T-61.5140 Machine Learning:
Advanced Probabilistic Methods

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Course Organization: Personnel

Lecturer: Jaakko Hollmén, D.Sc.(Tech.)
  - Lectures on Thursdays, from 10.15 - 12.00 in T3
Course Assistant: Tapani Raiko, D.Sc.(Tech.)
  - Problem sessions on Fridays, from 10.15-12.00 in T3
For the schedule, holidays and special program, see
Course Material

Lecture slides and lectures
- Lecture notes (aid the presentation on the lectures)
- Lecture notes (contain extra material)

Course book
- Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, 2006
  - Chapters 8, 9, 10, 11, and 13 covered during the course

Problem sessions
- Problems and solutions
- Demonstrations
Participating on the Course

- Interest in machine learning
- Student number at TKK needed
- Course registration on the WebTopi System: https://webtopi.tkk.fi
- Prerequisites: T-61.3050 Machine Learning: Basic principles taught in Autumn by Kai Puolamäki and the necessary prerequisites for that course
Passing the Course (5 ECTS credit points)

- Attend the lectures and the exercise sessions for best learning experience :-)
- Browse the material before attending the lectures and complete the exercises
- Complete the term project requiring solving of a machine learning problem by programming
- Pass the examination, next exam scheduled: Thursday, 15th of May, morning
- Requirements: passed exam and a acceptable term project, bonus for active participation and excellent term project (+1)
Relation to Other Courses

This course replaces the old course

- T-61.5040 Learning Models and Methods
- no more lectures, last exam in March, 2008

Little overlap expected in parts with courses like

- T-61.3050 Machine Learning: Basic Principles
- T-61.5130 Machine Learning and Neural Networks
- T-61.3020 Principles of Pattern Recognition

Some overlap is good!
Resources on Machine Learning

Machine Learning: Basic Principles course book

- Ethem Alpaydin: Introduction to Machine Learning, MIT Press, 2004

Conferences on Machine Learning:

- European Conference on Machine Learning (ECML), co-located with the Principles of Knowledge Discovery and Data Mining (PKDD)
Resources on Machine Learning

Journals in Machine Learning

- Also domain-related journals: BMC Bioinformatics, Bioinformatics, etc.

Community-based resources

- Mailing lists: UAI, connectionists, ML-news, ml-list, kdnuggets, etc.
What is machine learning?

- Machine learning people develop algorithms for computers to learn from data.
- We don’t cover all of machine learning!
- The modern approach to machine learning: the probabilistic approach
- The probabilistic approach to machine learning
  - Generative models, Finite mixture models
  - Graphical models, Bayesian networks
  - Inference and learning
  - Expectation Maximization algorithm
Topics covered on the course

Central topics

- Random variables
- Independence and conditional independence
- Bayes’s rule
- Naive Bayes classifier, finite mixture models, k-means clustering
- Expectation Maximization algorithm for inference and learning
- Computational algorithms for exact inference
- Computational algorithms for approximate inference
- Sampling techniques
- Bayesian modeling
Three simple examples

- Simple coin tossing with one coin
- A game two players: coin tossing with two coins
- Naive Bayes classification in a bioinformatics application
Simple coin tossing with one coin

- Throw a coin
- The coin lands either on heads (H) or tails (T).
- We don’t know the outcome before the experiment
- We model the outcome with a random variable $X$
  - $X = \{H, T\}$, $P(X = H) = ?$, $P(X = T) = 1 - ?$
- Perform an experiment, estimate the "?"
- Parameterization: $P(X = T) = \theta$, $P(X = H) = 1 - \theta$
- Fixed parameters tell about the properties of the coin
Simple coin tossing with one coin

After the experiment, we have $X_1 = x_1, \ldots, X_{12} = x_{12}$

- The likelihood function is the probability of observed data $P(x_1, \ldots, x_{12}; \theta_1, \theta_2, \ldots, \theta_{12})$
- What can we assume? What do we want to assume? Fair coin?
- Coin tosses are independent and identically distributed random variables
- Likelihood function factorizes to $P(x_1; \theta)P(x_2; \theta) \ldots P(x_{12}; \theta)$
- Maximum likelihood estimator gives a parameter value that maximizes the likelihood
Guessing game with two coins

Description of the game:
- Player one, player two
- Coin number one: $P(X_1 = T) = \theta_1$ (unknown)
- Coin number two: $P(X_2 = T) = \theta_2$ (unknown)
- Player one chooses a coin randomly, either one or two
- model the choice as a random variable
- Choose coin: $P(C = c_1) = \pi_1$, or $P(C = c_2) = \pi_2$
- $\pi_1 + \pi_2 = 1 \Rightarrow \pi_2 = 1 - \pi_1$
Guessing game with two coins

We would like to do better than guessing, let’s model the situation

- Outcome of the coin from coin j: $P(X|C = j)$
- Ingredients: $P(X|C = 1)$, $P(X|C = 2)$, $P(C)$
- First, the coin is chosen (secretly), then, thrown
- The outcome of the coin depends on the choice
- $P(X, C) = P(C)P(X|C)$
- $P(X) = \sum_{j=1}^{2} P(C = j)P(X|C = j)$

What is the probability of heads?
Guessing game with two coins

Guess which coin it was?

- $P(C = j | X)$? We know $P(C)$, $P(X|C)$, $P(X)$
- Use the Bayes’s rule!

$$P(C|X) = \frac{P(C)P(X|C)}{P(X)}$$

Which coin was it more probably if you observed heads?
Naive Bayes classification

Classify gastric cancers using DNA copy number amplification data $X_1, \ldots, X_6$

- The observed data: $X_i = \{0, 1\}, i = 1, \ldots, 6$
- Class labels: $C = 1, 2$
- The joint probability distribution
  $P(X_1, X_2, X_3, X_4, X_5, X_6, C)$
- Assumptions creep in...
  $X_i$ and $X_j$ are conditionally independent given $C$

  $P(X_1, X_2, X_3, X_4, X_5, X_6, C) = P(C)P(X_1|C)P(X_2|C) \ldots P(X_6|C)$

- Interest in $P(C|X_1, X_2, \ldots, X_6)$

Demo here!
Problem sessions

Schedule for the problem sessions:

▶ First Problem session: 25 of January, 10.15-12.00
▶ Problems posted on the Web site one week before the session