Artificial Intelligent Systems

(BMA-EL-IZB-LJ-RE 1. year 2024/2025)

Introduction

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Introductory Topics

- From robots to autonomous agents
- Artificial perception
- Artificial intelligence
- Introduction to Soft Computing
- Introduction to Machine Learning
- An example of Bayesian reasoning

From robots to autonomous agents

Robot - definition

- SSKJ (Slovene Literary Language Dictionary): *"An electronically controlled **device** that uniformly performs the pre-programmed tasks that are often harmful to human health."*
- RIA (Robotic Industries Association): *"A reprogrammable, multifunctional **manipulator** designed to move material, parts, tools or specialized devices with variable programmed motions for performing a variety of tasks."*
- Wikipedia: *"A mechanical or virtual **artificial agent**, usually an electro-mechanical machine that is guided by a computer program or electronic circuitry."*

Types of robots according to their usage

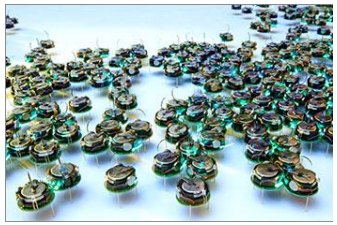
- Industrial and work robots
- Domestic or household robots
- Medical robots
- Personal assistant robots
- Military and police robots
- Entertainment and pet robots
- Research robots

Types of robots according to their locomotion and cinematics

- Stationary robots and robotic arms
- Mobile robots with wheels
- Mobile robots with legs
- Swimming robots.
- Flying robots.
- Swarm robots
- …



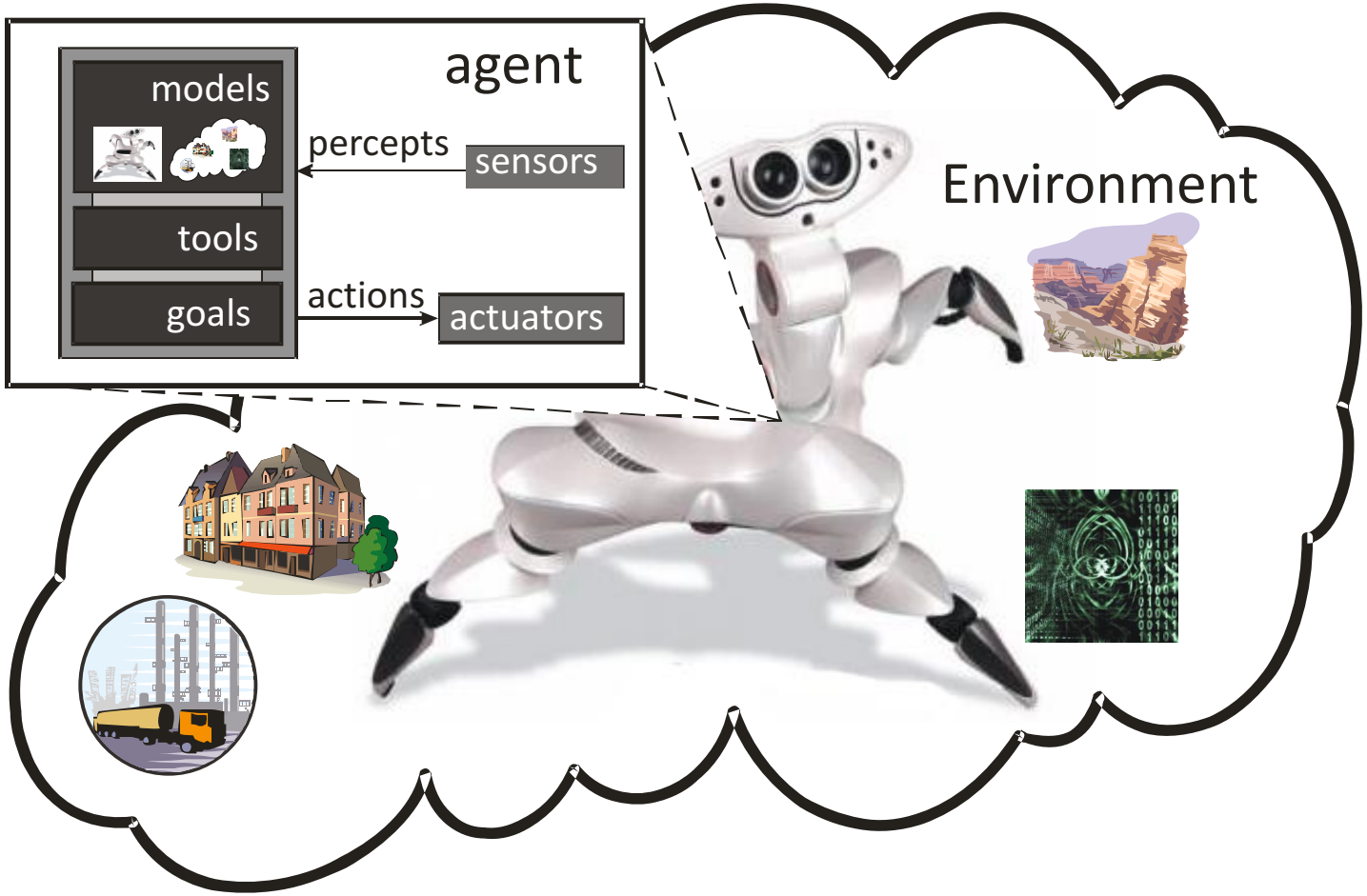



Autonomous agent – definition

- Autonomous agent is a system:
  - *situated within and/or a part of an environment,*
  - *that senses that environment,*
  - *and acts on it, over time,*
  - *in pursuit of its own agenda.*
- Examples of non-biological autonomous agents are:
  - *autonomous robots,*
  - *program agents,*
  - *virtual assistants,*
  - *artificial life agents,*
  - *computer viruses and worms.*

THE BASIC MODEL OF AUTONOMOUS AGENTS



Man as an autonomous agent

- Man is the ultimate example of an autonomous agent.
- With artificial agents, we are trying to imitate and surpass the capabilities of humans in solving the selected tasks

QUESTIONS

- What are the types of robots according to their usage?
- What are the types of robots according to their locomotion and cinematics?
- What is the definition of an autonomous agent?
- Give some examples of autonomous agents.

Artificial Perception

Artificial Perception

- ***Perception*** is the process of recognizing and interpreting sensory stimuli that enable an agent to be aware of the presence of objects or other agents as well as their mutual relations in its surrounding environment

- Perception is the basis for ***cognition,*** which is the process of translating the obtained ***percepts*** about the environment into relevant concepts (i.e., what can we say about what).

- ***Recognition*** is the perception of the already known objects, relations and events.

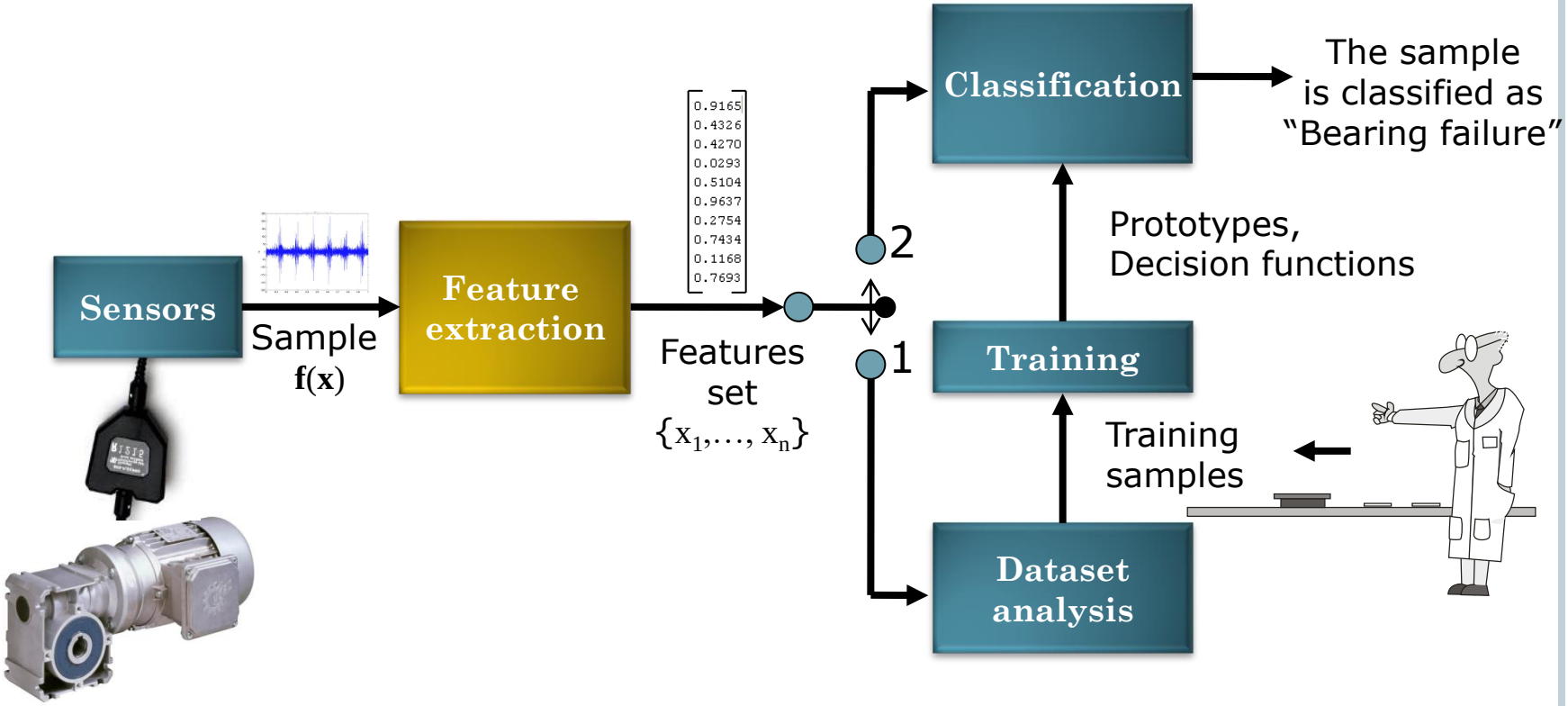
- ***Artificial perception*** is an imitation of these processes that is implemented in artificial autonomous agents.

Pattern recognition system

- A basic pattern recognition system usually consists of:
  - A sensor unit for data acquisition,
  - A unit for feature extraction,
  - A unit for pattern classification.
- Such pattern recognition systems work in two modes:
  1. In the **training** mode, the system is adapted to the given application domain,
  2. In the **operation** mode, the system classifies the objects in the application domain.
- In the training mode, a finite set of samples is mapped into a training set that is then used by training algorithms.
- The results of the training algorithms are prototypes used for pattern matching or decision functions. These are then used by the working algorithm that classifies test samples.

