Introduction to Statistical Machine Learning

Christfried Webers

Statistical Machine Learning Group NICTA and College of Engineering and Computer Science The Australian National University

> Canberra February – June 2013

(Many figures from C. M. Bishop, "Pattern Recognition and Machine Learning")

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Overview

Introduction Linear Algebra Probability Linear Regression 1 Linear Regression 2 Linear Classification 1 Linear Classification 2 Neural Networks 1

Neural Networks 2 Kernel Methods Sparse Kernel Methods Graphical Models 1

Graphical Models 2

Graphical Models 3

Mixture Models and FM 1 Mixture Models and EM 2 Approximate Inference

Sampling

Principal Component Analysis

Sequential Data 1 Sequential Data 2

Combining Models Selected Topics

Discussion and Summary

1of 73

Part I

Overview

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Search Machine Ranking – 2009

 Given a number of web sites which match some search phrase:
 Learn which pages most of the users are looking for.

Web Images Maps News Shopping Gmail more ▼ Sian in Web Results 1 - 10 of about 5,870,000 for Introduction to Statistical Machine Learning. (0.22 seconds) Introduction to Statistical Machine Learning 15 May 2008 ... The other speakers will detail or built upon this introduction. Statistical machine learning is concerned with the development of algorithms ... videolectures.net/mlss08au hutter isml/ - 75k - Cached - Similar pages Statistical Machine Learning (SML) Group, NICTA This course provides a broad but thorough introduction to the methods and practice of statistical machine learning. Topics covered will include Bayesian ... sml.nicta.com.au/isml09.html - 24k - Cached - Similar pages [PDF] An Introduction to Statistical Machine Learning - Introduction -File Format: PDF/Adobe Acrobat - View as HTML Statistical Machine Learning. - Introduction -. Samy Bengio, bengio@idiap.ch. Dalle Molle Institute for Perceptual Artificial Intelligence (IDIAP) ... bengio.abracadoudou.com/lectures/old/tex_intro.pdf - Similar pages

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Advanced Search

Search: () the web () pages from Australia

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Results 1 - 10 of about 3.840,000 for Introduction to Statistical Machine Learning, (0.41 seconds)

Introduction to Statistical Machine Learning - Statistical Machine ... - 2:21am 8 Jun 2009 ... This course provides a broad but thorough introduction to the methods and practice of statistical machine learning. ...

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Machine Learning c 2009. Christfried Webers, NICTA, The Australian National, University. 1of 600. Introduction to Statistical Machine Learning ...

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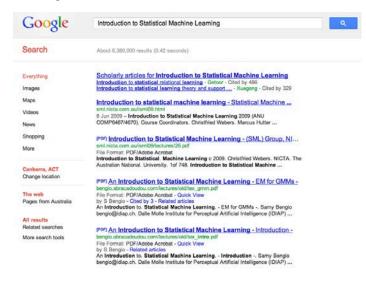
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Search Machine Ranking - 2012

Has Google learned more?



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2968 🔯	I⊤ ← Bases de Email	13/02/09 10:50	Nuevas Bases de Datos de Mexico
2969 2970 2970 2970 2970 2970 2970 2970 297	← Barrister Willi ◀ Isolde		WILL AND TESTAMENT A Valentine's Day Ecard Special Deli
071	NTI eNews	15/02/09 12:25	Super Sweet Deals From NTIus.com

2956 F + MISS MERCY... 29/01/09 23:13 -... Urgent Attention(YOUR FILE HAVE...

◆ PEPSI BOTTL... 25/07/08 11:23 -... OEP00934/UK

2960 REBECA RO... 11/02/09 18:48 + ... Dear sir/madam:

JOSEPH POON 11/02/09 12:04 +... MY PROPOSAL!!! 2959 MADAM ERL... 11/02/09 13:41 +... LOOKING FOR A TRUSTWORTHY...

nail.

10/02/09 7:45 +0... Message from eBay com au

2951 Tr christfried.web... 10/02/09 3:14 -0... Assistance, Petersen

10/02/09 14:12 + ... Fool them once, fool them twice, fool ...

9/02/09 4:53 -0800 Un negocio de por vida 1000% Renta...

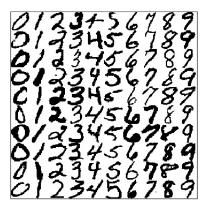
10/02/09 17:33 +... Now Contact my secretary ask him fo...

9/02/09 0:38 -0800 Un negocio de por vida 1000% Renta...

9/02/09 10:12 -0... Un negocio de por vida 1000% Renta...

 From these examples, learn to identify new incoming junk mail.

Handwritten Digit Recognition





- Given handwritten ZIP codes on letters, money amounts on cheques etc.
- Learn to recognise the correct digit written by hand.



