

Course 16 :198 :440 : Introduction To Artificial Intelligence
Lecture 1 :

Introduction and Overview

Abdeslam Boularias

Wednesday, January 17, 2024

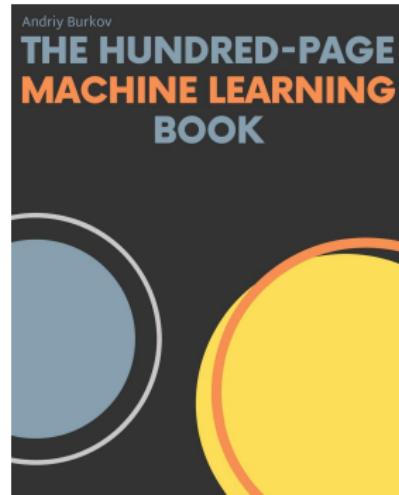
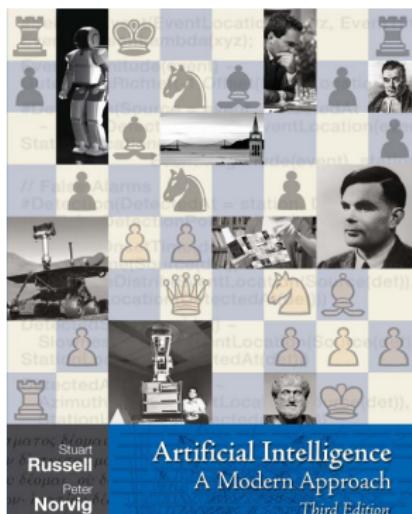


Course data

- Instructor : Abdeslam Boularias
(abdeslam.boularias@rutgers.edu)
- If you have a question, please post it on Piazza.
- Teaching assistants :
 - TBD
- Office hours : Fridays 5 :00 pm to 6 :00 pm
- Office address : One Spring Street, office 308, New Brunswick.
- No more Special Permission Numbers (SPNs).
- Grading scheme :
 - Midterm : 20%
 - Final Exam : 20%
 - Homework : 30%
 - Final Project : 30%

Course data

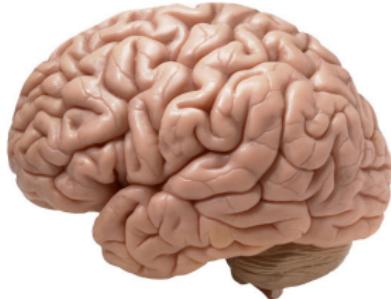
- Textbook : Stuart J. Russell and Peter Norvig. **Artificial Intelligence : A Modern Approach**. Pearson Education, 3rd edition, 2010.
- Suggested reading : Andriy Burkov. **The Hundred-Page Machine Learning Book**. 2019.
- Suggested reading : Christopher M. Bishop. **Pattern Recognition and Machine Learning**. Springer-Verlag, 2006.



What is intelligence ?



What is intelligence ?



- Oxford dictionary : The ability to acquire and apply knowledge and skills.
- Collins dictionary : The capacity for understanding ; ability to perceive and comprehend meaning.
- Encyclopedia Britannica : Mental quality that consists of the abilities to learn from experience, adapt to new situations, understand and handle abstract concepts, and use knowledge to manipulate one's environment.

Are these intelligent ?



FIGURE: Sunflowers tracking the sun. Copyright Wikimedia Commons

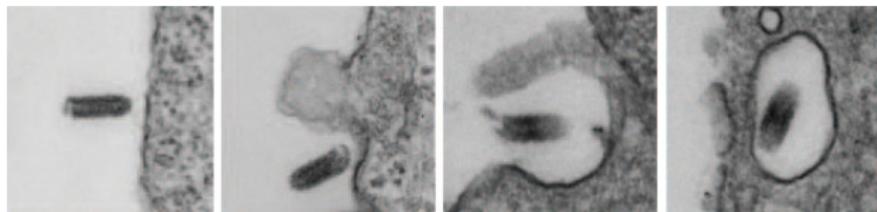


FIGURE: The Ebola virus entering a cell. Copyright Nature, 2011

Sternberg and Salter : Intelligence is a goal-directed adaptive behavior.

Artificial Intelligence

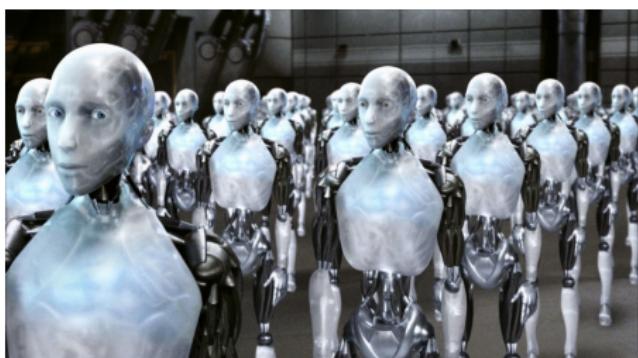
- Can we emulate intelligent behavior in machines ?
- How far can we take it ?

Intelligence need not be embodied

Artificial Intelligence

- Can we emulate intelligent behavior in machines ?
- How far can we take it ?

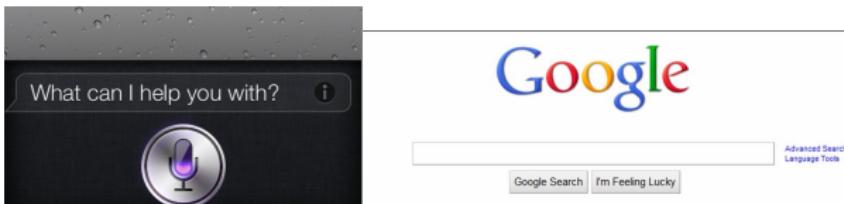
Intelligence need not be embodied
This is not what AI looks like (yet)



Artificial Intelligence

- Can we emulate intelligent behavior in machines ?
- How far can we take it ?

