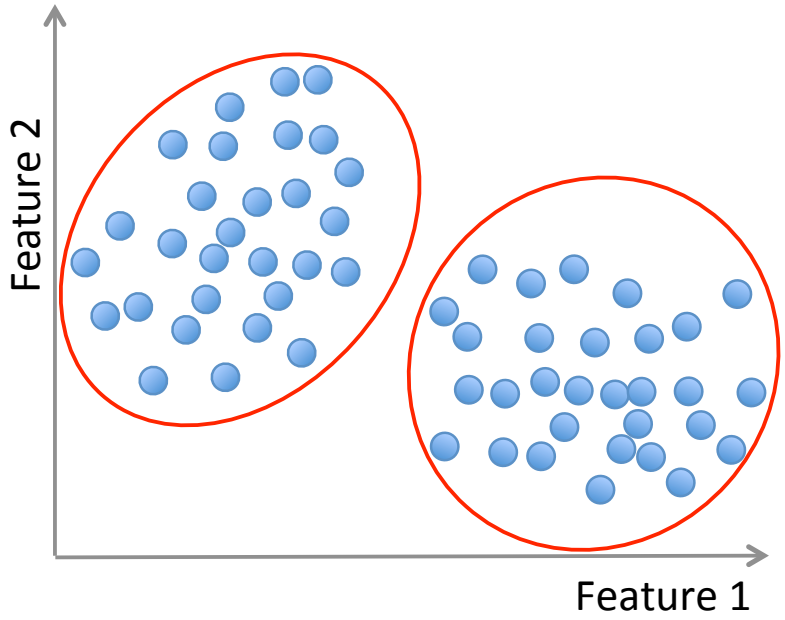
Machine learning

Data segmentation or Clustering

Input: "Examples" without labels.

$$x_1, \ldots, x_n, \; x_i \in X \subset \mathbb{R}^n$$

Output: $f : X \longrightarrow \{C_1, \ldots C_k\}$ (set of clusters).



Concepts/methods: Unsupervised learning, clustering, k-means, association rules, etc.

Machine learning

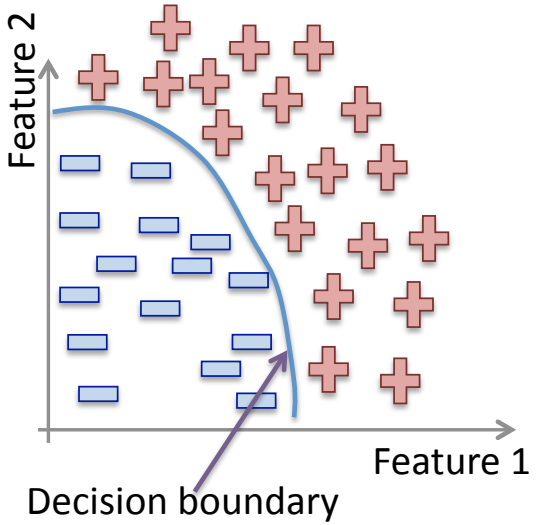
Binary classification (categorization)

Input: "Examples" with labels.

$$(x_1, y_1), \ldots, (x_n, y_n) \;/\; x_i \in X \subset \mathbb{R}^n, \quad y_i \in Y = \{-1, +1\}$$

Output: $h : X \longrightarrow Y$

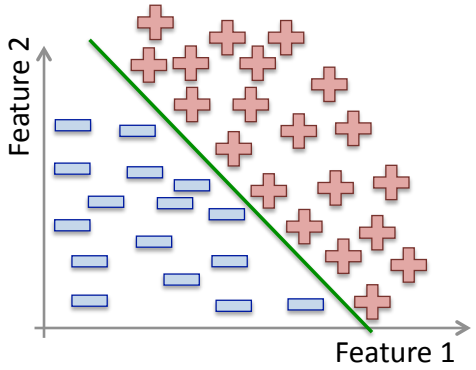
Example: Approve credit yes/no, spam/ham.