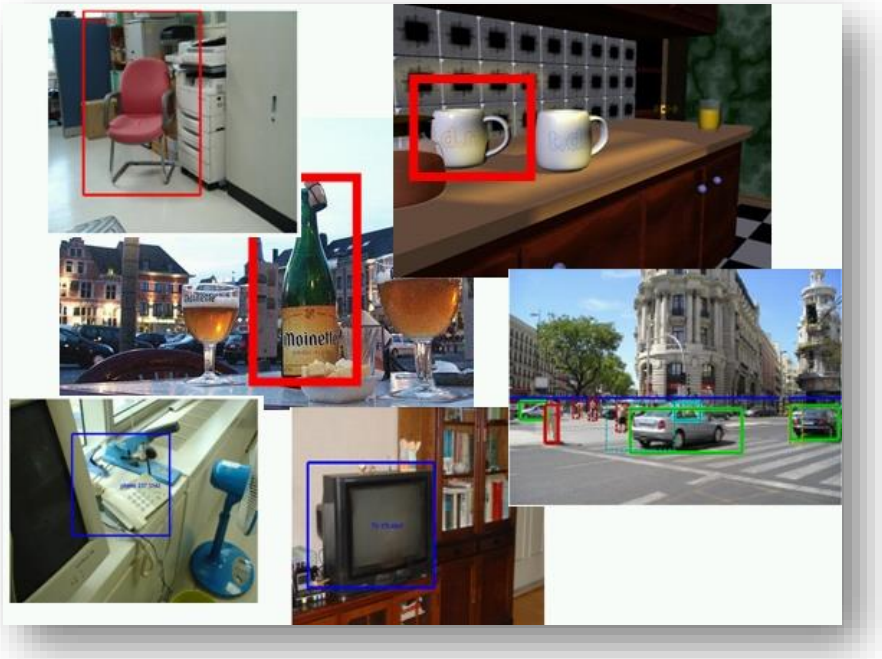
Pattern recognition system

Example: A system for detecting defects in electromechanical devices that is based on the analysis of vibrations (sounds) .



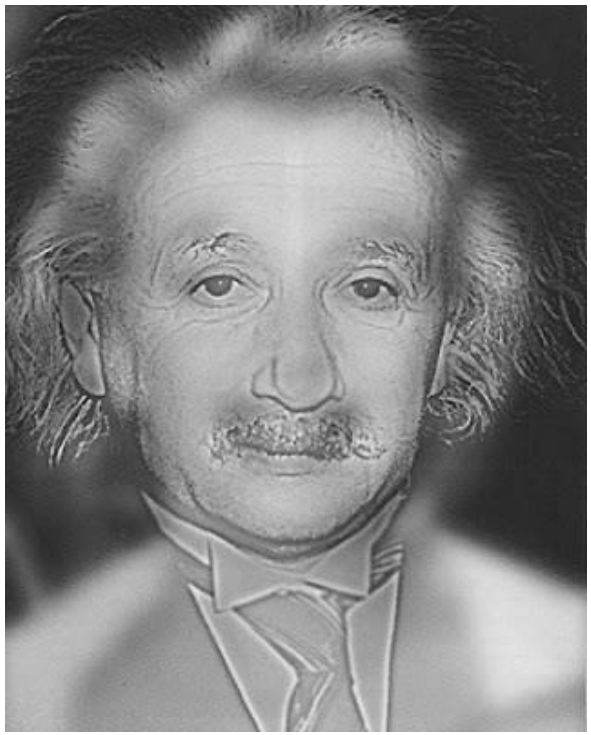
Artificial perception based on image analysis

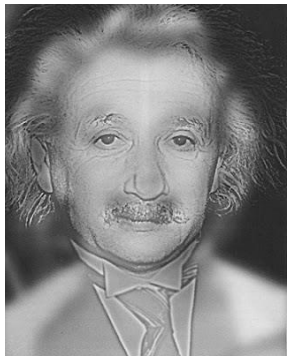
- In computer vision, the process of artificial perception is performed by computer algorithms that analyze and ***partition*** input images into ***sub-segments*** or ***regions*** that represent some meaningful entities (objects, creatures etc), and identify their mutual relations.



Visual perception of images

- Human visual perception is not a simple mapping of the stimuli of the retina (an image on the retina) into some symbolic representation

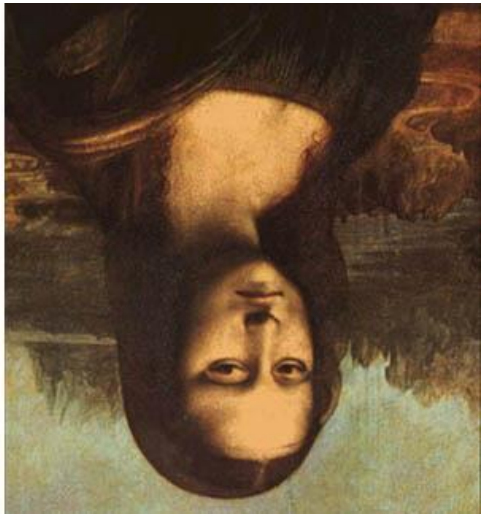


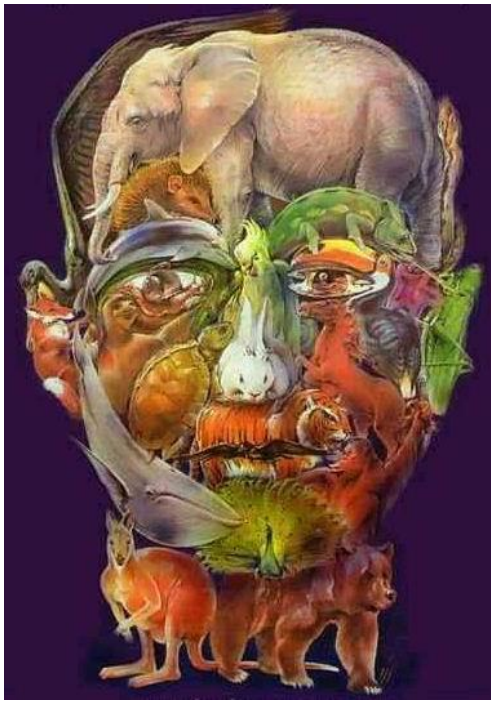


Visual perception of images

- Optical illusions reveal complex characteristics of human perception of images.

Face perception





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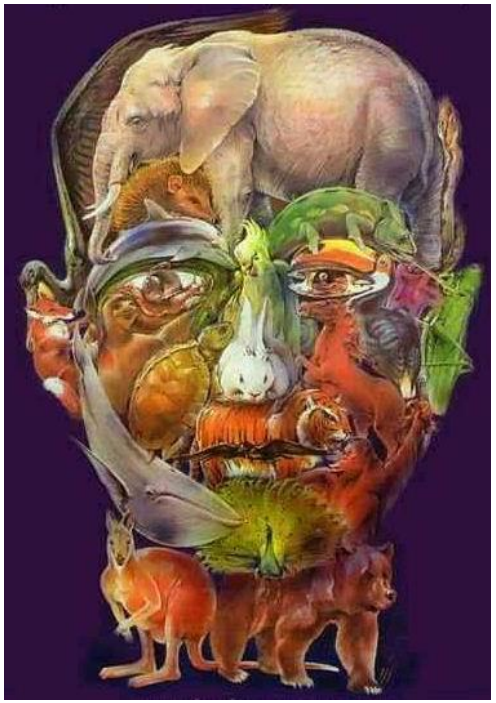
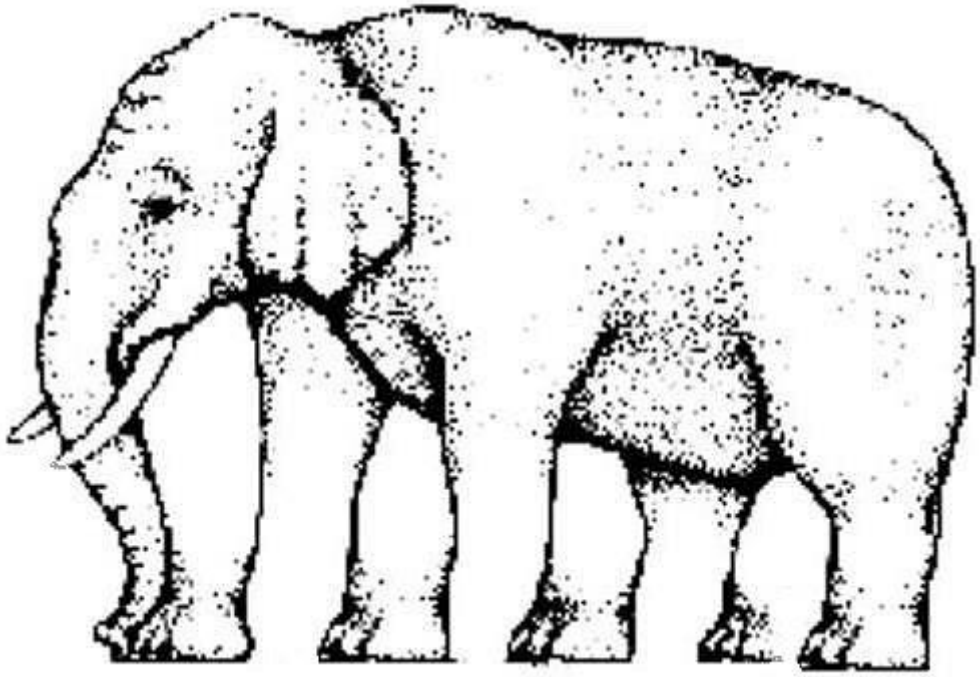


Visual perception of images

Perception of the depth of space

Visual perception of images

Local vs. global perception



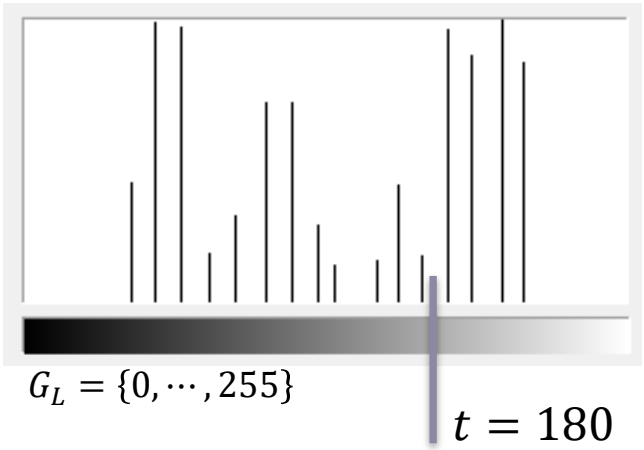
Computational algorithms for segmentation of images