Intelligence need not be embodied
AI often looks like this



Customers Who Bought This Item Also Bought



What Do Customers Ultimately Buy After Viewing This Item?

	68% buy Simple Heuristics That Make Us Smart (Evolution & Cognition) £18.99
	17% buy Gut Feelings: Short Cuts to Better Decision Making £6.74
	9% buy Influence: The Psychology of Persuasion ★★★★☆ (12) £7.09

What is Artificial Intelligence?

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

What is Artificial Intelligence ?

- **Acting Humanly :**
 - Turing test : natural language processing, knowledge representation, automated reasoning, and machine learning.
 - Complete Turing test : additionally uses computer vision and robotics.
- **Thinking Humanly :**
 - Example : The General Problem Solver (Newell and Simon, 1961) was designed to mimic human reasoning.
 - Understanding how humans think through : introspection, psychological experiments, or brain imaging.
 - Cognitive science : constructing theories of the human mind using AI techniques and psychological experiments.
 - Cognitive science became a separate discipline with goals different from AI's goals.

Rationality

- Humans are not necessarily the best reference : aircrafts do not imitate birds (and outperform them in many aspects).
- Rationality : being reasonable, based on facts or reason ; doing the right thing.
- Rationality requires a precise mathematical (or logical) measure of the ideal behavior.
- The measure can be a continuous or binary metric, it defines a precise benchmark to evaluate the performance of the system we want to build.
- There is no universal agreement about the ideal behavior.
- Modern AI paradigm : Fix a measure of performance and see how different algorithms do.

What is Artificial Intelligence ?

- **Thinking Rationally :**
 - Aristotle (384 - 322 BC) was one of the first to attempt to codify “right thinking”
 - Syllogisms : (Socrates is a man \wedge all men are mortal) \Rightarrow Socrates is mortal
- **Acting Rationally :**
 - This notion came from different fields, such as economic theories (utility theory, game theory, etc..) on how to best act and how self-interested agents interact.
 - Since acting rationally includes thinking rationally, we will focus on acting rationally.
 - AI is the discipline of studying and designing rational **agents**.

Foundations of Artificial Intelligence : Philosophy

- Aristotle : First step toward automating the reasoning process. Syllogisms are formal rules that can be used to draw valid conclusions.
- Automation of computation : da Vinci, Schickard, Pascal, Leibniz.
- The mind-body problem : how are mental states related to physical states ?
 - Dualism : The mind is distinct from matter.
 - Materialism : The brain's operation according to the laws of physics constitutes the mind (similar to the software/hardware in a computer).
- Source of knowledge : where does knowledge come from ?
 - Empiricism : knowledge comes from experience (*Tabula rasa*). "Nothing is in the understanding, which was not first in the senses." - John Locke.
 - Logical positivism : Bertrand Russell. Knowledge comes from logical theories connected to observation from sensory inputs.

Foundations of Artificial Intelligence : Mathematics

- Logic : What are the formal rules to draw valid conclusions ?
 - George Boole (1815-1864) introduced propositional (Boolean) logic.
- Computation : What can be computed ?
 - Euclid (323-283 BC) came up with the first known algorithm, al-Khowarazmi (780-850) introduced the concept of an algorithm.
 - Kurt Gödel (1906-1978) showed in his incompleteness theorem that there exist undecidable statements.
 - Alan Turing (1912-1954) characterized exactly which functions are computable.
 - Tractability (polynomial vs exponential complexity) introduced in the mid-1960s.
- Probability : How do we reason with uncertain information ?
 - Thomas Bayes (1702-1761) showed how to update probabilities based on new evidence.
 - Judea Pearl introduced Bayesian networks in late 1980's, a probabilistic graphical model for representing dependencies between random variables.

Foundations of Artificial Intelligence : Economics

- How should we make decisions so as to maximize payoff ?
 - Adam Smith (1776) was the first to think of economics as a set of individual agents maximizing their well-being (utility).
 - Decision theory : rational agents choose actions that maximize their expected utility (reward).
- How to behave optimally in a group of (competitive or collaborative) rational agents ?
 - Game theory : Von Neumann proved the minimax theorem in 1928.
- How should we do this when the payoff may be far in the future ?
 - Early work on planning where to install radars in WW2 lead to the creation of Operations Research.
 - Richard Bellman (1957) formalized sequential decision-making problems as Markov Decision Processes.

How do brains process information ?

- Paul Broca (1824-1880) discovered the existence of regions in the brain that are specialized in different functions.
- Functional magnetic resonance imaging (fMRI) revolutionized our understanding of the brain.
- However, we still do not understand how areas of the brain can take over the functions of other areas.
- There is still no solid theory of how memories are maintained in the brain.

Foundations of Artificial Intelligence : Neuroscience

Computer vs Brain



IBM Blue Gene

	Supercomputer	Personal Computer	Human Brain
Computational units	10^4 CPUs, 10^{12} transistors	4 CPUs, 10^9 transistors	10^{11} neurons
Storage units	10^{14} bits RAM 10^{15} bits disk	10^{11} bits RAM 10^{13} bits disk	10^{11} neurons 10^{14} synapses
Cycle time	10^{-9} sec	10^{-9} sec	10^{-3} sec
Operations/sec	10^{15}	10^{10}	10^{17}
Memory updates/sec	10^{14}	10^{10}	10^{14}

Very different architectures : brains are slow and massively parallel, computers are fast and serial.