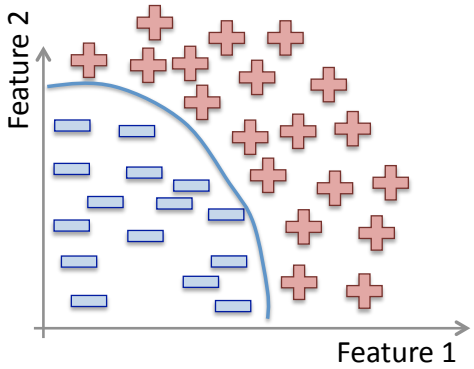


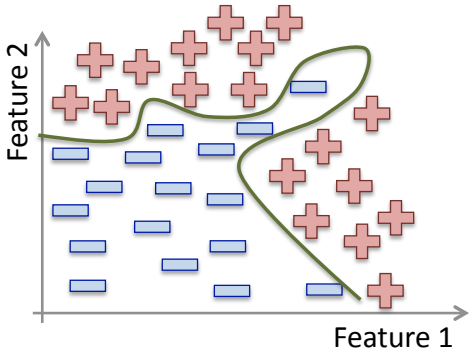
Concepts/methods: Supervised learning, classification, K nearest neighbors, perceptrons, neural networks, linear regression, etc.

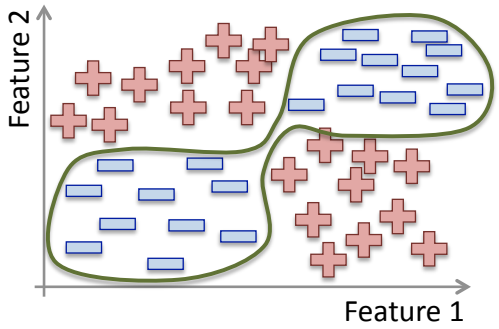
Supervised learning

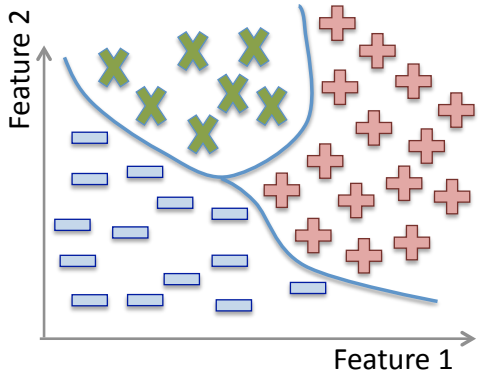
Classification:











Methods: Support Vector Machines, neural networks, decision trees, K-nearest neighbors, naive Bayes, etc.