- Image segmentation techniques based on identifying ***homogeneous*** image regions
- Image segmentation techniques based on detecting image contours.
- Detecting object regions using integral images and cascade classifiers

A SIMPLE GRAY IMAGE THRESHOLDING TECHNIQUE

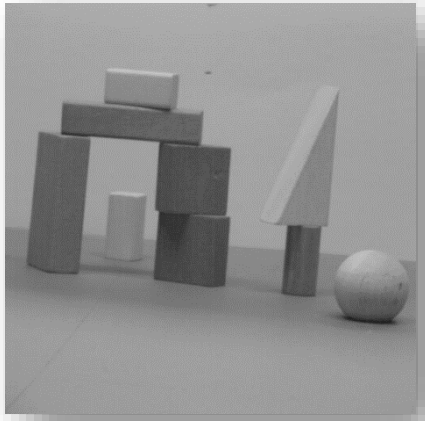
$$f(x,y) = \begin{Bmatrix} 192, & 198, & 209, & 189, & 182, & 209, & 208, & 209 \\ 183, & 190, & 122, & 53, & 54, & 114, & 206, & 209 \\ 176, & 149, & 49, & 59, & 108, & 53, & 161, & 209 \\ 175, & 105, & 101, & 53, & 60, & 57, & 114, & 207 \\ 181, & 93, & 78, & 71, & 70, & 117, & 99, & 204 \\ 187, & 109, & 46, & 64, & 45, & 63, & 126, & 202 \\ 185, & 152, & 61, & 107, & 47, & 66, & 176, & 200 \\ 180, & 177, & 131, & 86, & 96, & 159, & 191, & 198 \end{Bmatrix}$$

$$P_i = \frac{n_i}{n}$$

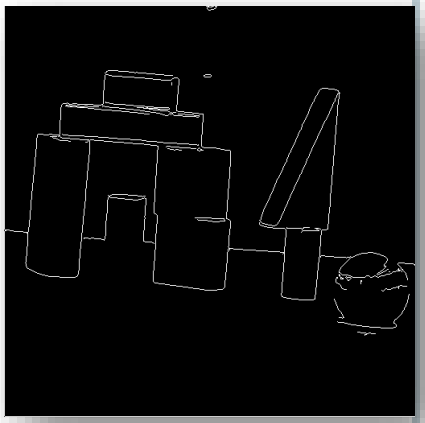


Canny Edge Detector

- The Canny edge detector is an edge detection operator that uses a multi-stage algorithm to detect a wide range of edges in images.

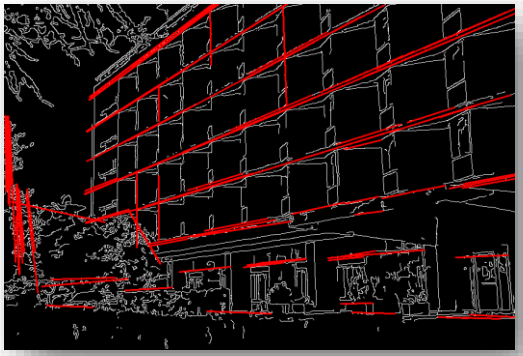


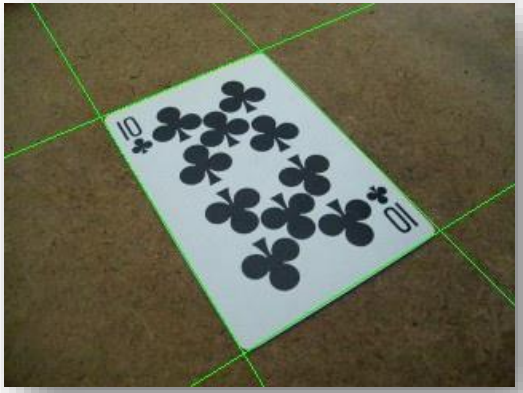
- Apply Gaussian filter to smooth the image in order to remove the noise
- Find the intensity gradients of the image
- Apply non-maximum suppression to get rid of spurious response to edge detection
- Apply double threshold to determine potential edges
- Track edge by hysteresis: Finalize the detection of edges by suppressing all the other edges that are weak and not connected to strong edges.



Contour detection using Hough transform

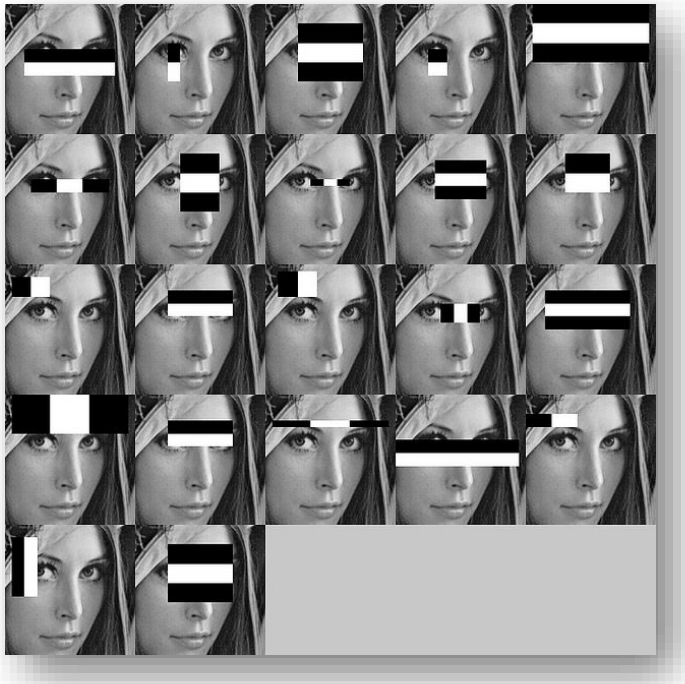
- The purpose of the technique is to find imperfect instances of objects within a certain class of shapes by a voting procedure.



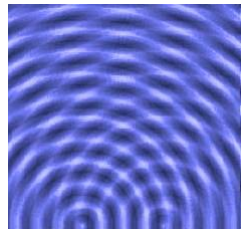


Detecting object regions using integral images and cascade classifiers

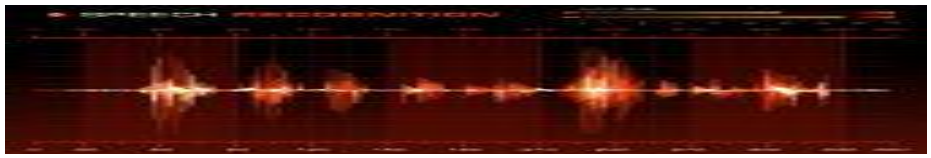
- The Viola–Jones algorithm is often used that has four stages:
  - Haar Feature Selection
  - Creating an Integral Image
  - Adaboost Training
  - Cascading Classifiers



Artificial perception of sound

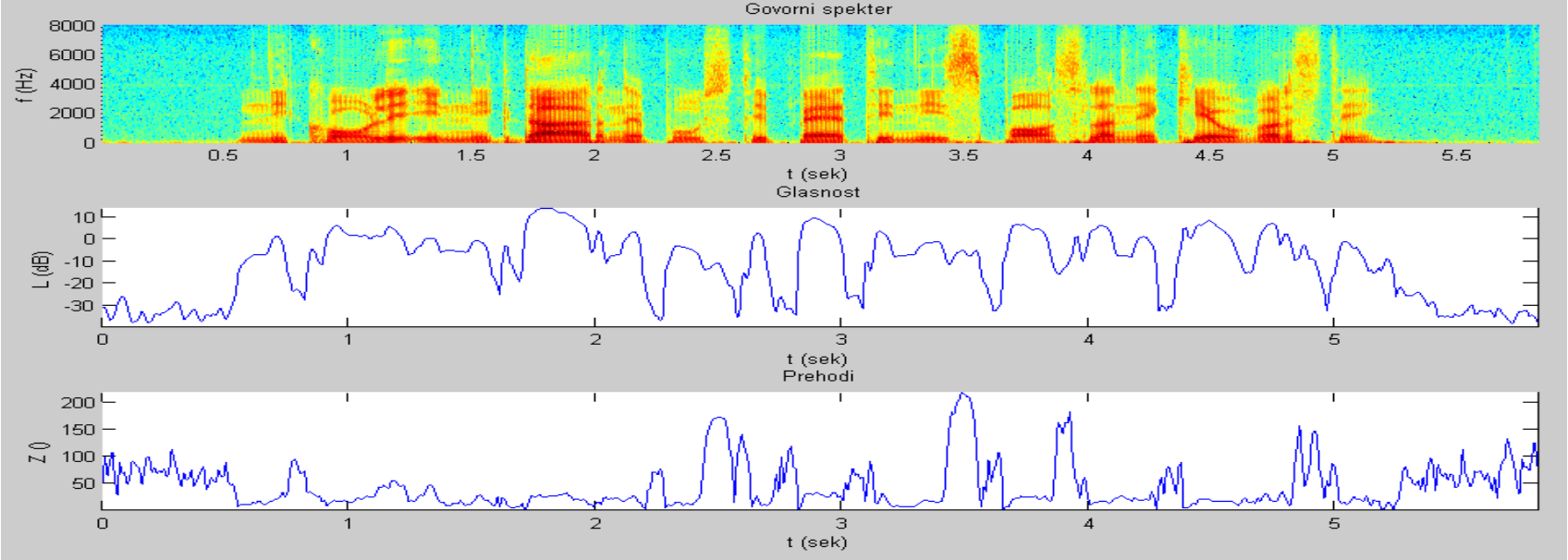


- Analyzing and partitioning of sound signals into sub-segments that represent some meaningful entities (objects, artefacts etc), and identifying their mutual relations.
- In the case of audio perception, sound sources often overlap and their spatial localization in the surrounding environment is required.
- In the field of developing artificial intelligence, speech perception and recognition have special importance.
- Spoken language represents a foundation of human reasoning and intelligence.



Segmentation of speech signals

- Speech signal segmentation is based on the measurements of different short-term features, such as loudness, pitch or zero-crossing rate.
- The analysis of short-term loudness and zero-crossing rate usually suffice for the segmentation of a speech signal into sentences.