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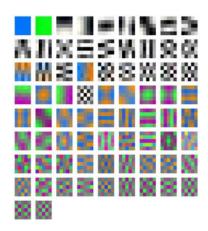
Examples





- World best computer program TD-GAMMON (Tesauro 1992, 1995) played over a million games against itself.
- Plays now on the level of human world champion.

1 Learn a statistics over patches from many images of natural scenes



50 000 patches (5 \times 5 \times 3) from the Berkeley Segmentation Database. McAuley et. al., "Learning High-Order MRF Priors of Color Images", ICML2006

Image Denoising

2 Use this knowledge to a denoise a yet unseen image

2.5 and the days to a donorous a you and on image

Original image



Noise added





McAuley et. al., "Learning High-Order MRF Priors of Color Images", ICML2006

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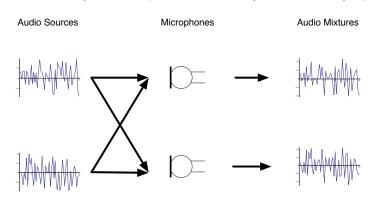
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Separating Audio Sources

Cocktail Party Problem (human brains may do it differently ;-)



(J. Steinbauer et. al., http://cnx.org/content/m15712/latest/)

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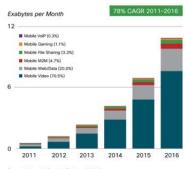
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Smart Mobile Content Delivery

- 70% of all traffic on mobile networks is video
- Streaming of video is awful because of congestions
- Preload content with spare network capacity
- Play from local storage
- Learn the user behaviour on the device (privacy!)



Figures in legend refer to traffic share in 2016. Source: Cisco VNI Mobile, 2012 Introduction to Statistical Machine Learning

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Smart Mobile Content Delivery

- Trial on Android OS
- http://watch.incoming.tv



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- Photovoltaics now very close to grid electricity in price
- Distributed system of generators
- Energy market
- Great Machine Learning Problem: Predict the solar energy output (variability primarily due to clouds) for Australia
- Pilot project in Canberra: Use cheap cameras to take 360° sky photos in several location.
- Learn to predict 3-D model of cloud movement.
- Learn orientation and efficiency of solar panels for each house from time series of energy output.
- Predict output of each solar panel for 15 min to 1 hour from current snapshots.







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Other applications of Machine Learning

- autonomous robotics,
- detecting credit card fraud,
- · detecting network intrusion,
- bioinformatics,
- neuroscience.
- medical diagnosis,
- stock market analysis,
- Stock market analysis
- playing games by self-play: Checker and Backgammon.

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Given some data (e.g. hand written digits).

 Possibly some extra information (e.g. which digit does this number represent)

 Goal: Built a machine which can learn from the given data utilising the extra information (if available).

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Definition (First Try)

Machine learning is concerned with the design and development of algorithms that allow machines to learn.

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Definition

Definition (First Try)

Machine learning is concerned with the design and development of algorithms that allow machines to learn.

- machines? computers? HAL?
- to learn?



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Definition (First Try)

Machine learning is concerned with the design and development of algorithms that allow machines to learn.

- machines? computers? HAL?
- to learn?
- need to quantify "learning"
- to improve their performance over time

Definition (Second Try)

Machine learning is concerned with the design and development of algorithms that allow computers (machines) to improve their performance over time.

- What is the source of the improved performance?
- New insights by the algorithm designer?



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- What is the source of the improved performance?
- New insights by the algorithm designer?

Definition (Final Version)

Machine learning is concerned with the design and development of algorithms that allow computers (machines) to improve their performance over time based on data.







Examples

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Definition (Mitchell, 1998)

A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E.



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- Given only some examples.
- Need to derive a relation for many more (possibly infinite) unseen examples.
- Occam's Razor (William Ockham, circa 1285 1349):
 "Plurality must never be posited without necessity"
- "The simplest explanation or strategy tends to be the best one."
- By the way: Often cited "Entities should not be multiplied unnecessarily." can not be found literally in Ockham's works. Multiple versions;—)



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- 1960's: symbolic AI; computers learn rules from data; analysis of the underlying statistics is seldom done.
- Perceptron (Rosenblatt, 1957), "Perceptrons" (Minsky and Papert, 1969)

•

- 1980's : artificial neural networks
- 1990's 2000's : statistical machine learning (kernel methods, decision trees, graphical models)
- Why Statistical Machine Learning not earlier?
 - faster computers with larger memory to represent statistical models have become available
 - numerical methods on the desktop computer (BLAS, LAPACK, Optimisation)
 - found new interesting classes of algorithms (e.g. on graphs)
 - large amounts of data available which can be tapped into (flickr, social networks)
 - many data sets with partial/incomplete data (e.g. netflix)



Definition

Machine Learning is essential when

- humans are unable to explain their expertise (speech recognition).
- humans are not around for help (navigation on Mars, underwater robotics).
- large amount of data with possible hidden relationships and correlations
- environment changes (fast) in time (mobile phone network).
- solutions need to be adapted to many particular cases (junk mail).