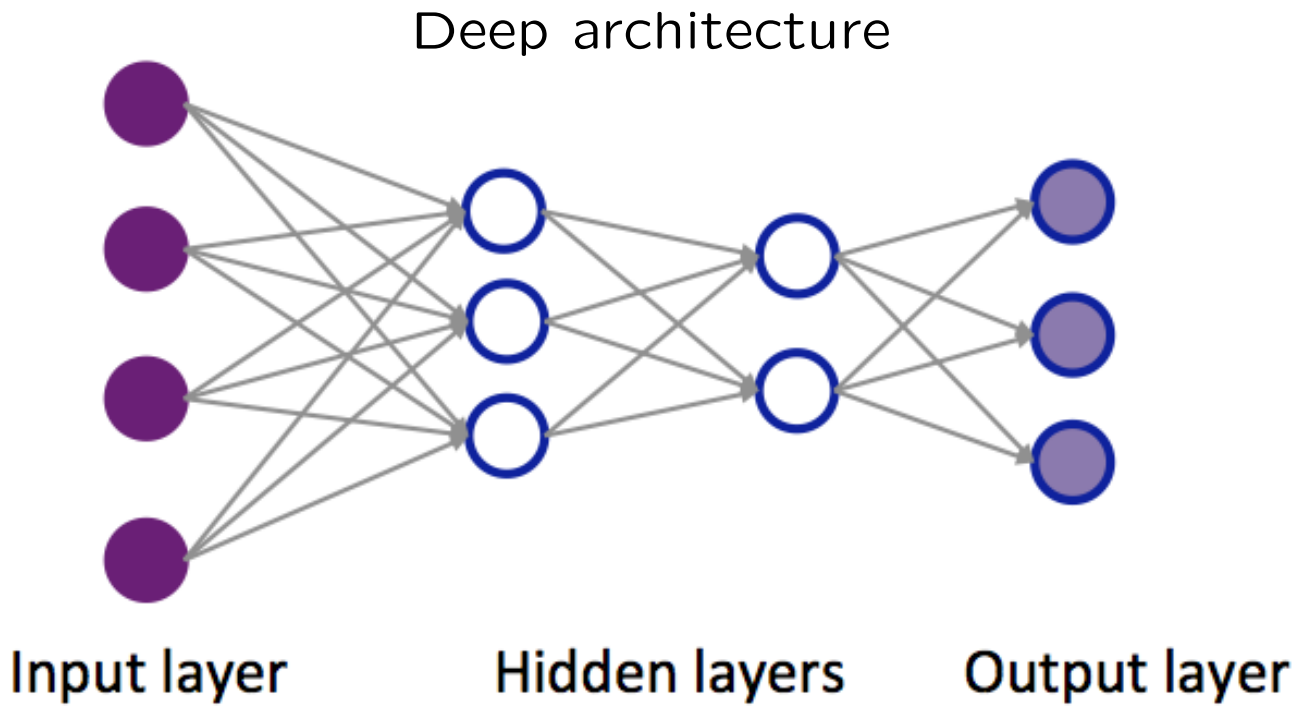
Neural Networks

- 1950-60s: Neural networks (Rosenblatt, etc.)
- 1970's: Slow progress
- 1986: Backpropagation
- 1990s: Convolutional neural networks (LeCun)
- 1990s: Recurrent neural networks (Schmidhuber)
- 2006: NN, le retour. Breakthrough: Deep belief networks (Hinton et al., 2006) and Autoencoders (Bengio et al., 2007).
- 2013: Huge industrial interest. Why now?

Lots of data and more computational power!

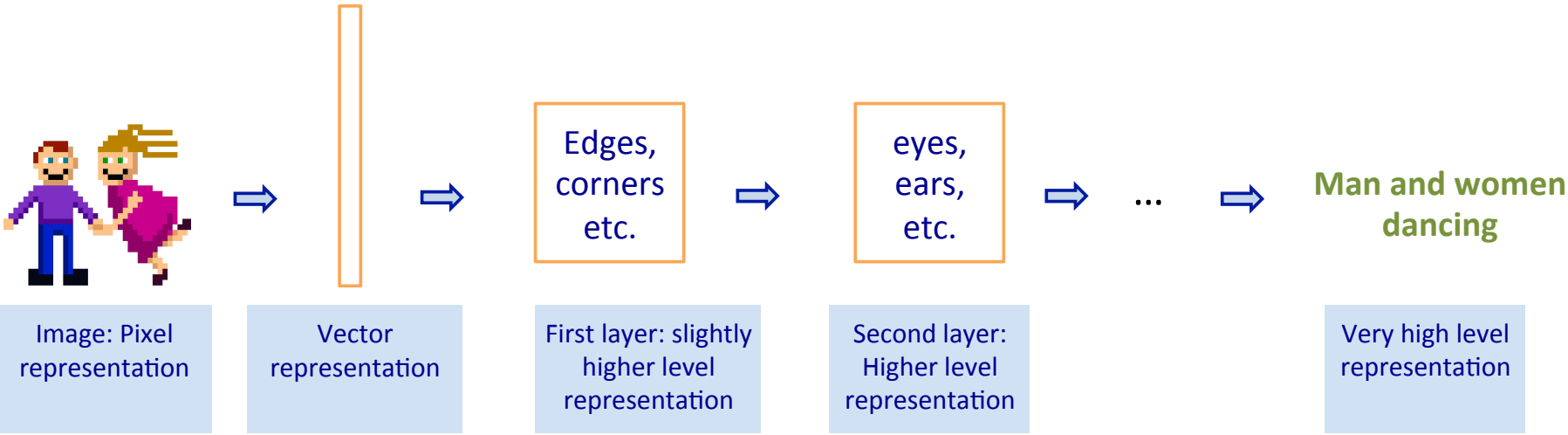
Work well, breakthrough results (vision and speech)