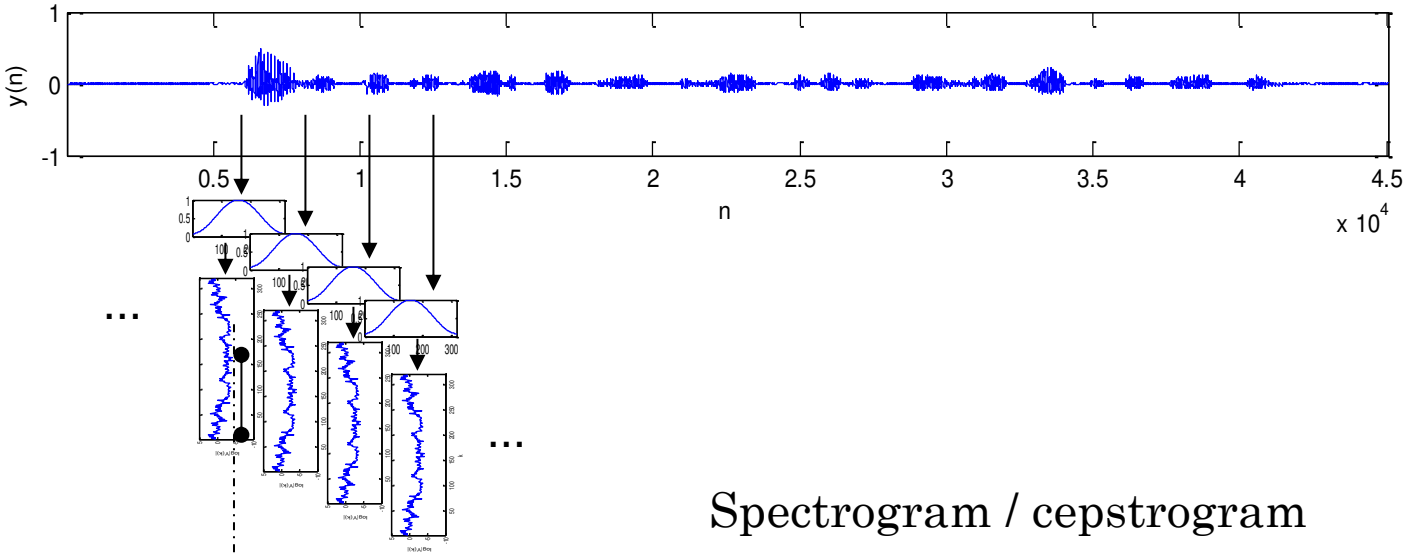


SPEECH UNITS

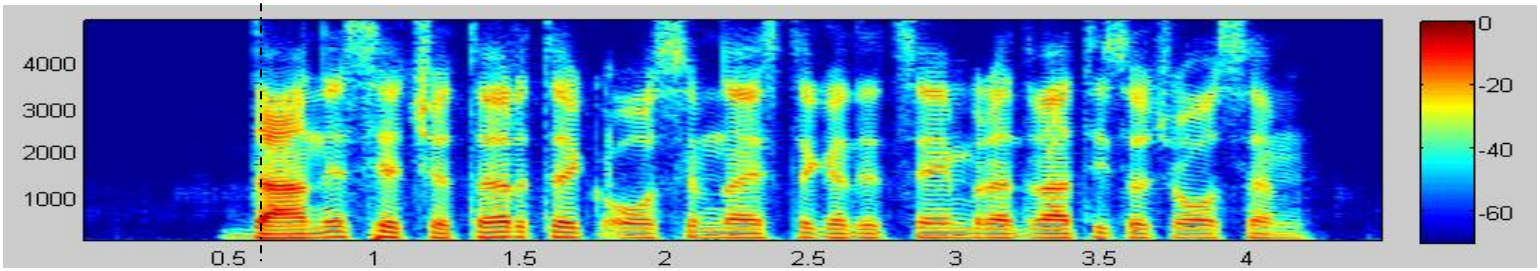
- **Words** are the smallest meaningful units of a language, i.e. the shortest possible message.
- Word segmentation is relatively simple if the words (commands) are pronounced separately. However, words are often pronounced without pauses, which makes the segmentation task difficult or even impossible.
- A **phoneme** is the smallest contrastive unit in the sound system of a language. An **allophone** is a phonetic variant of a phoneme in a particular language.
- **Syllables** are the phonological "building blocks" of words. A syllable is typically made up of a syllable nucleus (most often a vowel) with optional initial and final margins (typically, consonants)