History of Artificial Intelligence

- The gestation of AI (1943-1955)
- The birth of AI (1956)
- Early success (1952-1969)
- Failing to solve real-world problems (1966-1973)
- Knowledge-based systems (1969-1979)
- AI becomes an industry (1980-present)
- Neural networks rediscovered (1986-present)
- AI becomes a rigorous scientific discipline (1987-present)
- Intelligent agents (1995-present)
- “Big Data” (2001-present)
- Deep Learning (2011-present)
- Transformers, Large Models (2017-present)

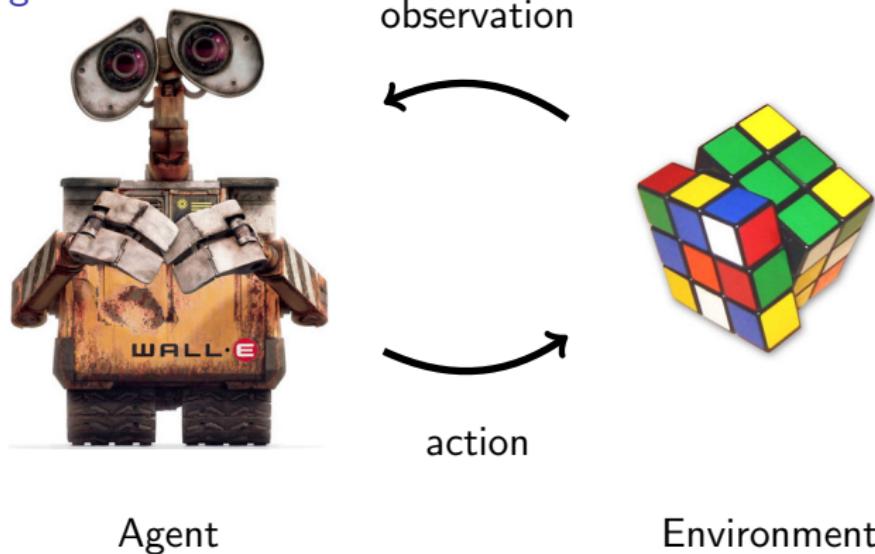
Intelligent Agents

Intelligent Agents



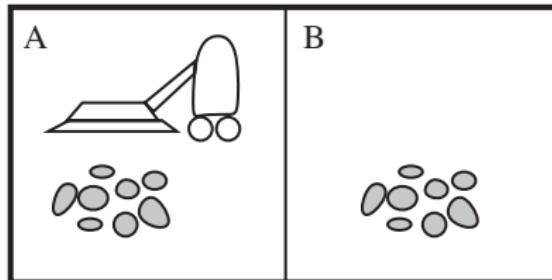
Not these agents

Intelligent Agent



- An agent could be a robot, a human, a software, etc.
- An agent chooses its actions based on only its previous actions and observations.
- Mathematically, an agent is a function that maps a history of actions and observations into an action.

Example of an Intelligent Agent : a simple vacuum cleaner



Observations : (location, {dirty square , clean square}).

Actions : suck, move left, move right.

Percept sequence	Action
[A, Clean]	Right
[A, Dirty]	Suck
[B, Clean]	Left
[B, Dirty]	Suck
[A, Clean], [A, Clean]	Right
[A, Clean], [A, Dirty]	Suck
:	:
[A, Clean], [A, Clean], [A, Clean]	Right
[A, Clean], [A, Clean], [A, Dirty]	Suck
:	:

Example of an Intelligent Agent : a simple vacuum cleaner

Percept sequence	Action
[A, Clean]	Right
[A, Dirty]	Suck
[B, Clean]	Left
[B, Dirty]	Suck
[A, Clean], [A, Clean]	Right
[A, Clean], [A, Dirty]	Suck
:	:
[A, Clean], [A, Clean], [A, Clean]	Right
[A, Clean], [A, Clean], [A, Dirty]	Suck
:	:

- Is that agent rational (doing the right thing) ?

Example of an Intelligent Agent : a simple vacuum cleaner

Percept sequence	Action
[A, Clean]	Right
[A, Dirty]	Suck
[B, Clean]	Left
[B, Dirty]	Suck
[A, Clean], [A, Clean]	Right
[A, Clean], [A, Dirty]	Suck
:	:
[A, Clean], [A, Clean], [A, Clean]	Right
[A, Clean], [A, Clean], [A, Dirty]	Suck
:	:

- Is that agent rational (doing the right thing) ?
- This question cannot be answered unless we define a precise measure of performance.
- The agent is rational if and only if its performance is maximal.
- There is no universal measure of performance. Performance depends on what we want to achieve :
 - ① Reward (points) proportional to the quantity of absorbed dust.
 - ② Reward (points) proportional to the quantity of absorbed dust and disproportional to used energy.
- Is this agent always rational ?

Properties of task environments

- Fully observable vs. partially observable
- Single agent vs. multiagent
- Deterministic vs. stochastic
- Episodic vs. sequential
- Discrete vs. continuous
- Known vs. unknown

- In this course, we focus on AI fundamentals.
- We will often use toy examples, but AI techniques are used in a huge number of applications : Robotics, Biology, Scheduling, Diagnosis, Games, Data Mining, Recommendation Systems, etc.