Example: It is easier to write a program that learns to play checkers or backgammon well by self-play rather than converting the expertise of a master player to a program.

Related Fields

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- Related Fields

- Artificial Intelligence Al
- Statistics
- Game Theory
- Neuroscience, Psychology
- Data Mining
- Computer Science
- Adaptive Control Theory



Related Fields

- Artificial intelligence is the intelligence of machines and the branch of computer science which aims to create it.
- The field was founded on the claim that human intelligence can be so precisely described that it can be simulated by a machine.
- Central areas: reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects (autonomous robotics).
- Philosophical questions: Can a machine have a mind and consciousness? Are there limits to how intelligent machines can be?





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Descriptive Statistics: Summarize or describe a collection of data

- Inferential Statistics: Draw inferences about a process taking randomness and uncertainty into account
- What can be inferred from data and some modelling assumptions?
- How reliable are the results?

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- Related Fields

- How do animals learn?
- Modelling of human learning (e.g. Bayesian models of human inductive learning)
- increasing interaction between Statistical Machine Learning and Neuroscience, Psychology e.g. NIPS - Neural Information Processing Systems Conference 2009:
 - "Discriminative Network Models of Schizophrenia",
 - "Functional network reorganization in motor cortex can be explained by reward-modulated Hebbian learning",
 - "Canonical Time Warping for Alignment of Human Behavior"
- new technologies (e.g. functional magnetic imaging resonance [fMRI])

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- searching through large data sets (databases)
- goal: extracting hidden patterns from data
- examples: bioinformatics, genetics, medicine
- genetics: how do differences in the DNA between humans relate to different risks of getting diseases such as cancer
- no magic: can not uncover patterns which are not already present in the data

Computer Science

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- "What can be (efficiently) automated?"
- Algorithms
- Data Structures
- Computational complexity theory

Adaptive Control Theory

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- consider systems with parameters changing (slowly) over time or being uncertain
- Example: aircraft which changes its weight over time depending on fuel consumption (which in turn depends on the wind)
- how to control such a system?
- how to estimate the parameters?

Examples

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Some Basic Notation

• The set of all input data is denoted as \mathcal{X} . For instance, $\mathcal{X} = \{x \mid x \text{ is an image containing a handwritten digit } \}.$

One data point with D elements :

$$\mathbf{x} = \begin{bmatrix} x_1 \\ \dots \\ x_D \end{bmatrix} = (x_1, \dots, x_D)^T.$$

• Data matrix: A set of N data points x_i , where $i = 1 \dots N$,

$$\mathbf{X} = \begin{bmatrix} x_{1,1} \dots x_{1,D} \\ x_{2,1} \dots x_{2,D} \\ \dots \\ x_{N,1} \dots x_{N,D} \end{bmatrix} = \begin{bmatrix} \mathbf{x}_1^T \\ \dots \\ \mathbf{x}_N^T \end{bmatrix}.$$

(Note: Each data point x_i is a column vector, but appears as a row vector in X.)

• If D=1, X is a vector of N scalar data points. We write

$$\mathbf{x} = \begin{bmatrix} \mathbf{x}_1 \\ \dots \\ \mathbf{x}_N \end{bmatrix}.$$

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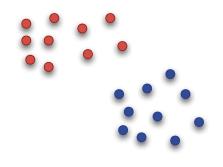
 \bullet A target can be from a finite discrete set ('labels') or from $\mathbb R.$

(Note: Can extend this idea to m-dimensional labels and \mathbb{R}^m .)

• Set of Targets \mathcal{T} , e.g. $\mathcal{T} = \{\text{one, two, three, four, five, six, seven, eight, nine, zero}\}.$

• An ordered set of
$$N$$
 scalar labels $\mathbf{t} = \begin{bmatrix} t_1 \\ \dots \\ t_N \end{bmatrix} = (t_1,\dots,t_N)^T.$

Supervised Learning



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Example.

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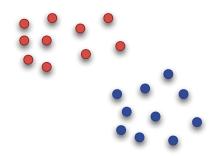
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Supervised Learning



- Given are pairs of data $x_i \in \mathcal{X}$ and targets $t_i \in \mathcal{T}$ in the form (x_i, t_i) , where i = 1..N.
- Learn a mapping between the data X and the target t which generalises well to new data.

