Course 01 :198 :440 : Introduction To Artificial Intelligence
Lecture 0 :

Introduction and Overview

Abdeslam Boularias

Wednesday, September 7, 2016

THE STATE UNIVERSITY OF NEW JERSEY
RUTGERS

Today's agenda

1. Course data
2. Introduction
3. Course topics

Course data

Up-to-date information is on Sakai and on the course web page :
http ://www.abdeslam.net/cs440

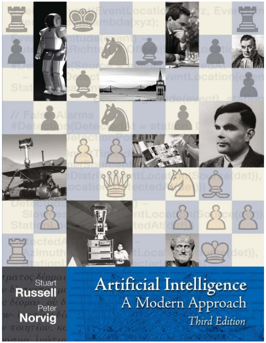
Instructor : Abdeslam Boularias (boularias@gmail.com)

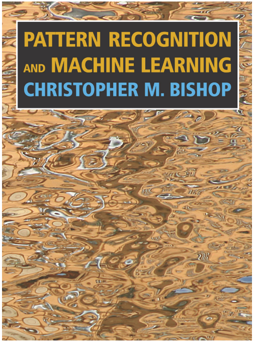
Assistant Professor at Rutgers University since September 2015. Studied Computer Science at Paris Sud (XI) University (France) and Laval University (Canada). Ph.D. in 2010 at Laval University, Research Scientist at the Max Planck Institutes (MPI) in Tuebingen (Germany) from 2010 to 2013, and Postdoc and Project Scientist at Carnegie Mellon University (US) from 2013 to 2015.

Office hours : Fridays 04 :30 - 05 :30 PM in CBIM 07

Course data

- Teaching assistant : Chaitanya Mitash (cm1074@scarletmail.rutgers.edu)
- Textbook 1 : Stuart J. Russell and Peter Norvig. **Artificial Intelligence : A Modern Approach**. Pearson Education, 3rd edition, 2010.
- Textbook 2 : Christopher M. Bishop. **Pattern Recognition and Machine Learning**. Springer-Verlag, 2006.





Course data

Course Learning Goals

The objective of the class is to :

- Show how to identify the appropriate AI solutions for different classes of computational challenges
- Provide experience in implementing such techniques on representative challenges

Expected work

Expected work

Regular readings and homework, written exams, projects.

Grading Scheme

- Midterm : 20%
- Final Exam : 20%
- Homework : 40%
- Final Project : 20%

No curved grading !

What do you need to know before you take this class ?

- Probabilities and Statistics
- Calculus
- Algorithms
- How to make a formal proof
- Software engineering (any programming language is fine)

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

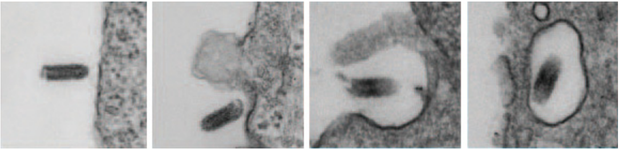


FIGURE: The Ebola virus entering a cell. Copyright Nature, 2011

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

Smart material

Smart materials are designed materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields. [Wikipedia]

FIGURE: A material that can remember its original shape. Could be used in the automobile industry

Intelligence

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

Artificial Intelligence

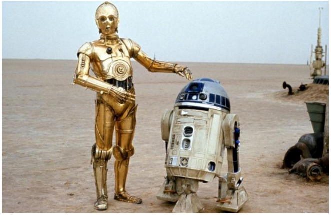
- Can we emulate intelligent behavior in machines ?
- How far can we take it ?

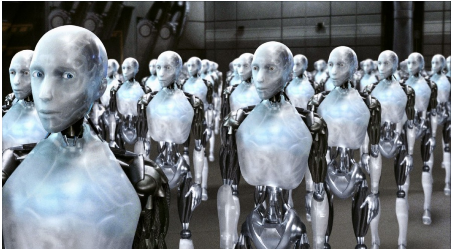
Intelligence need not be embodied

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)



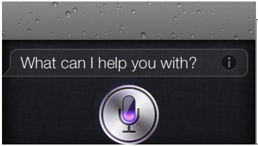


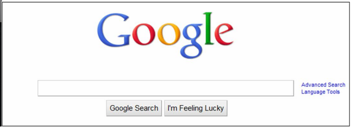
Artificial Intelligence

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

Intelligence need not be embodied

AI often looks like this





What is Artificial Intelligence ?