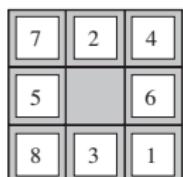
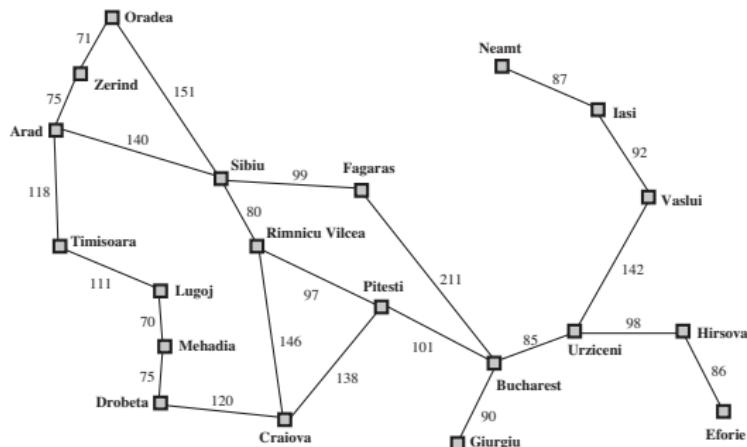
We will study the following three main topics :

- ① Problem-solving
- ② Probabilistic reasoning
- ③ Machine learning

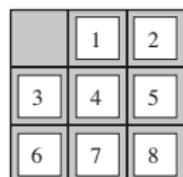
Problem-solving

Problem-solving : Search

- For a single agent
- Find an optimal sequence of states between current state and goal state.

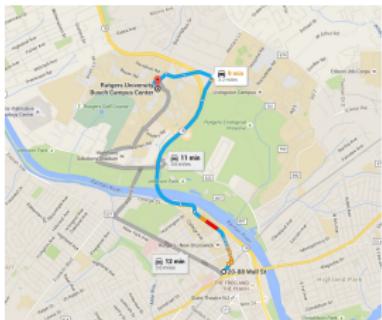


Start State



Goal State

Problem-solving : Search

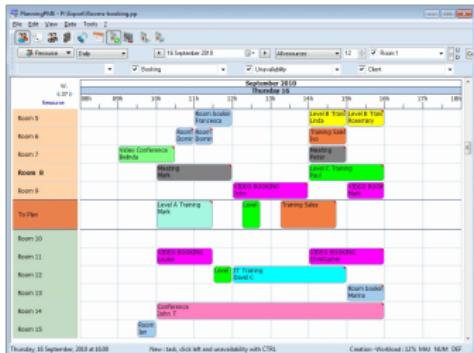


route planning



robot navigation
(Copyright Wikimedia Commons)

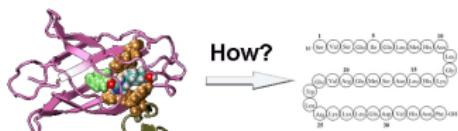
Problem-solving : Constraint Satisfaction



scheduling
<http://www.planningpme.com/>

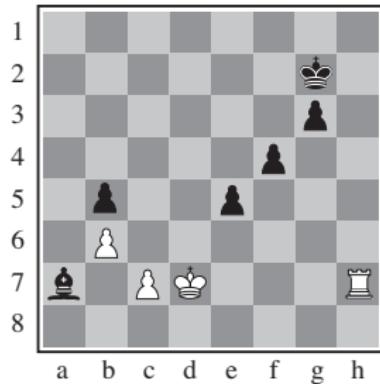
5	3		7			
6		1	9	5		
	9	8			6	
8			6			3
4		8		3		1
7			2		6	
	6			2	8	
		4	1	9		5
			8		7	9

sudoku

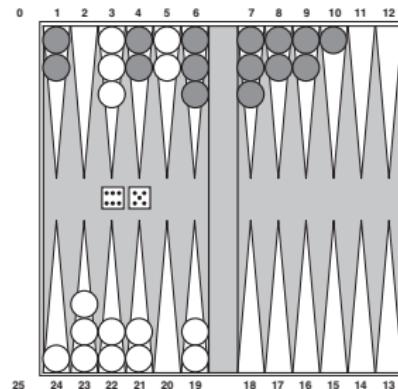


protein design
<http://zhanglab.ccmb.med.umich.edu/>

Problem-solving : Adversarial Search



chess

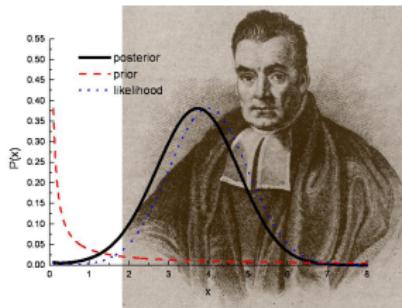


backgammon

Probabilistic reasoning

Probabilistic reasoning

Reasoning with uncertain models, observations, actions and knowledge



Bayesian reasoning

www.lanl.gov

The Posterior

The probability of getting this evidence if this hypothesis were true

$$P(H|E) = \frac{P(H|E) P(H)}{P(E)}$$

The probability that the hypothesis (H) is true given the evidence (E)

The Evidence

The probability of H being true, before gathering evidence

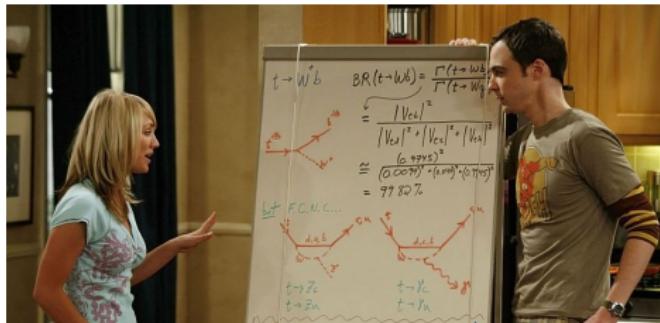
The marginal probability of the evidence (Prob of E over all possibilities)