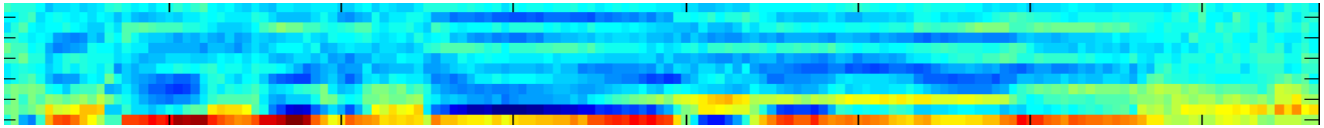
SEGMENTATION OF SPEECH SIGNALS

- Speech signal is usually segmented into equally-sized time frames



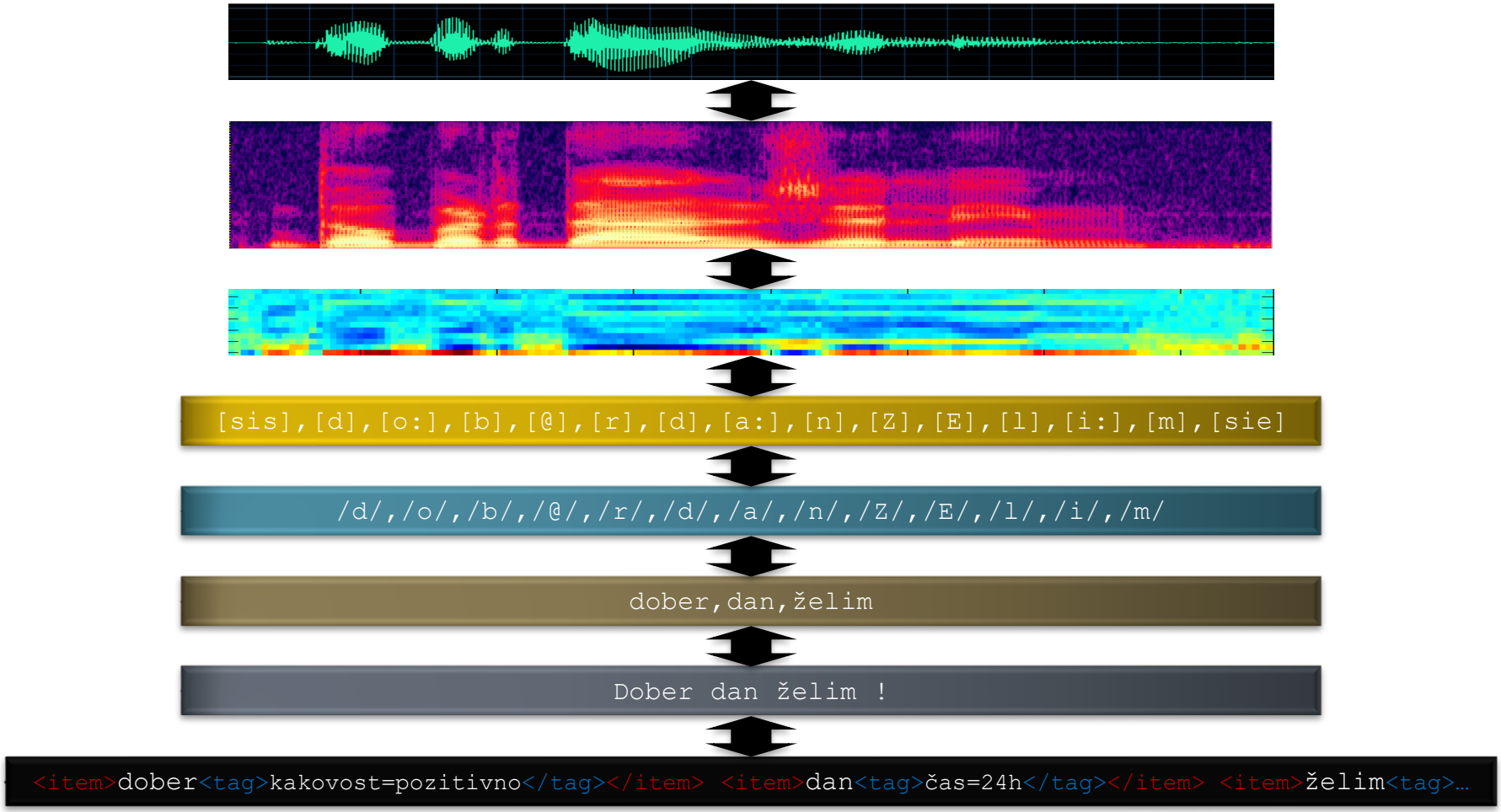
Spectrogram / cepstrogram





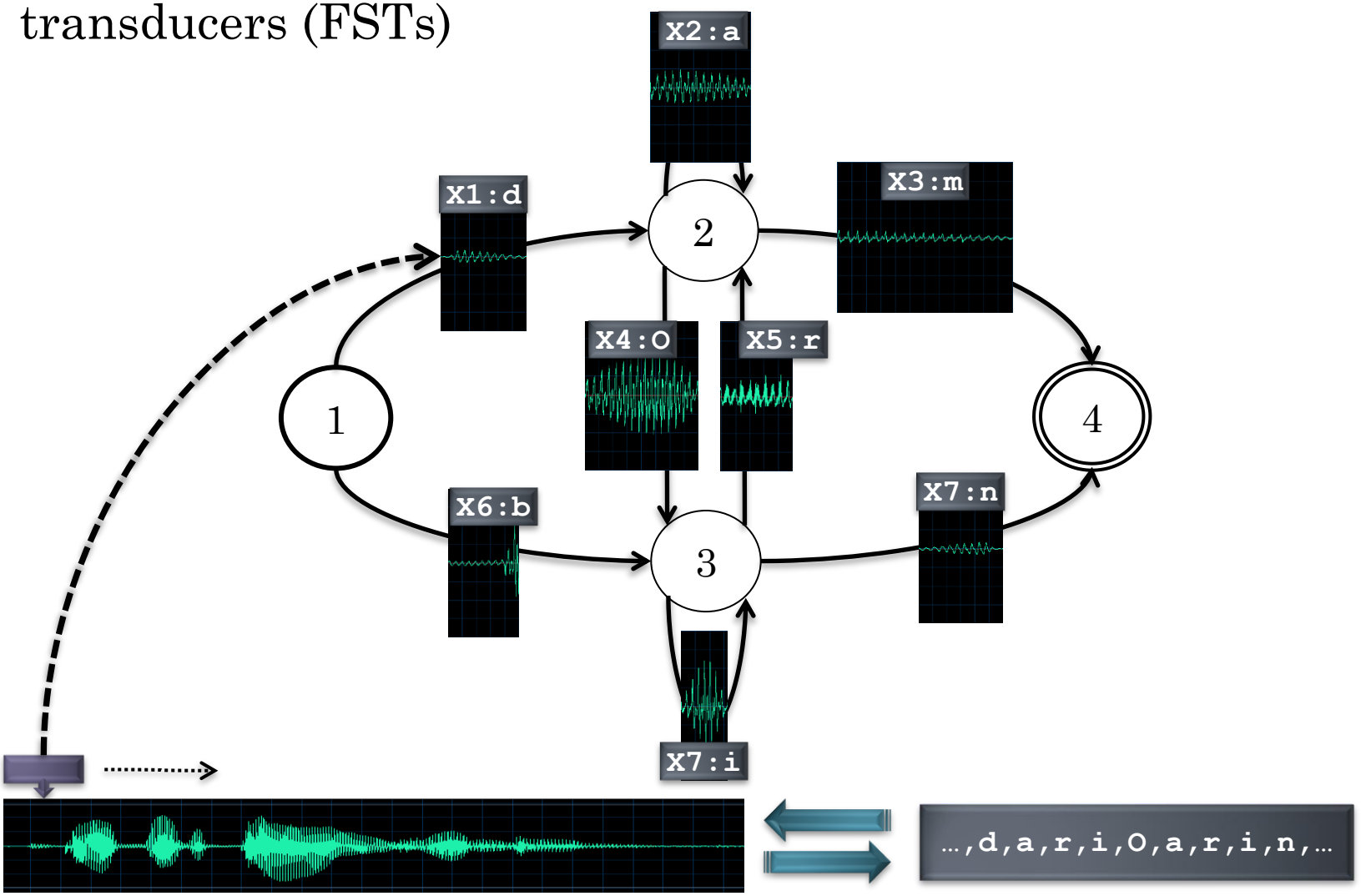
HUMAN SPEECH COMMUNICATION PROCESS

- Human speech communication process is usually modelled as a sequence of stochastic mappings of random processes.



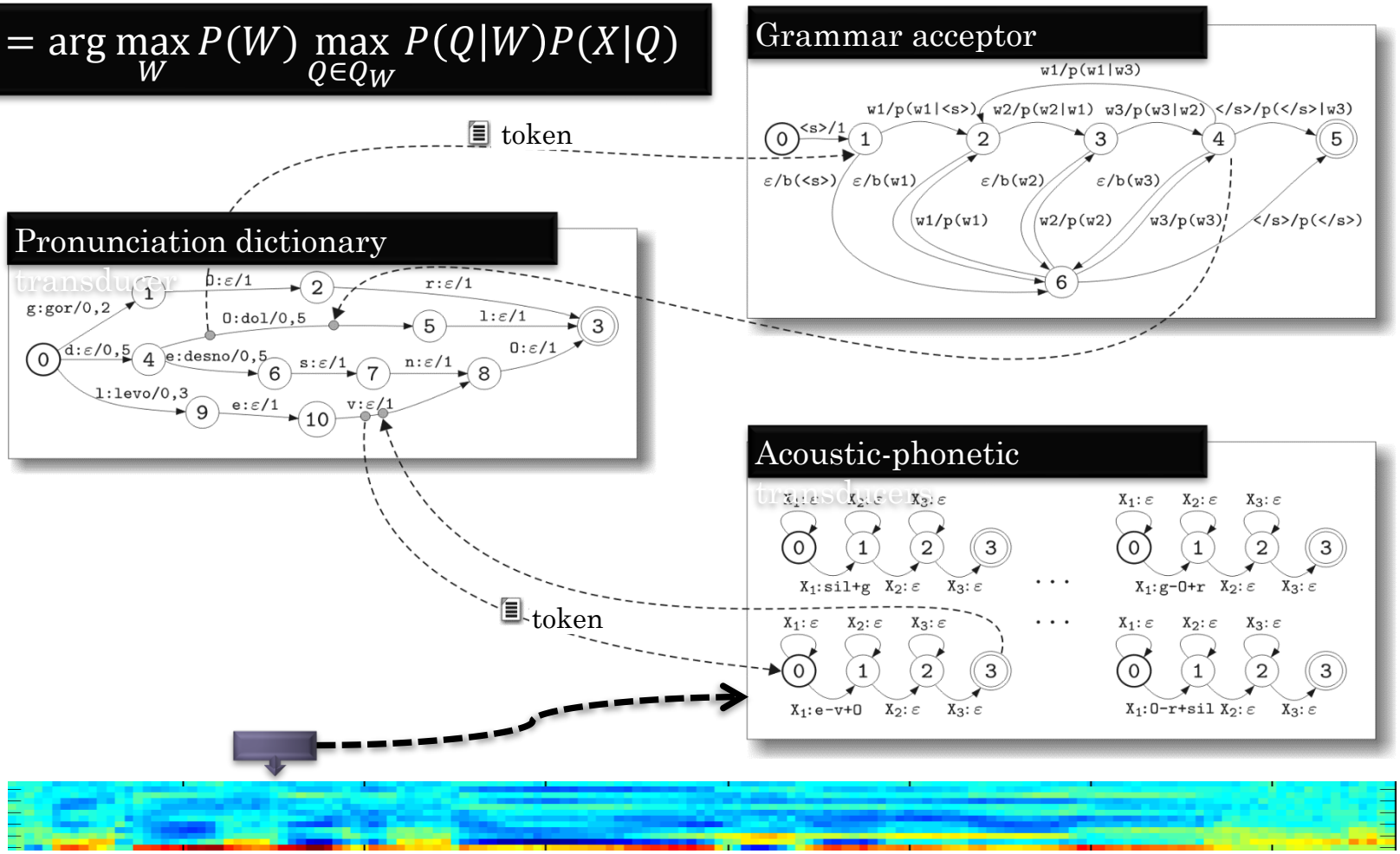
HUMAN SPEECH COMMUNICATION PROCESS

- Spoken languages are usually modelled as finite state transducers (FSTs)



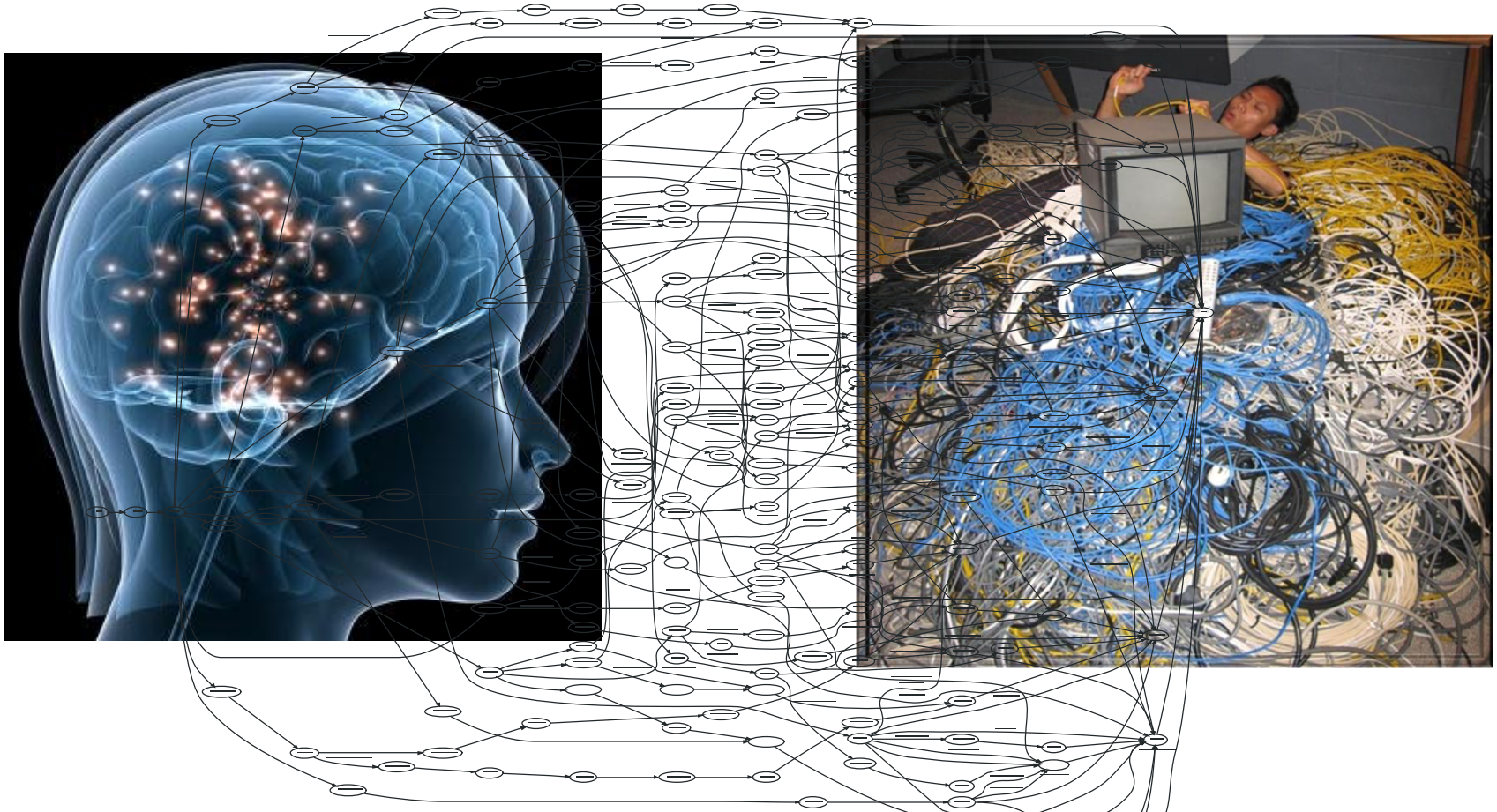
A FST-BASED SPEECH-TO-TEXT MODEL

$$\hat{W} = \arg\max_{W} P(W) \max_{Q \in Q_W} P(Q|W)P(X|Q)$$



A FST-BASED SPEECH-TO-TEXT MODEL

- A cascade of finite-state transducers can be merged into one huge unified finite-state model that represent a model of human speech communication system.