Thinking Humanly	**Thinking Rationally**
"The exciting new effort to make computers think . . . *machines with minds*, in the full and literal sense." (Haugeland, 1985) "[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) "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) "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) "AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998)

Stuart J. Russell and Peter Norvig. Artificial Intelligence : A Modern Approach

What is Artificial Intelligence ?

- **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.
- **Acting Humanly** :
  - Turing test : natural language processing, knowledge representation, automated reasoning, and machine learning.
  - Complete Turing test : additionally uses computer vision and robotics.

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. "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.

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^{11} bits RAM	10^{11} neurons
	10^{15} bits disk	10^{13} bits disk	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.

Stuart J. Russell and Peter Norvig. Artificial Intelligence : A Modern Approach

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” (2006-present)

Intelligent Agents

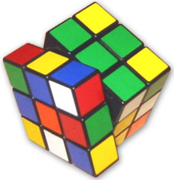
Intelligent Agents

No, not these agents !

Intelligent Agent

observation

action

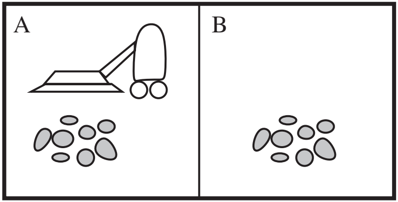


Agent

Environment

- An agent could be a robot, a human, a software, etc.
- An agents 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 : dirty square , clean square.

Actions : suck, move left, move right.

Percept sequence	Action
$[A, Clean]$	$Right$
$[A, Dirty]$	$Suck$
$[B, Clean]$	$Left$
$[B, Dirty]$	$Suck$
$[A, Clean], [A, Clean]$	$Right$
$[A, Clean], [A, Dirty]$	$Suck$
$\vdots$	$\vdots$
$[A, Clean], [A, Clean], [A, Clean]$	$Right$
$[A, Clean], [A, Clean], [A, Dirty]$	$Suck$
$\vdots$	$\vdots$

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*
$\vdots$	$\vdots$
$[A, Clean], [A, Clean], [A, Clean]$	*Right*
$[A, Clean], [A, Clean], [A, Dirty]$	*Suck*
$\vdots$	$\vdots$

- 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.

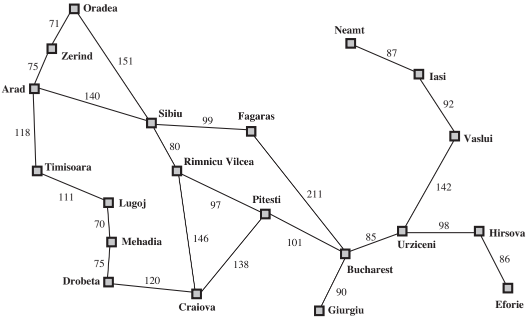
We will study the following three main topics :

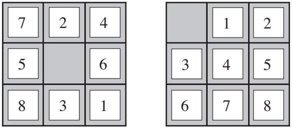
1. Problem-solving
2. Probabilistic reasoning
3. Machine learning

Problem-solving

Problem-solving : Search

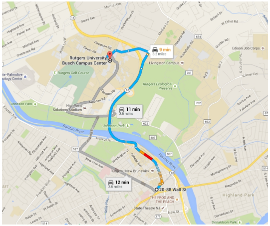
- For a single agent
- Find an optimal sequence of states between current state and goal state.





Start State Goal State

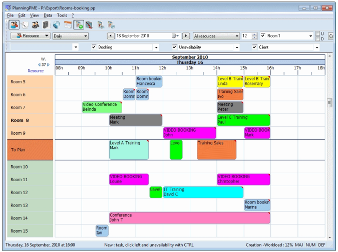
Problem-solving : Search



route planning

robot navigation
(Copyright Wikimedia Commons)

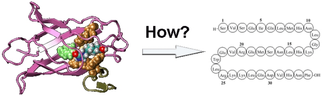
Problem-solving : Constraint Satisfaction



scheduling
http ://www.planningpme.com/

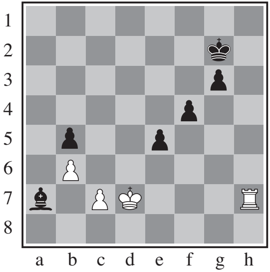
5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