The Prior

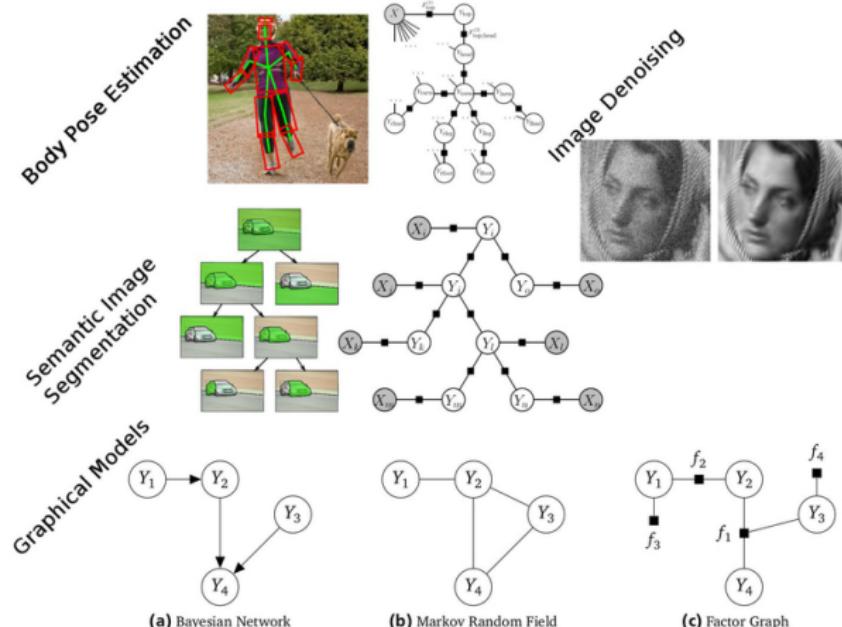
The probability of H being true, before gathering evidence

Bayes Rule

<http://www.labtimes.org/>

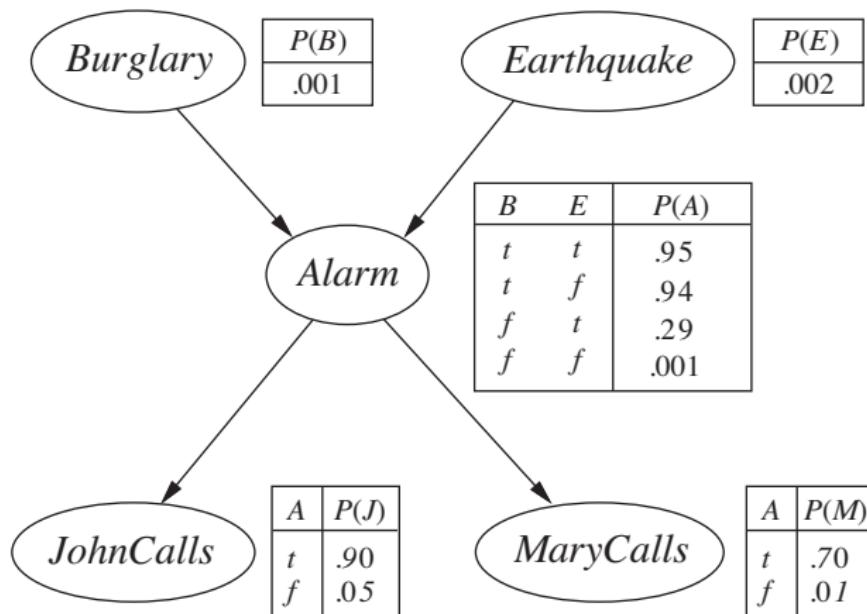


Probabilistic reasoning : graphical models

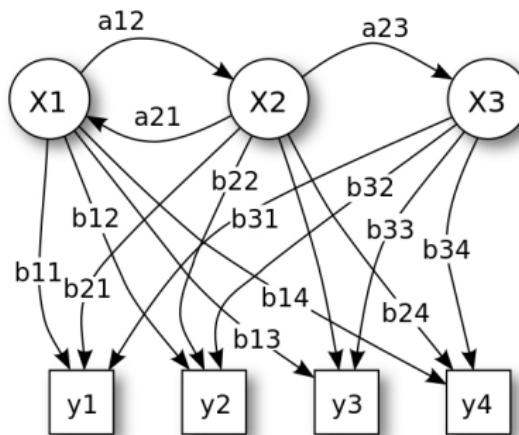


<https://www.mpi-inf.mpg.de/departments/computer-vision-and-multimodal-computing/teaching/courses/probabilistic-graphical-models-and-their-applications/>

