

# Lecture 1: Basic Concepts of Machine Learning

## Cognitive Systems - Machine Learning

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Based on slides prepared March 2005 by Maximilian Röglinger,  
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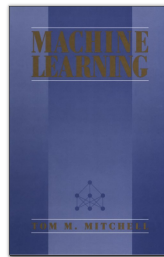
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# Organization of the Course

- **Homepage:**

<http://www.uni-bamberg.de/kogsys/teaching/courses/lernende-systeme/>

- **Textbook:** Tom Mitchell (1997).  
Machine Learning. McGraw Hill.



- **Practice**

- ▶ Rapid Miner
- ▶ Programming Assignments
- ▶ **Marked exercise sheets and extra points for the exam**

# Outline of the Course

- Basic Concepts of Machine Learning
- Basic Approaches to Classification Learning
  - ▶ Foundations of Classification Learning
  - ▶ Decision Trees
  - ▶ Perceptrons and Multilayer-Perceptrons
  - ▶ Human Concept Learning
- Special Aspects of Classification Learning
  - ▶ Inductive Logic Programming
  - ▶ Genetic Algorithms
  - ▶ Instance-based Learning
  - ▶ Bayesian Learning
  - ▶ Kernel Methods

# Outline of the Course

- Theoretical Aspects of Learning
  - ▶ Evaluating Hypotheses
  - ▶ Computational Learning Theory
  
- Learning Programs and Strategies
  - ▶ Reinforcement Learning
  - ▶ Inductive Function Synthesis
  - ▶ Analytical Learning
  
- Further Topics and Applications in Machine Learning (e.g. data mining)

# Course Objectives

- Introduce central approaches of machine learning
- Point out relations to human learning
- Provide understanding of the fundamental structure of learning problems and processes
- **Explore algorithms that solve such problems**

## Some Quotes as Motivation

*If an expert system—brilliantly designed, engineered and implemented—cannot learn not to repeat its mistakes, it is not as intelligent as a worm or a sea anemone or a kitten.*

Oliver G. Selfridge, from *The Gardens of Learning*

*If we are ever to make claims of creating an artificial intelligence, we must address issues in natural language, automated reasoning, and machine learning.*

George F. Luger

# What is Machine Learning?

- Some definitions
  - ▶ *Machine learning refers to a system capable of the **autonomous acquisition and integration of knowledge**. This capacity to **learn from experience, analytical observation, and other means**, results in a system that can **continuously self-improve and thereby offer increased efficiency and effectiveness**.*

<http://www.aaai.org/AITopics/html/machine.html>
  - ▶ *The field of machine learning is concerned with the question of how to **construct computer programmes that automatically improve with experience**.*

Tom M. Mitchell, Machine Learning (1997)

# ML as Multidisciplinary Field

Machine learning is inherently a **multidisciplinary** field

- artificial intelligence
- probability theory, statistics
- computational complexity theory
- information theory
- philosophy
- psychology
- neurobiology
- ...

e.g. CALD (Center of Automated Learning and Discovery at CMU)



# Knowledge-based vs. Learning Systems

**Knowledge-based Systems:** Acquisition and modeling of common-sense knowledge and expert knowledge

- ⇒ limited to given knowledge base and rule set
- ⇒ Inference: **Deduction** generates no new knowledge but makes implicitly given knowledge explicit
- ⇒ **Top-Down:** from rules to facts

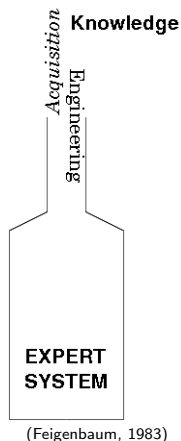
**Learning Systems:** Extraction of knowledge and rules from examples/experience

- Teach the system vs. program the system
- Learning as **inductive process**
- ⇒ **Bottom-Up:** from facts to rules

# Knowledge-based vs. Learning Systems

- ⇒ *A flexible and adaptive organism cannot rely on a fixed set of behavior rules but must learn (over its complete life-span)!*
- ⇒ Motivation for Learning Systems

# Knowledge Acquisition Bottleneck



- Break-through in computer chess with *Deep Blue*: Evaluation function of chess grandmaster Joel Benjamin. *Deep Blue* cannot change the evaluation function by itself!
- Experts are often not able to verbalize their special knowledge.  
⇒ Indirect methods: Extraction of knowledge from expert *behavior* in *example* situations (diagnosis of X-rays, controlling a chemical plant, ...)

# Merit of Machine Learning

- Great practical value in many application domains
- Data Mining: large databases may contain valuable implicit regularities that can be discovered automatically (outcomes of medical treatments, consumer preferences)
- Poorly understood domains where humans might not have the knowledge needed to develop efficient algorithms (human face recognition from images)
- Domains where the program must dynamically adapt to changing conditions (controlling manufacturing processes under changing supply stocks)

# Learning as Induction

Deduction		Induction	
All humans are mortal.	(Axiom)	Socrates is human.	(Background K.)
Socrates is human.	(Fact)	Socrates is mortal.	(Observation(s))
<i>Conclusion:</i>		<i>Generalization:</i>	
Socrates is mortal.		All humans are mortal.	