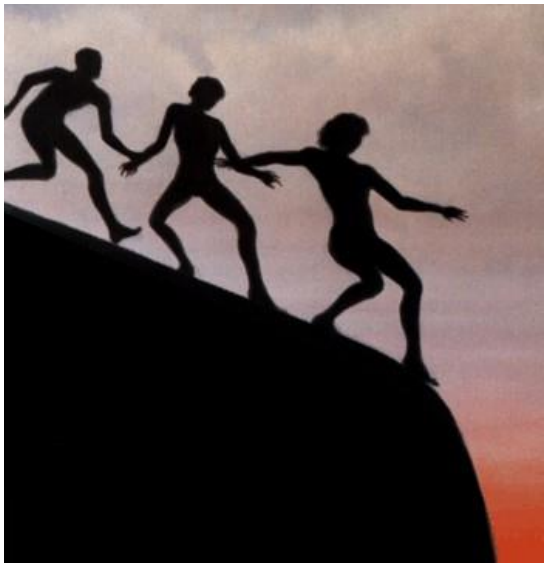


Questions

- What is artificial perception?
- What is the relation between artificial perception, cognition and recognition?
- How artificial visual perception is performed by computer analysis of images?
- How artificial sound perception is performed by computer analysis of sound?
- Why dealing with spoken language is so important in the field of developing artificial intelligence?

Artificial Intelligence

What is intelligence?



- Intelligence is the ability to effectively solve problems in a creative way that is not pre-programmed – Stephen Jay Gould.
- Intelligence is the ability to take over and adapt the ways that others solve problems for own needs – Jack Copeland.

What defines intelligence?

- The ability to adapt to changing circumstances.
- The ability to memorize knowledge and of its application.
- The ability of reasoning and abstract thinking.
- The ability of learning and comprehending relations.
- The ability to assess situations and making decisions.
- The ability of forming original and creative thoughts.
- …

What is artificial intelligence?

Comparison with humans	Ideal of intelligence
The exciting new effort to make computers think – machines with minds, in the full literal sense. (Haugeland)	The study of mental faculties through the use of computational models. (Charniak in McDermont)
The automation of activities that we associate with human thinking and activities such as decision-making, problem solving, learning. (Bellman)	The study of the computations that make it possible to percieve, reason and act (Winston)
The art of creating machines that perform functions that require intelligence when performed by people (Kurzweil).	A field of study that seeks to explain and emulate intelligent behaviour in terms of computational process (Schalkoff)
The study of how to make computers do things at which, at the moment, people are better (Rich in Knight)	The branch of computer science that is concerned with automation of intelligent behaviour. (Luger in Stubblefield)

Reasoning

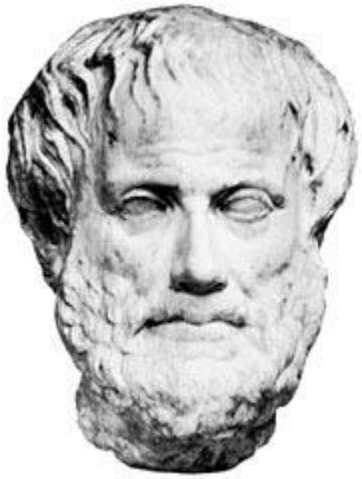
Behaviour

Intelligent behaviour

- Intelligent behaviour should include:
  - Perceiving one's environment,
  - Acting in demanding and complex environments,
  - Learning and understanding from experience,
  - Reasoning to solve problems,
  - Discovering hidden knowledge by reasoning,
  - Applying knowledge in new situations,
  - Communication with others
  - Understanding natural languages,
  - Creativity ingenuity, curiosity, …

Rational thinking and acting

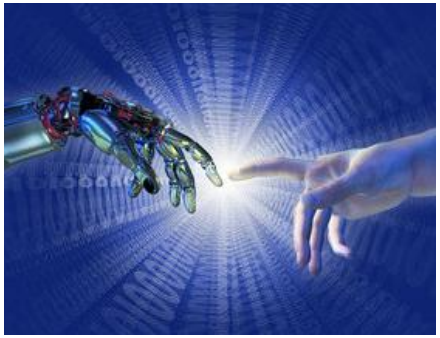
- Rational thinking is thinking in accordance with the principles of formal logic:
  - The correct assumptions must lead to the correct conclusions.
- Rational acting is acting by:
  - Clear preferences,
  - Taking into account the uncertainties in expectations, and
  - Choosing actions/operations with the best expected outcomes.



What do we need to understand in the development of artificial intelligence?

- How knowledge is acquired, presented and stored;
- How to create and learn intelligent behaviour;
- How to develop and apply beliefs, intentions, desires, emotions and preferences;
- How sensor stimuli are converted into symbols;
- How to handle with symbols in logical reasoning about the past and plans for the future;
- How to communicate and understand a language.

Strong Artificial Intelligence



- Strong artificial intelligence (AI) refers to the development of machines that fully achieve or exceed the human intellectual and cognitive abilities.
- The objective of strong AI is to develop machines that have the intellectual ability that can not be distinguished from the people.
- Strong artificial intelligence should at least to some extent show self-awareness.

Weak Artificial Intelligence

- Weak artificial intelligence refers to the development of the machines that can solve specific complex problems that does not require the full range of human mental and cognitive abilities.
- For the weak artificial intelligence, it is not required to demonstrate self-awareness.

The aims of Artificial Intelligence

- The development of a system that think and/or act as a human being
- The development of a system that think and/or act rationally.

	Human alike	Rational
Think	Cognitive science	Researching the principles of reasoning
Act	Turing approach	Developing a rational agent

- Cognitive science is interested mainly in the development of the systems that actually **think as humans**.
- Turing test approach focuses on the development of the systems that **act as humans**.
- The development of artificial intelligence is mainly dedicated to the systems that think and/or act rationally.

The Turing test of artificial intelligence

- Realization of the Turing test
  - A questioner interrogates a human respondent and a machine according to a specified format, within a certain subject area and context.
  - The Turing test is passed if the questioner is unable to consistently determine whether an answer has been given by a machine or by another human being.
- Weaknesses of the test
  - A machine that imitates human conversation habits is not necessarily intelligent.
  - A machine could be very intelligent but would still be unable to engage into conversation with a human being.
  - Many less educated people would fail this test.

Predictions of Alan Turing for the year 2000

- Computers with 10^9 bits (119MB) of memory will be be able to convince a third of the human judges during the five-minute test.
- People will generally accept the term “thinking machine”.
- Learning will become a key process in building powerful machines.

Intelligent chatbots

- There are many online systems (www.chatbots.org) that were inspired by the Turing test.

ALICE
http://alice.pandorabots.com/

EUGEN
https://www.youtube.com/watch?v=[illegible]PTle0

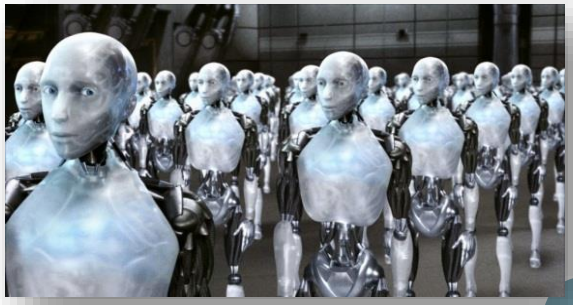
Two chatbots talking to each other
https://www.youtube.com/watch?v=WnzlbyTZsQY
https://www.youtube.com/watch?v=WfwvoFSf9Z4

Jimmy Meets Sophia the Human-Like Robot
https://www.youtube.com/watch?v=Bg_tJvCA8zw

AI-powered language model ChatGPT
https://chat.openai.com/

Possible consequences of the development of AI

- Artilect - the successor of the human species.
- Can the AI be defined as a new species?
- The freedoms and rights of those systems.
- Specialty and uniqueness of those systems.
- The degree of security protection.



Areas of Artificial Intelligence

- Artificial intelligence as science:
  - Attempting to understand and model the information processing capabilities of typical human minds,
  - Attempting to understand the general principles for explaining and modelling intelligent systems, whether human, animal or artificial.
- Artificial intelligence as engineering:
  - Attempting to design new kinds of machines able to do things previously done only by humans.
  - Attempting to design design machines and environments, and educational strategies that can help human beings in everyday life.

Sub-fields of Artificial Intelligence

- Sub-fields based on content:
  - Artificial perception
  - Natural language processing
  - Learning and development
  - Planning, problem solving, automatic design
  - Varieties of reasoning
  - Robotics
  - Multi-agent systems
  - Memory mechanisms and techniques
  - Knowledge representation
  - Programming languages and tools
  - …

Sub-fields of Artificial Intelligence

- Sub-fields based on research field:
  - Combinatorial search
  - Machine and computer vision
  - Expert systems
  - Soft computing
  - Knowledge representation
  - Machine learning and data mining
  - Pattern recognition
  - Natural language processing
  - Artificial life
  - Robotics
  - Ambient intelligence and smart environments
  - Smart surveillance systems
  - …

Sub-fields of Artificial Intelligence

- Sub-fields based on application
  - AI in medicine
  - AI in robotics:
  - AI in many aspects of engineering:
  - AI in interfaces and "help" systems:
  - AI in education:
  - AI in information management:
  - AI in mathematics:
  - AI in entertainment:
  - AI in biology:
  - AI in Law:
  - AI in architecture,
  - AI in literature,
  - AI in crime prevention and detection:
  - AI in commerce:
  - AI in space:
  - AI in military activities.
  - …

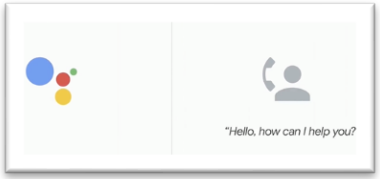
Milestones in Artificial Intelligence

- 1997: IBM's chess program Deep Blue beats world champion Garry Kasparov.

- 2005: A self-driving car of Stanford University drives 132 miles on the desert roads to the finish line (DARPA Grand Challenge).

- 2011: IBM's computer program Watson beats people in the Jeopardy quiz.