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Unsupervised Learning



- Given only the data $x_i \in \mathcal{X}$.
- Discover (=learn) some interesting structure inherent in the data X.

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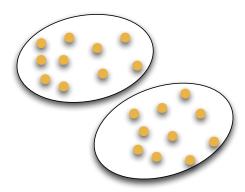
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Unsupervised Learning



- Given only the data $x_i \in \mathcal{X}$.
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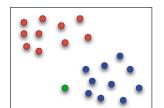
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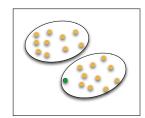
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Some Fundamental Types of Learning

Testing - Supervised versus Unsupervised Learning





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Reinforcement Learning

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- Example: Game playing. There is one reward at the end of the game (negative or positive).
- Find suitable actions in a given environment with the goal of maximising some reward.
- correct input/output pairs never presented
- Reward might only come after many actions.
- Current action may not only influence the current reward, but future rewards too.

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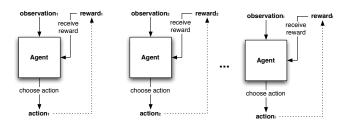
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Reinforcement Learning



- Exploration versus Exploitation.
- Well suited for problems with a long-term versus short-term reward trade-off.
- Naturally focusing on online performance.

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Some Fundamental Types of Learning

Active Learning

- The algorithm may choose which data $x_i \in \mathcal{X}$ to select next when building the model.
- The order of the data is actively chosen by the algorithm at run-time.

Transduction

- The algorithms is allowed to use the test data (but of course not labels!) when building a model.
- Estimation with missing variables.
- Co-training with two different but related data sets.
- ... and others.



Batch Learning

- All training data $X = \{x_1, \dots, x_n\}$ and targets $\mathbf{t} = \{t_1, \dots, t_n\}$ are given.
- Learn a mapping from x_i to t_i which can then be applied to yet unseen data $X' = \{x'_1, \dots, x'_m\}$ to find $\mathbf{t}' = \{t'_1, \dots, t'_m\}$.
- Online Processing
 - Pairs of (x_i, t_i) become available one at a time.
 - At each step, learn and refine a mapping from x_i to t_i which can then be applied to yet unseen data x_i'.

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- Journal of Machine Learning Research
- Machine Learning
- IEEE Transactions on Pattern Analysis and Machine Intelligence
- Neural Computation
- Neural Networks
- IEEE Transactions on Neural Networks
- Annals of Statistics
- Journal of the American Statistical Association
- SIAM Journal on Applied Mathematics (SIAP)



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- Algorithmic Learning Theory (ALT)
- Computational Learning Theory (COLT)
- Uncertainty in Artificial Intelligence (UAI)
- Neural Information Processing Systems (NIPS)
- European Conference on Machine Learning (ECML)
- International Conference on Machine Learning (ICML)
- International Joint Conference on Artificial Intelligence (IJCAI)
- International Conference on Artificial Neural Networks (ICANN)



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 dynamically typed programming language (no declarations for variables)

- supports object oriented, imperative, and functional programming style
- many built-in data types (str, tuple, list, set, dict, ...)
- packages for scientific programming (numpy, scipy)
- easily extensible to use code written in C and C++ (or FORTRAN for that matter)
- Python runs on Windows, Linux/Unix, Mac OS X, OS/2, Amiga, Palm Handhelds, and Nokia mobile phones
- OSI-approved Open Source License

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- Efficient Learning, Large-scale Inference, and Optimization Toolkit
- Mozilla Public License
- Two Layer
 - Functional Interface
 - Graphical User Interface

Elefant - System Diagram

Applications Document Bioinformation teinforcement Dotimization Analysis of NLP ELEFANT Toolkit in Python Programming Interface Python Application Programming Interface Graphical User Interface Components ML Algorithm Components for Components for sources and pre-Components Model Selection data visualization Light weight component based framework **Core ELEFANT Modules** Various machine learning algorithms Support Vector Machines, Feature selections, Estimation, Classification, Quantile and Novelty detection, Neural Networks, Decision Trees, CRF, Graphical Models, etc. Kernels - Linear, RBF, Dot Algorithms written in C or Optimizers and Solvers Product. String. Multi class C++ or JAVA or Fortran Linear Algebra Library: Natural Language processing tools PyPETSc. PyTAO, PySLEPc, PyOOQP Interface to GateD and UIMA Scipy and Numpy External packages Packages for extending C. C++, Fortran and JAVA code into python: CTypesLib, SWIG, JPype, F2PY Fortran External Modules C or C++ External Packages: JAVA External Packages BLAS/LAPACK PETSc, TAO, SLEPc, OOQP UIMA GATE Mallet

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