sudoku

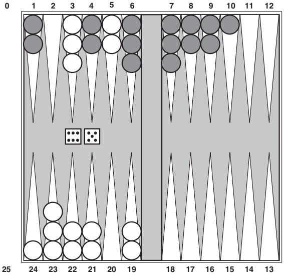


protein design
http ://zhanglab.ccmb.med.umich.edu/

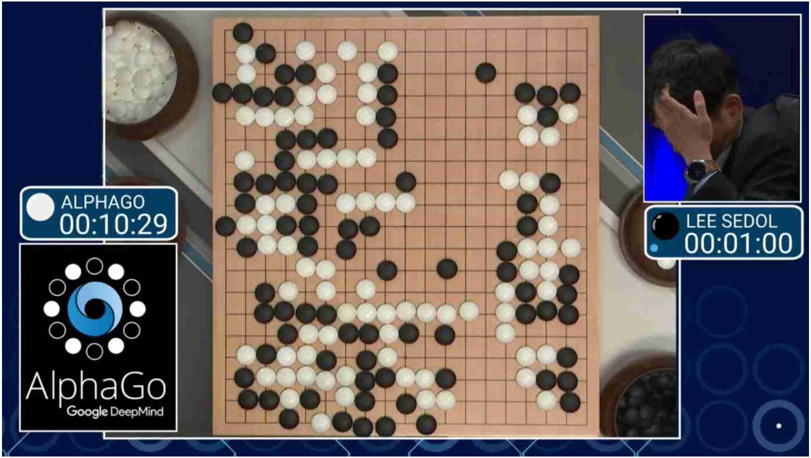
Problem-solving : Adversarial Search



chess



backgammon

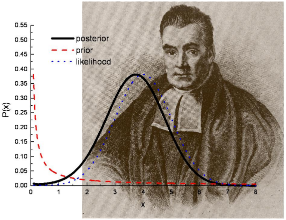


AlphaGo (Google DeepMind)

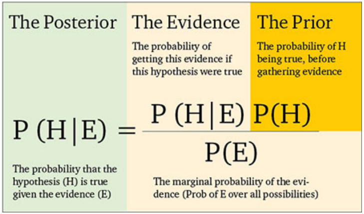
Probabilistic reasoning

Probabilistic reasoning

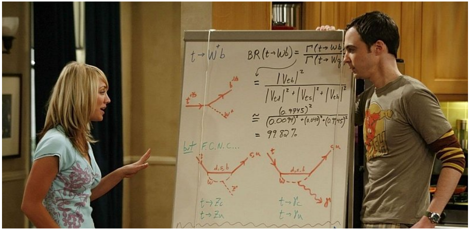
Reasoning with uncertain models, observations, actions and knowledge