- 2018: Googles Assistant makes a telephone reservation https://www.youtube.com/watch?v=7gh6_U7Nfjs



- 2022: Launching a large language model-based chatbot ChatGPT https://chat.openai.com/

New Milestones in Artificial Intelligence

- Improvements in computer vision/object detection, recognition and generation (e.g., Microsoft Cognitive Services) http://www.youtube.com/watch?v=Kq1NkrURTAo

- Natural language understanding meets image recognition (e.g. “What is on the photo?”)
- Improvements in unsupervised, or predictive learning

  (Facebook’s AI Research (FAIR) team)

Questions

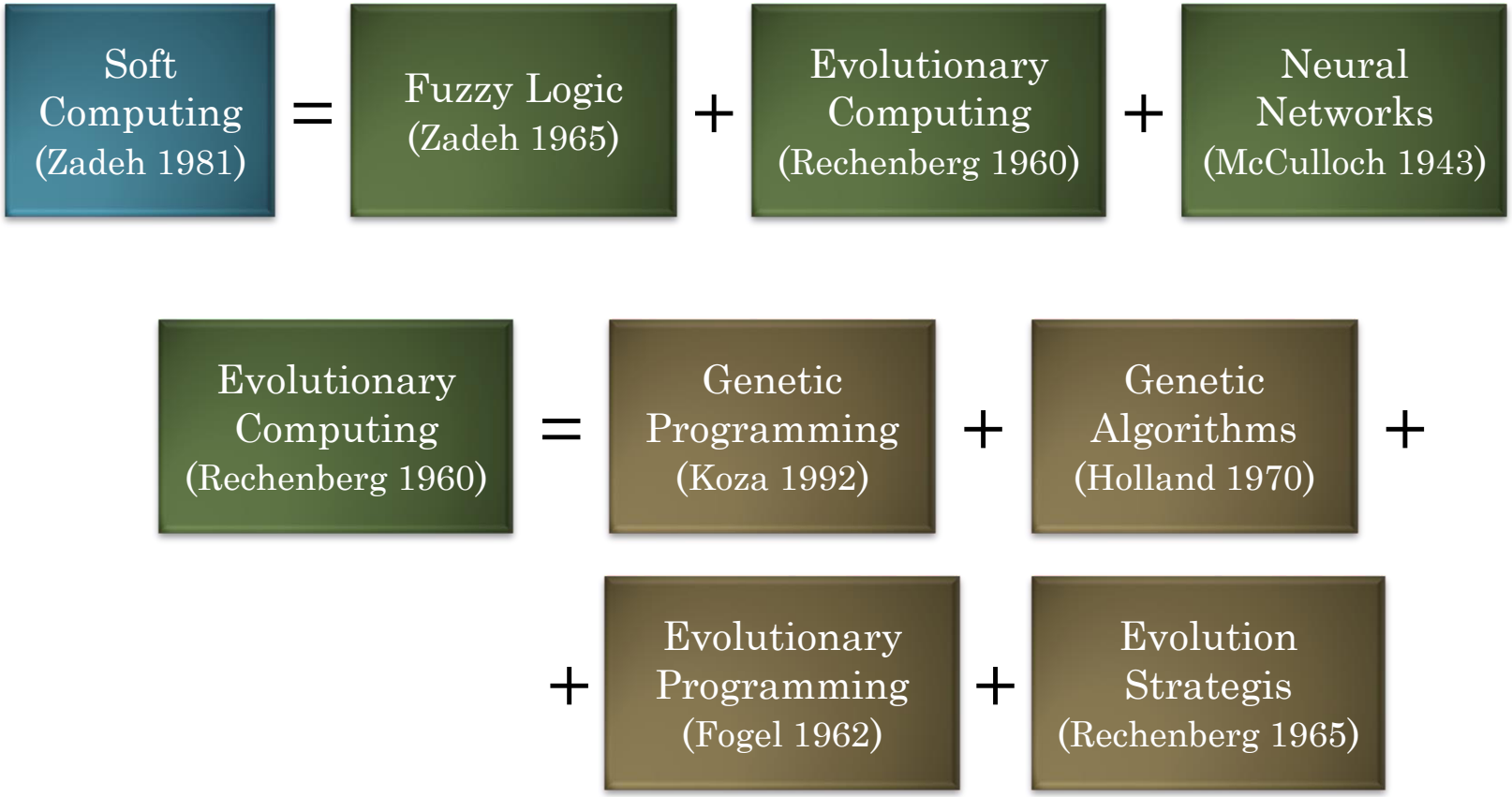
- What is intelligence?
- What determines intelligent behaviour?
- Define Artificial Intelligence (AI).
- What is the difference between strong AI and weak AI?
- What are the goals of AI?
- What are the sub-fields of AI?
- What are the applications of AI?
- What are the possible consequences of the development of the AI?

Introduction to Soft Computing

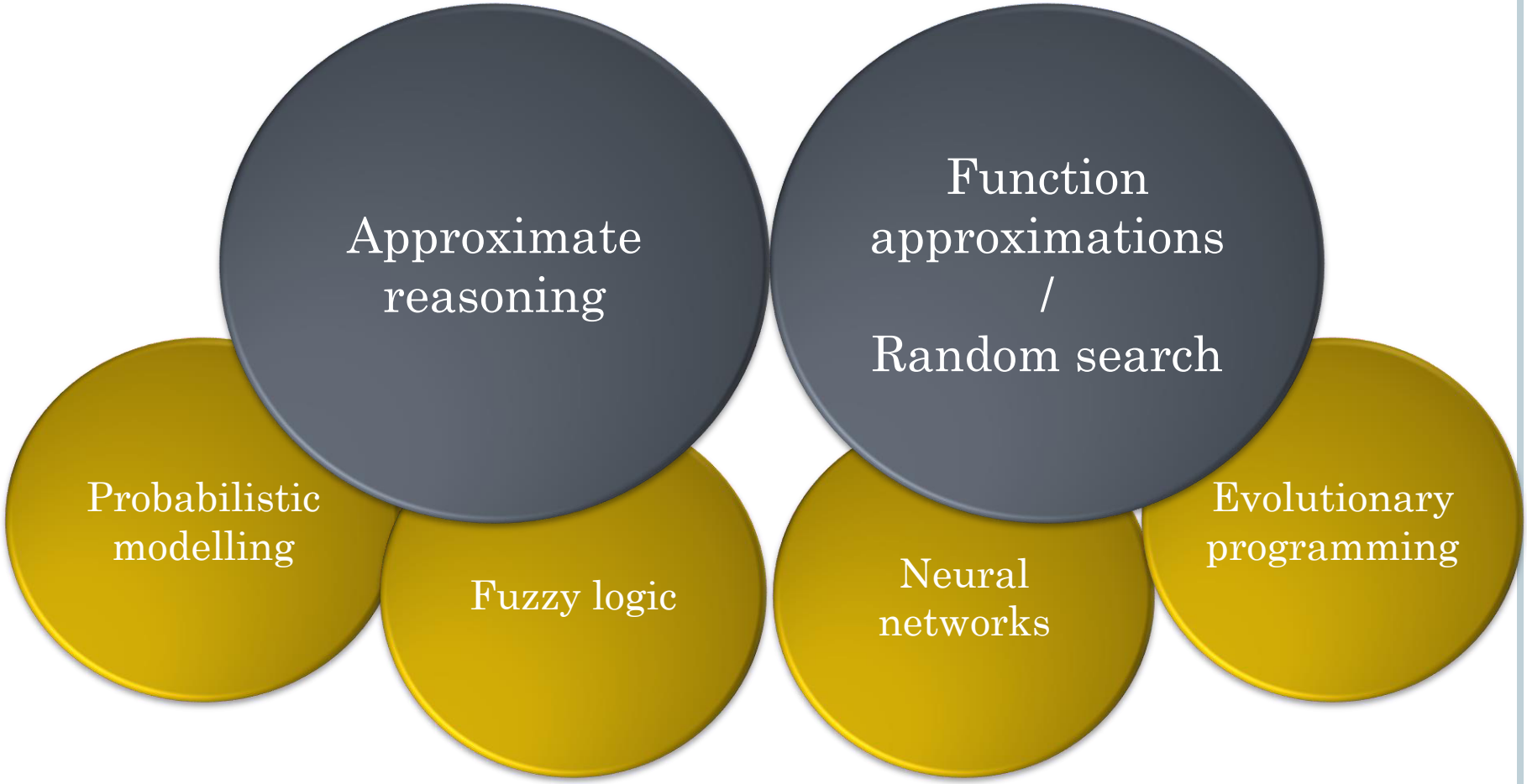
Soft Computing

- Soft computing covers a wider field of computational methods and procedures for modelling and solving problems that are too complex for classical mathematical modelling.
- Unlike hard (conventional) computing, the soft computing is tolerant to imprecision, uncertainty, partial truths, and approximation, which is inspired by the human way of reasoning and decision-making.
- The sub-fields of Soft Computing are: Fuzzy Computing, Evolutionary Computing, Neural Computing, and Probabilistic Computing.

The History of Soft Computing



SOFT COMPUTING



Fuzzy Computing

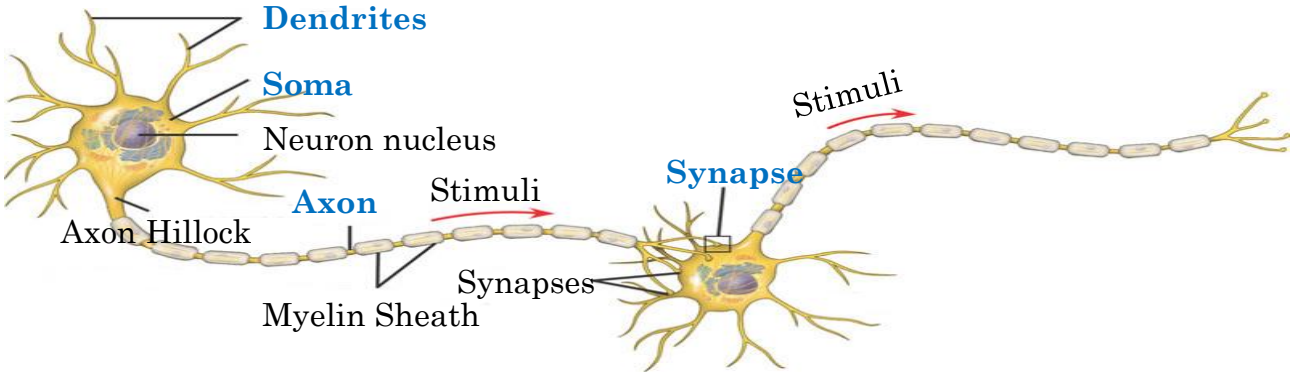
- The real world knowledge is mostly imprecise, vague, uncertain, ambiguous, inexact or probabilistic in nature.
- Human thinking often involve fuzzy information, originating from inexact concepts and non-identical experiences.
- Fuzzy computing give human like answers with the description of their degree of reality.

IF *man_height increases to tall* **THEN** *man_weight probably grows to heavy*;

- Typical application areas are: industrial control, human decision making, image processing etc.

Neural computing

- An information processing paradigm that is inspired by biological neural systems that compose a large number of highly interconnected processing units.