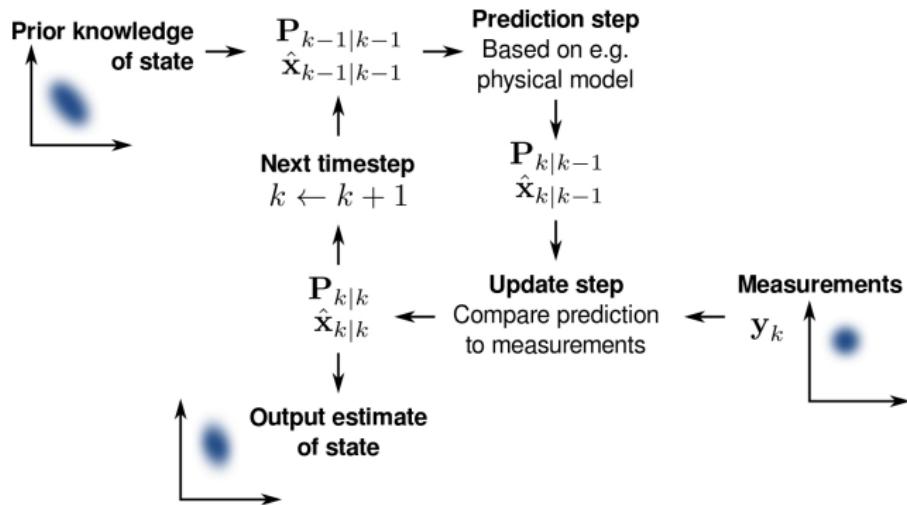
Probabilistic reasoning : Bayesian networks



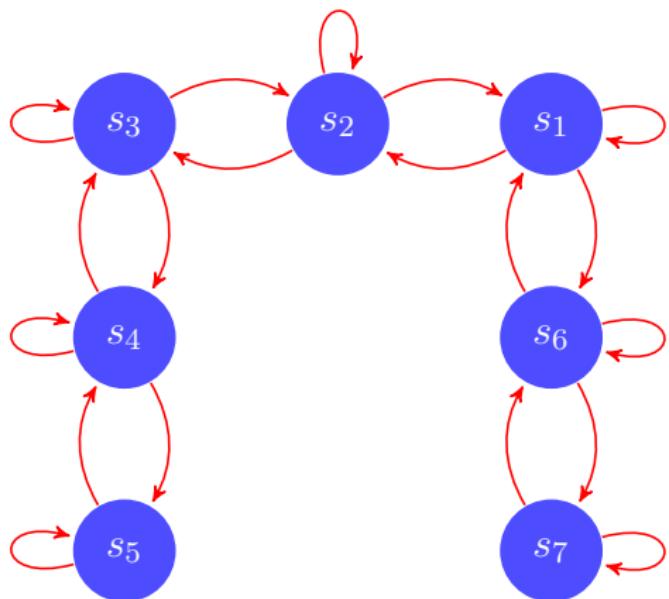
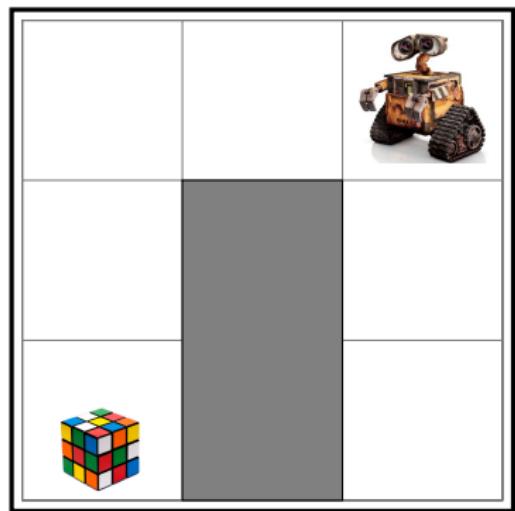
Probabilistic reasoning : Hidden Markov Models