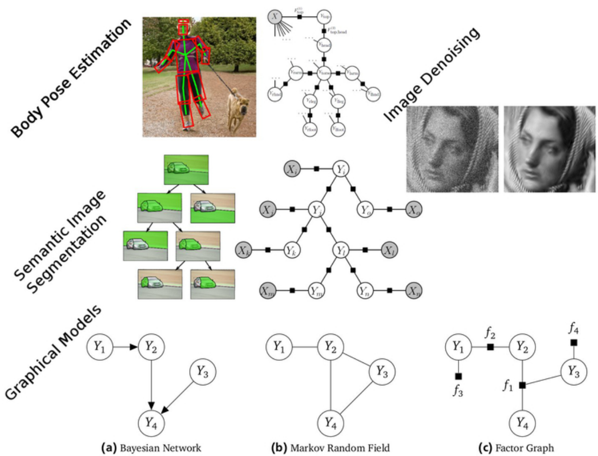
Bayesian reasoning
www.lanl.gov



Bayes Rule
http ://www.labtimes.org/

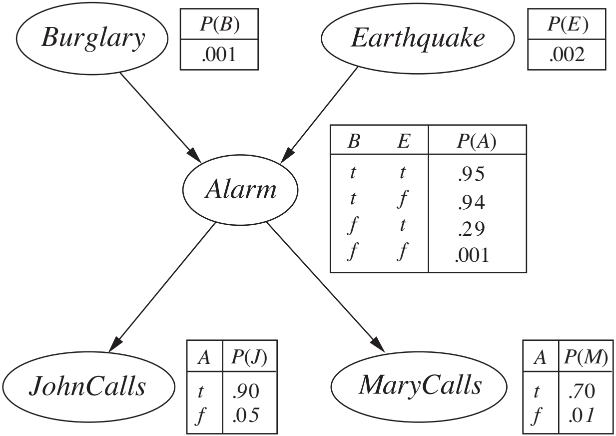


Probabilistic reasoning : graphical models



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

Probabilistic reasoning : Bayesian networks



$P(B)$
.001

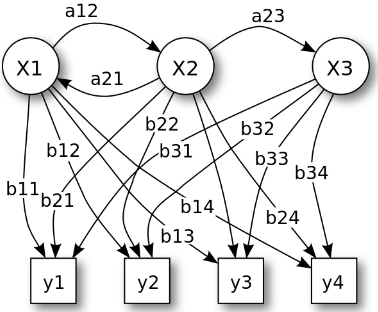
$P(E)$
.002

B	E	$P(A)$
t	t	.95
t	f	.94
f	t	.29
f	f	.001

A	$P(J)$
t	.90
f	.05

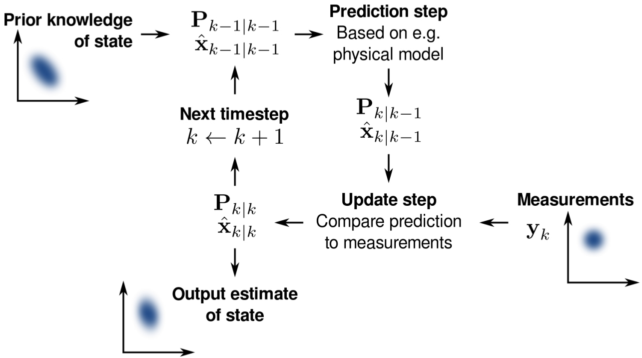
A	$P(M)$
t	.70
f	.01

Probabilistic reasoning : Hidden Markov Models



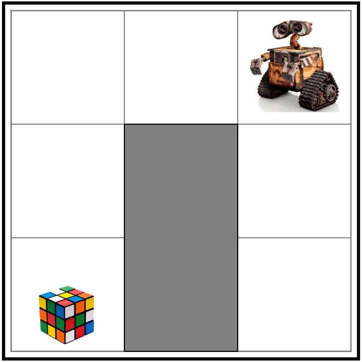
Wikipedia

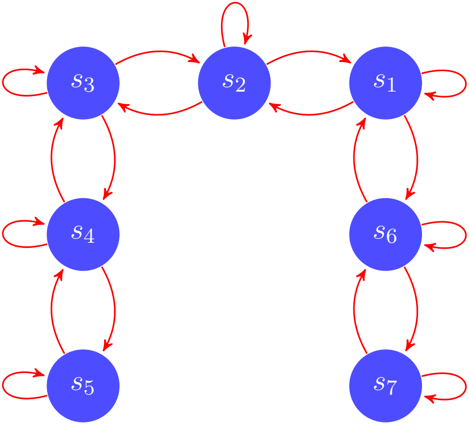
Probabilistic reasoning : Kalman Filter



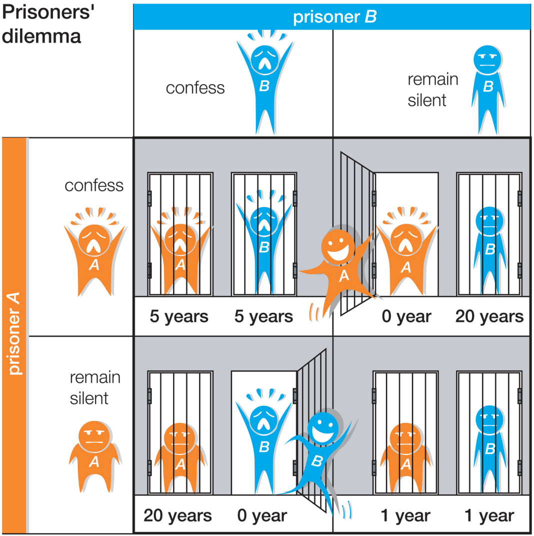
Wikipedia