**Deduction:** from general to specific  $\Rightarrow$  **proven** correctness

**Induction:** from specific to general  $\Rightarrow$  (**unproven**) knowledge gain

**Induction generates hypotheses  
not knowledge!**

# Epistemological problems

⇒ pragmatic solutions

- *Confirmation Theory*: A hypothesis obtained by generalization gets supported by new observations (not proven!).

- *grue* Paradox:

*All emeralds are grue.*

*Something is grue, if it is green before a future time  $t$  and blue thereafter.*

⇒ Not learnable from examples!

# Inductive Learning Hypothesis

- As shown above inductive learning is **not** proven correct
- The learning task is to determine a hypothesis  $h \in H$  identical to the target concept  $c$  for all possible instances in instance space  $X$   
 $(\forall x \in X)[h(x) = c(x)]$
- Only training examples  $D \subset X$  are available
- Inductive algorithms can at best guarantee that the output hypothesis  $h$  fits the target concept over  $D$   
 $(\forall x \in D)[h(x) = c(x)]$
- **Inductive Learning Hypothesis:** Any hypothesis found to approximate the target concept well over a sufficiently large set of training examples will also approximate the target function well over other unobserved examples

# Concept and Classification Learning

## Concept learning:

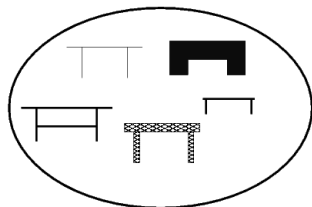
- Objects are clustered in concepts.

**Extensional:** (infinite) set  $X$  of all exemplars

**Intensional:** finite characterization

$$T = \{x \mid \text{has-3/4-legs}(x), \text{has-top}(x)\}$$

- Construction of a finite characterization from a subset of examples in  $X$  (“training set”  $D$ ).
- $h : X \rightarrow \{0, 1\}$        $c(x) \in \{0, 1\}$



## Natural extended to classes:

- Identification of relevant attributes and their interrelation, which characterize an object as member of a class.
- $h : X \rightarrow K$        $c(x) \in \{k_1, \dots, k_n\}$



# Constituents of Classification Learning

- A set of training examples  $D \subset X$   
Each example is represented by an  $n$ -ary feature vector  $x \in X$  and associated with a class  $c(x) \in K$ :  $\langle x, c(x) \rangle$
- A learning algorithm constructing a hypothesis  $h \in H$
- A set of new objects, also represented by feature vectors which can be classified according to  $h$

## Examples for features and values

- Sky  $\in$  {sunny, rainy}
- AirTemp  $\in$  {warm, cold}
- Humidity  $\in$  {normal, high}

# Concept Learning / Examples

- Occurrence of Tse-Tse fly yes/no, given geographic and climatic attributes
- Risk of cardiac arrest yes/no, given medical data
- Credit-worthiness of customer yes/no, given personal and customer data
- Safe chemical process yes/no, given physical and chemical measurements
  
- Generalization of pre-classified example data, application for prognosis

# Learning Terminology

- Supervised learning: pre-classified examples
- Unsupervised learning: no classification available (data exploration)

## Different approaches

- Concept/Classification vs. Policy Learning
- Symbolic vs. Statistical/Neural Network Learning
- Inductive vs. Analytical Learning

## Some General Learning Strategies

- rote learning/learning by being told (no generalization/induction)
- learning by analogy (generalization over base and target problem)
- learning from discovery (unsupervised learning)
- learning from experience
- learning from examples (classical inductive approach)

# Further Example Learning Problems

- Handwriting recognition
- Play checkers
- Robot driving

# Designing a Learning System

- **Learning system:** 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  $E$ .
- i.e. Handwriting recognition
  - ▶  $T$ : recognizing and classifying handwritten words within images
  - ▶  $P$ : percent of words correctly classified
  - ▶  $E$ : database of handwritten words with given classifications
- consider designing a program to learn to recognize handwritten words in order to illustrate some of the basic design issues and approaches to machine learning

# Designing a Learning System

## 1 Choosing the Training Experience

- ▶ direct or indirect feedback
  - ▶ degree to which the learner controls the sequence of training examples
  - ▶ representativity of the distribution of the training examples
- ⇒ significant impact on success or failure

## 2 Choosing the Target Function

- ▶ determine what type of knowledge will be learned
- ▶ most obvious form is some kind of combination of feature values which can be associated with a class (word/letter)

## 3 Choosing a Representation for the Target Function

- ▶ e.g. a large table, a set of rules, a linear function, an arbitrary function

## 4 Choosing a Learning Algorithm

- ▶ Decision Tree, Multi-Layer Perceptron, ...