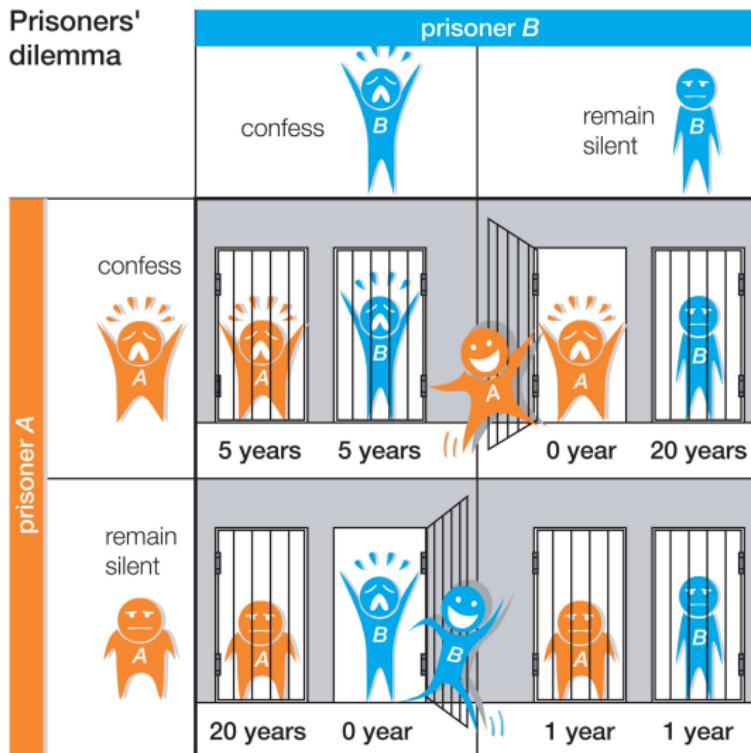
Probabilistic reasoning : Kalman Filter



Probabilistic reasoning : Markov Decision Processes



Probabilistic reasoning : Game Theory

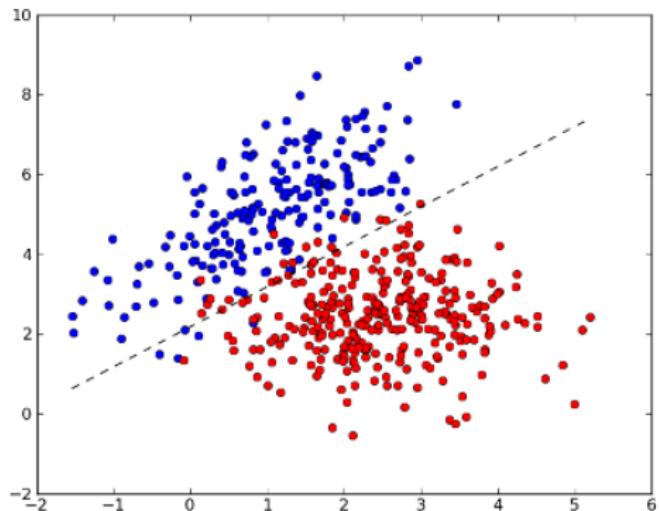


© 2010 Encyclopædia Britannica, Inc.

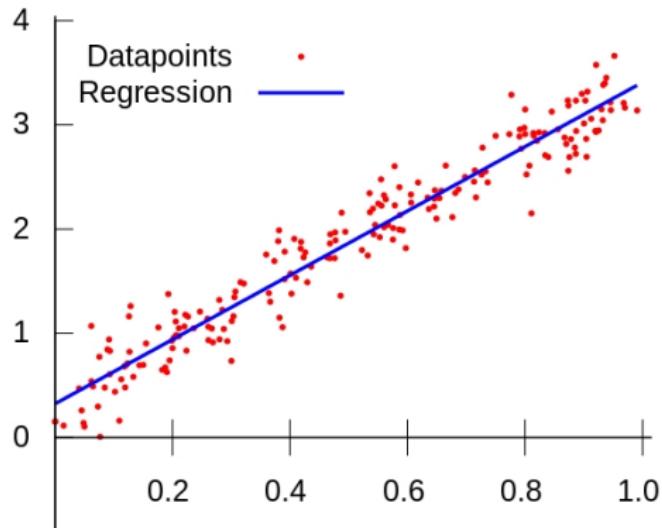
Machine learning

Machine learning : Empirical Inference

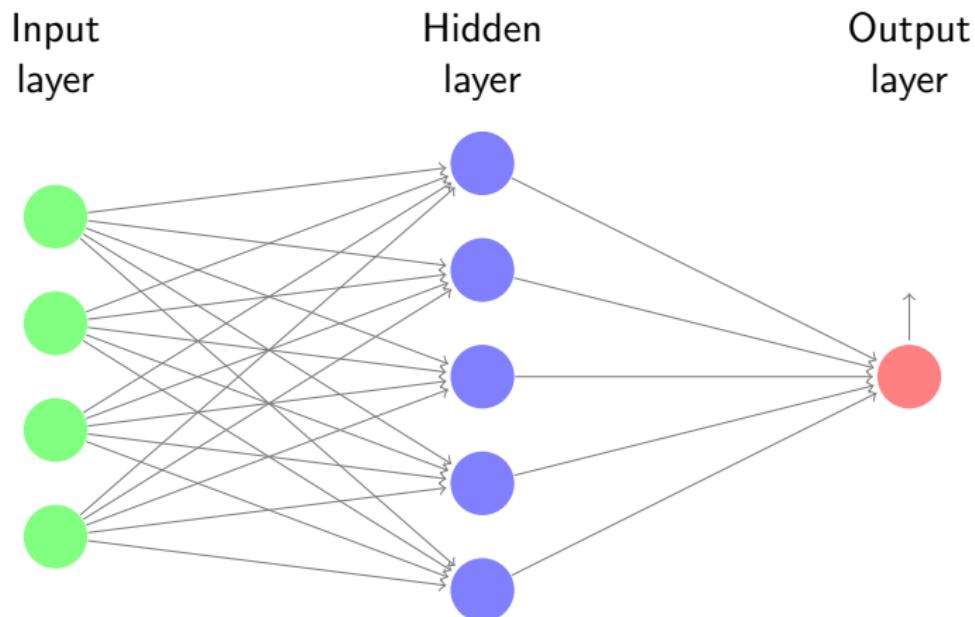
Machine learning : Linear Classification