Probabilistic reasoning : Markov Decision Processes





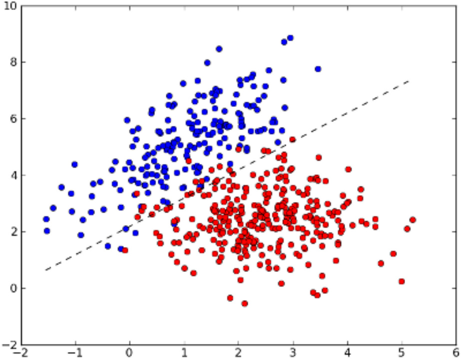
Probabilistic reasoning : Game Theory



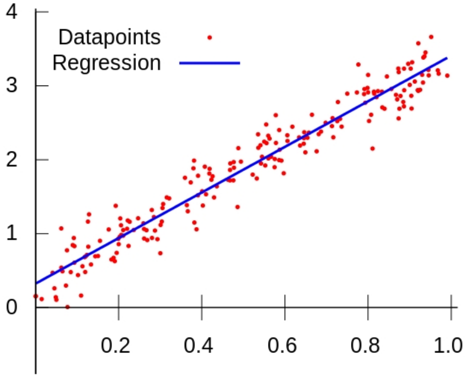
Machine learning

Machine learning : Empirical Inference

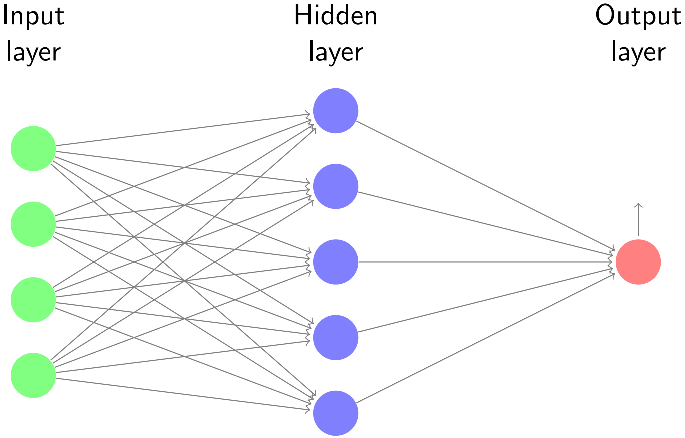
Machine learning : Linear Classification



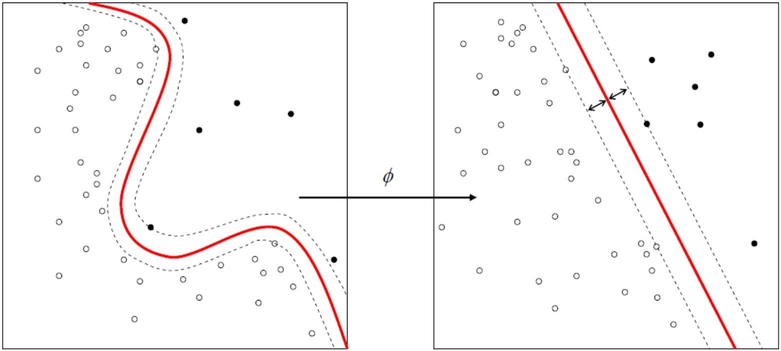
Machine learning : Linear Regression



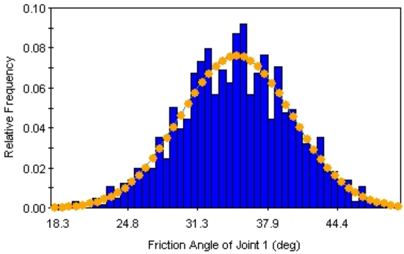
Machine learning : Neural Networks



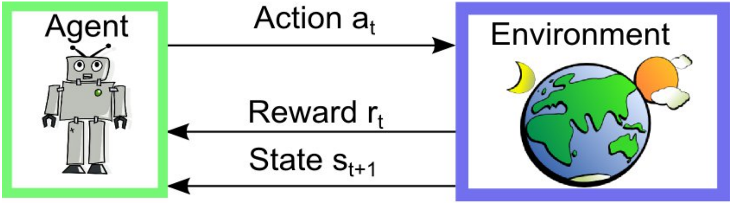
Machine learning : Kernel Methods



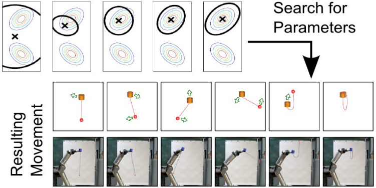
Machine learning : Sampling Methods



Machine learning : Reinforcement Learning



Reinforcement Learning Setup



Learning the game 'Ball in the Cup'