What is Deep Learning?



Deep learning: means using a neural network with a series of hidden layers of non-linear operations between input and output.

Why a deep architecture?



Deep architecture: The series of layers between input and output learn feature hierarchies/feature identification at different levels.

Hidden layers: Act as **feature detectors**, will leads to an *automatic abstraction of data*.

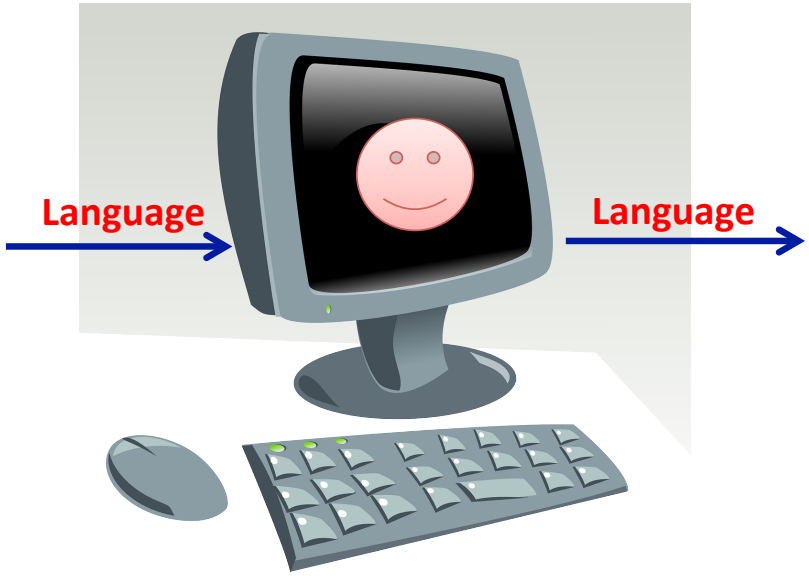
Successive layers: Learn high level features.

Reinforcement learning

- Agent evolves in a stochastic and uncertain environment.
- Agent learns from **reinforcement** or delayed **reward**.
- Learning approaches for **decision making** in situations where outcomes are stochastic.
- Agent continues to plan and learn to affect its environment.
- Reinforcement learning agents are driven by **maximizing their rewards on the long run**.

Applications

- **Natural Language Processing (NLP)**: concerned with the interactions between computers and human languages.



AI Challenges and potential

- AI is a flourishing, and a broad field shaping our world
- AI **potential**: to be applied broadly from education, health, to manufacturing, transportation and deeply impact everyday life
  - End poverty and hunger?
  - Reduce inequalities?
  - Promote clean energy? protect the planet?
  - Offer quality education?
  - Lead to a better health?

AI Challenges and potential

- AI **concerns**:
  - How will AI impact the job market?
  - How will AI transform our work, cities, politics?
  - How will AI change our regulations and laws?
- Should we be afraid of AI? Is AI a threat to our humankind?
- Professor Stephen Hawking, eminent scientist told BBC:

  "The development of full artificial intelligence could spell the end of the human race."