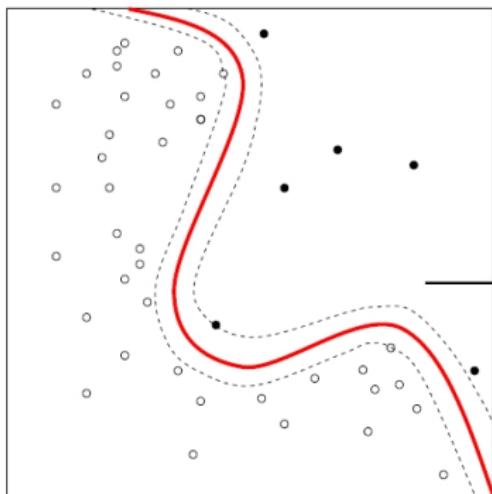
Machine learning : Linear Regression



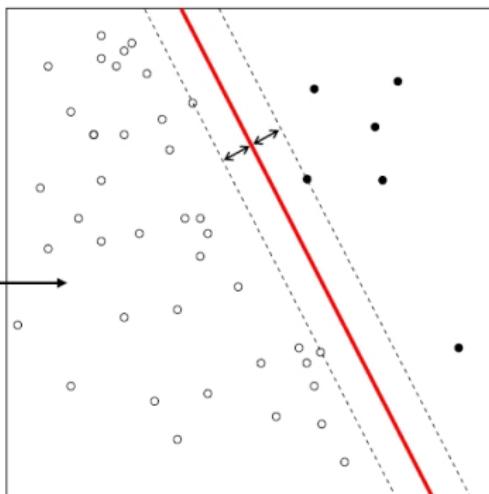
Machine learning : Neural Networks



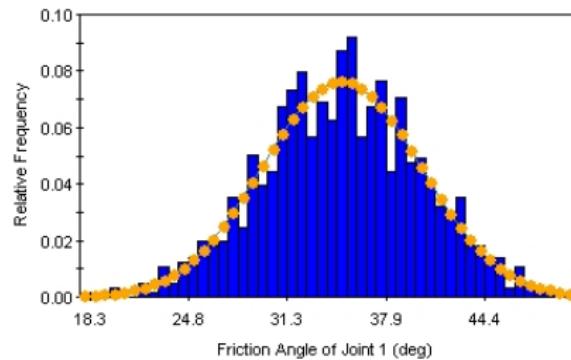
Machine learning : Kernel Methods



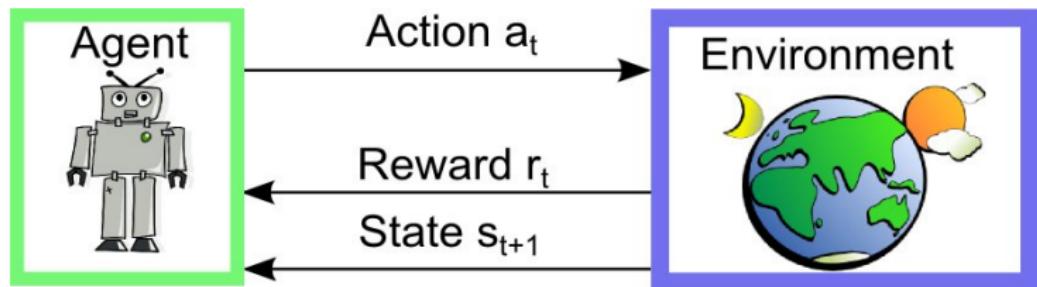
ϕ



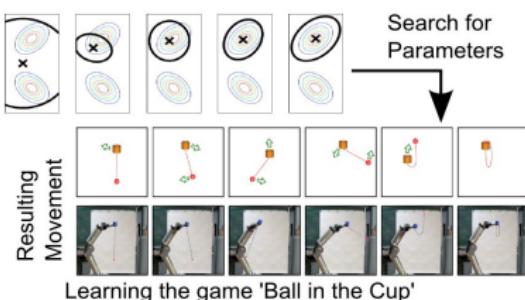
Machine learning : Sampling Methods



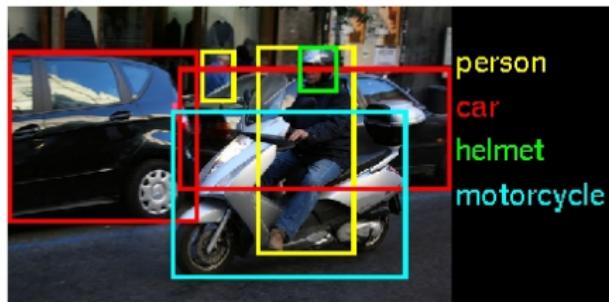
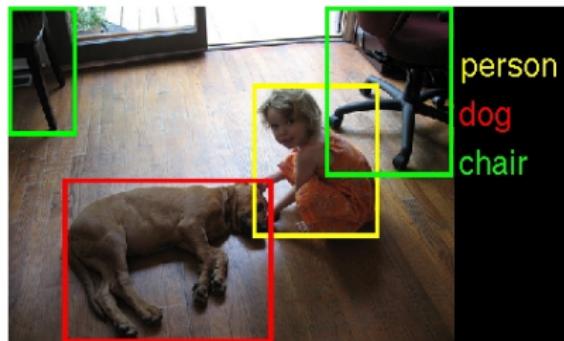
Machine learning : Reinforcement Learning



Reinforcement Learning Setup



Machine learning : Perception



<http://www.image-net.org/challenges/LSVRC/2014/>

Tentative schedule (subject to change)

Topic	Chapter
Lecture 1 : Introduction and Overview	
Lecture 2 : Uninformed Search	
Lecture 3 : Heuristic Search	
Lecture 4 : Adversarial Search	
Lecture 5 : Local Search	
Lecture 6 : Constraint Satisfaction Problems	
Lecture 7 : Probabilistic Reasoning	
Lecture 8 : Graphical models	
Lecture 9 : Bayesian Networks	
Lecture 10 : Temporal Models	
Lecture 11 : Hidden Markov Models	
Lecture 12 : Kalman and Particle Filters	
Lecture 13 : Utility Theory	
Midterm	
Lecture 14 : Markov Decision Processes	
Lecture 15 : Game Theory	

Tentative schedule (subject to change)

Topic	Chap
Lecture 16 : Introduction to Machine Learning	
Lecture 17 : Linear Models for Regression	
Lecture 18 : Linear Models for Classification	
Lecture 19 : Neural Networks	
Lecture 20 : Kernel Methods	
Lecture 21 : Gaussian Processes	
Lecture 22 : Sparse Kernel Machines	
Lecture 23 : Sampling Methods	
Lecture 24 : Learning Probabilistic Models	
Lecture 25 : Reinforcement Learning	
Lecture 25 : Imitation Learning	
Lecture 26 : Perception	
Lecture 27 : Future Prospects of AI and Application Domains	
Final Exam	