http ://www.ausy.tu-darmstadt.de/Research/Research

Machine learning : Reinforcement Learning

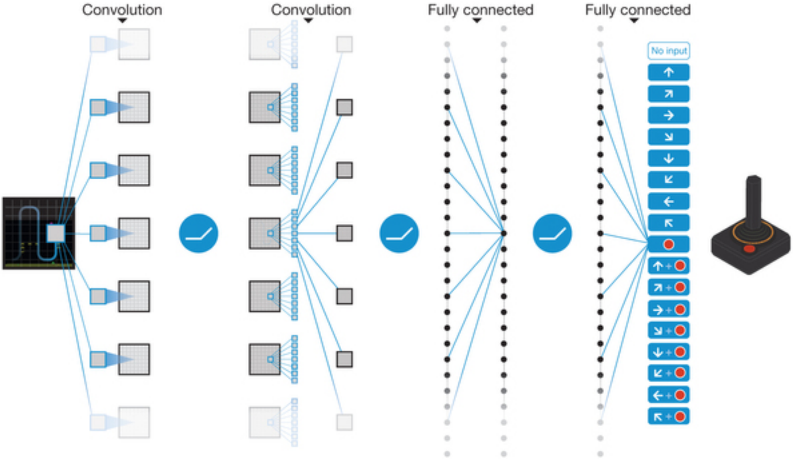
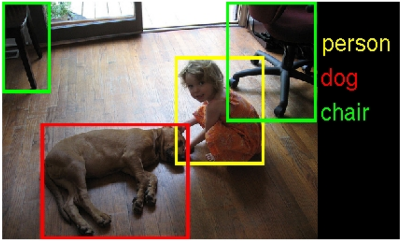
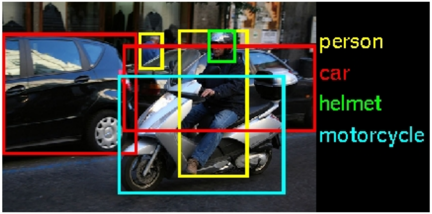


FIGURE: Human-level control of Atari games through deep reinforcement learning (Google DeepMind)

Machine learning : Perception





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

Machine learning : Perception

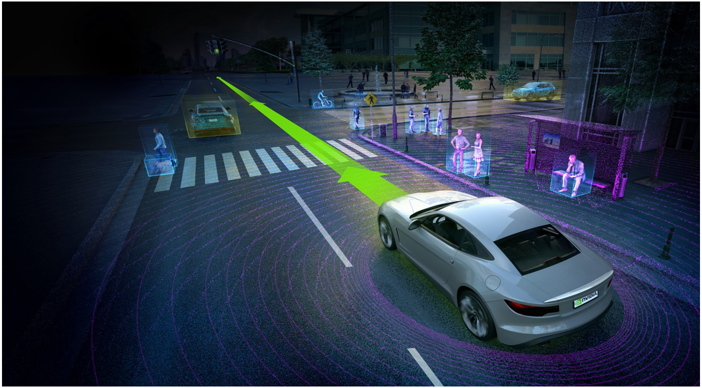


FIGURE: Computer vision for self-driving vehicles

Tentative schedule (subject to change)

Date	Topic
Sept. 7	Lecture 1 : Introduction and Overview
Sept. 9	Lecture 2 : Uninformed Search
Sept. 14	Lecture 3 : Heuristic Search
Sept. 16	Lecture 4 : Adversarial Search
Sept. 21	Lecture 5 : Local Search
Sept. 23	Lecture 6 : Constraint Satisfaction Problems
Sept. 28	Lecture 7 : Probabilistic Reasoning
Sept. 30	Lecture 8 : Graphical models
Oct. 5	Lecture 9 : Bayesian Networks
Oct. 7	Lecture 10 : Temporal Models
Oct. 12	Lecture 11 : Hidden Markov Models
Oct. 14	Lecture 12 : Kalman and Particle Filters
Oct. 19	Lecture 13 : Utility Theory
Oct. 21	**Midterm**
Oct. 26	Lecture 14 : Markov Decision Processes
Oct. 28	Lecture 15 : Game Theory

Tentative schedule (subject to change)

Date	Topic
Nov. 2	Lecture 16 : Introduction to Machine Learning
Nov. 4	Lecture 17 : Linear Models for Regression
Nov. 9	Lecture 18 : Linear Models for Classification
Nov. 11	Lecture 19 : Neural Networks
Nov. 16	Lecture 20 : Kernel Methods
Nov. 18	Lecture 21 : Gaussian Processes
Nov. 23	Lecture 22 : Sparse Kernel Machines
Dec. 2	Lecture 23 : Sampling Methods
Dec. 4	Lecture 24 : Learning Probabilistic Models
Dec. 9	Lecture 25 : Reinforcement Learning
Dec. 11	Lecture 25 : Imitation Learning
Dec. 16	Lecture 26 : Perception
Dec. 9	Lecture 27 : Future Prospects of AI and Application Domains
Dec. 16	**Final Exam**