## 5 Presenting Training Examples

- ▶ all at once
- ▶ incrementally

## Recapitulation: Notation

- **Instance Space**  $X$ : set of all possible examples over which the concept is defined (possibly attribute vectors)
- **Target Concept**  $c : X \rightarrow \{0, 1\}$ : concept or function to be learned  
**Target Class**  $c : X \rightarrow \{k_1, \dots, k_n\}$
- **Training example**  $x \in X$  of the form  $\langle x, c(x) \rangle$
- **Training Set**  $D$ : set of all available training examples
- **Hypothesis Space**  $H$ : set of all possible hypotheses according to the hypothesis language
- **Hypothesis**  $h \in H$ : boolean valued function of the form  $X \rightarrow \{0, 1\}$  or  $X \rightarrow K$

$\Rightarrow$  the goal is to find a  $h \in H$ , such that  $(\forall x \in X)[h(x) = c(x)]$

# Hypothesis Language

- $H$  is determined by the predefined language in which hypotheses can be formulated
- e.g.: Conjunctions of feature values  
vs. Disjunction of conjunctions  
vs. matrix of real numbers  
vs. Horn clauses  
...
- Hypothesis language and learning algorithm are highly interdependent
- Each hypothesis language implies a bias!



# Properties of Hypotheses

- general-to-specific ordering
  - ▶ naturally occurring order over  $H$
  - ▶ learning algorithms can be designed to search  $H$  exhaustively without explicitly enumerating each hypothesis  $h$
  - ▶  $h_i$  is **more\_general\_or\_equal\_to**  $h_k$  (written  $h_i \geq_g h_k$ )  
 $\Leftrightarrow (\forall x \in X)[(h_k(x) = 1) \rightarrow (h_i(x) = 1)]$
  - ▶  $h_i$  is (strictly) **more\_general\_to**  $h_k$  (written  $h_i >_g h_k$ )  
 $\Leftrightarrow (h_i \geq_g h_k) \wedge (h_k \not\geq_g h_i)$
  - ▶  $\geq_g$  defines a **partial ordering** over the Hypothesis Space  $H$

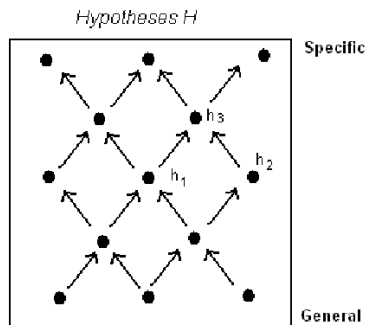
# Running Example

- example target concept *Enjoy*: “days on which Aldo enjoys his favorite sport”
- set of example days  $D$ , each represented by a set of attributes

Example	<i>Sky</i>	<i>AirTemp</i>	<i>Humidity</i>	<i>Wind</i>	<i>Water</i>	<i>Forecast</i>	<i>Enjoy</i>
1	Sunny	Warm	Normal	Strong	Warm	Same	Yes
2	Sunny	Warm	High	Strong	Warm	Same	Yes
3	Rainy	Cold	High	Strong	Warm	Change	No
4	Sunny	Warm	High	Strong	Cool	Change	Yes

- the task is to learn to predict the value of *Enjoy* for an arbitrary day, based on the values of its other attributes

# Properties of Hypotheses - Example



$h_1$  = Aldo loves playing Tennis if the sky is sunny

$h_2$  = Aldo loves playing Tennis if the water is warm

$h_3$  = Aldo loves playing Tennis if the sky is sunny and the water is warm

$\Rightarrow h_1 >_g h_3, h_2 >_g h_3, h_2 \not>_g h_1, h_1 \not>_g h_2$

# Properties of Hypotheses

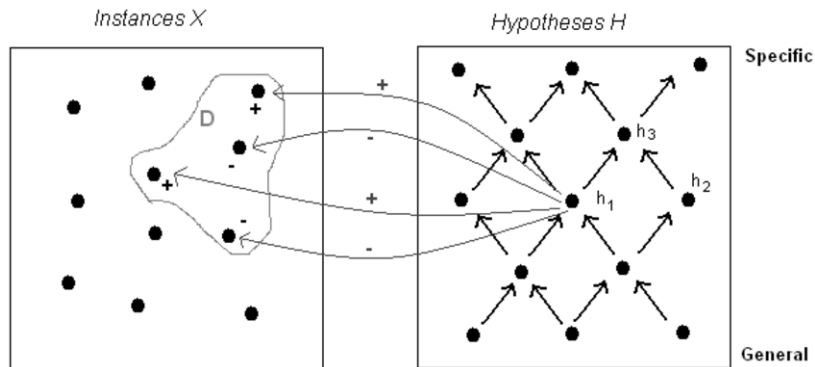
- consistency

- ▶ a hypothesis  $h$  is **consistent** with a set of training examples  $D$  iff  $h(x) = c(x)$  for each example  $\langle x, c(x) \rangle$  in  $D$

$$\text{Consistent}(h, D) \equiv (\forall \langle x, c(x) \rangle \in D)[h(x) = c(x)]$$

- ▶ that is, every example in  $D$  is classified correctly by the hypothesis

# Properties of Hypotheses - Example



$h_1$  is consistent with  $D$

# Learning Involves Search

- Searching through a space of possible hypotheses to find the hypothesis that best fits the available training examples and other prior constraints or knowledge
- Different learning methods search different hypothesis spaces
- Learning methods can be characterized by the conditions under which these search methods converge toward an “optimal” hypothesis