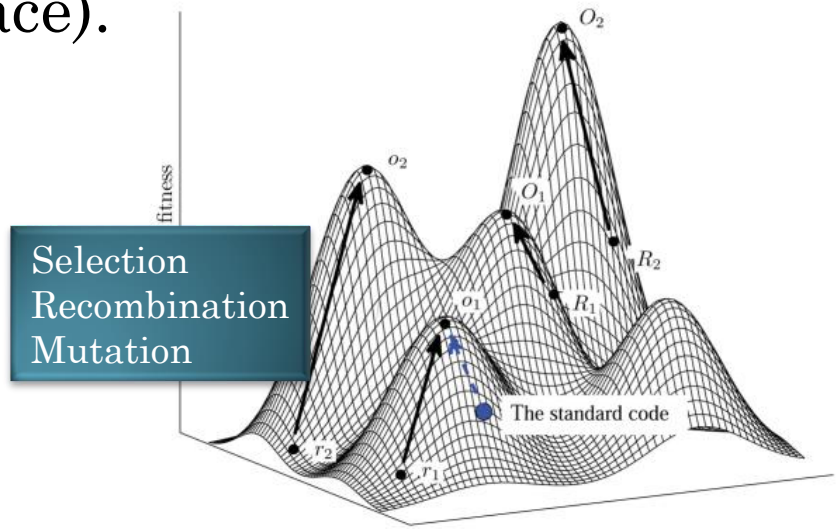


- An artificial neural network (ANN) is a representation of the biological brain that tries to simulate its learning process.

- An ANN is normally configured for specific applications, such as pattern recognition and data classification that are based on (machine) learning principles.

Evolutionary Computing

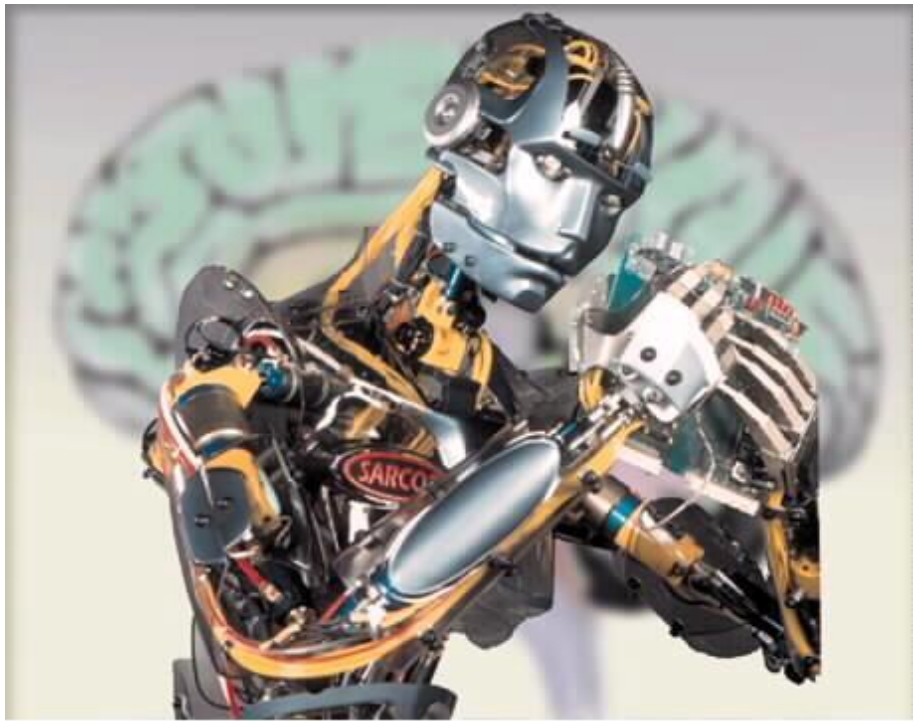
- Characterized by the family of trial-and-error problem solvers that can be considered as global optimization methods with a metaheuristic or stochastic principles.
- Evolutionary algorithms are distinguished by the use of a population of candidate solutions (rather than just iterating over one point in the search space).
- Evolutionary (genetic) algorithms simulate the survival of the fittest among "individuals" over consecutive generations.



Questions

- What is Soft Computing?
- What are the aims of Soft Computing?
- What computing paradigms are covered by Soft Computing?

Introduction to Machine Learning



Machine Learning

- The branch of artificial intelligence research that is based on modelling environment from data and is related to the field of pattern recognition and data mining.
- The development of techniques that give a computer system the ability to "learn" from the (sensor) data and to provide it with inductive probabilistic reasoning.
- Machine learning is a process of adaptive changes in a system that allow it to solve the next task of the same type more efficiently.

Types of Natural Learning

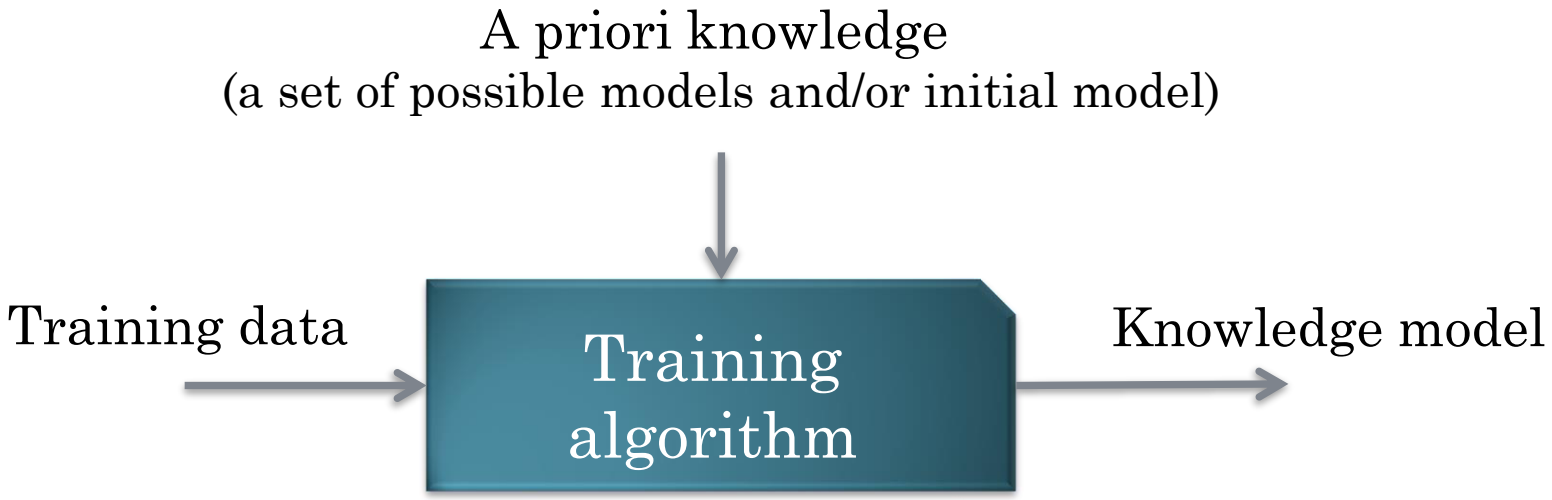
- Learning with imprinting (unchangeable knowledge)
- Learning through conditioning (Pavlov)
- Probabilistic (Bayesian) learning
- Learning with memorizing
- Learning by trial and error
- Learning by imitation
- Learning with understanding and insight

Types of Machine Learning

- Learning with a teacher (supervised learning).
- Learning without a teacher (unsupervised learning).
- Semi-supervised learning.
- Reinforcement learning
  (encouraging or discouraging behaviors).
- Learning transduction / transformation
- Learning to learn
  (inductive transfer, transfer learning).

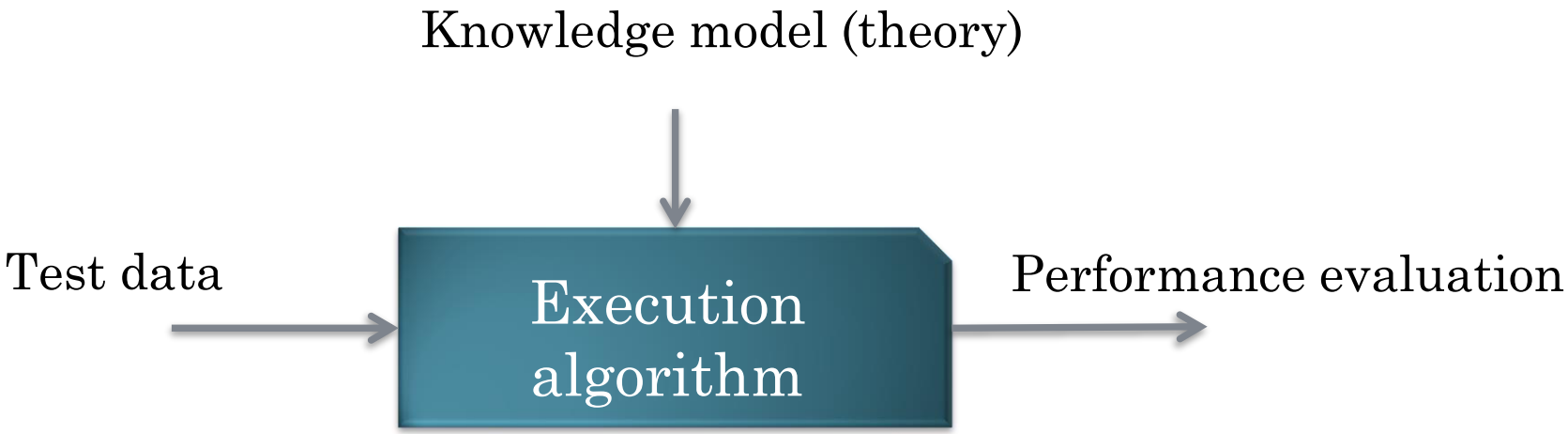
Basic Principles of Machine Learning

- Basic terms are: training data, a priori knowledge, training algorithm, execution algorithm, knowledge model (theory).



Assessing Performance

- Assessing the effectiveness of solving new problems.



An Example of Learning with Bayesian Inference

- In Bayesian inference, the a priori knowledge is modelled as a prior belief (trust, uncertainty) and is often called *prior* .
- In accordance with the Bayesian theorem, a belief model M is adjusted according to the likelihood of the obtained data (evidence) E given the model M
- The adjusted belief model is called *posterior*.

$$M \in \{M_i\}$$

$$E \in \{E_j\}$$

$$P(E) = \sum_i P(M_i)P(E|M_i)$$

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

$$P(M|E) \to P(M)$$

An Example of Learning with Bayesian Inference

- $P(M)$ denotes the prior probability of M (model, hypothesis) before E is observed.
- $P(E|M)$ denotes the probability (likelihood) of observing E given M.
- $P(E)$ denotes the marginal likelihood or "model evidence" that is the same for all possible models being considered

$$M \in \{M_i\}$$

$$E \in \{E_j\}$$

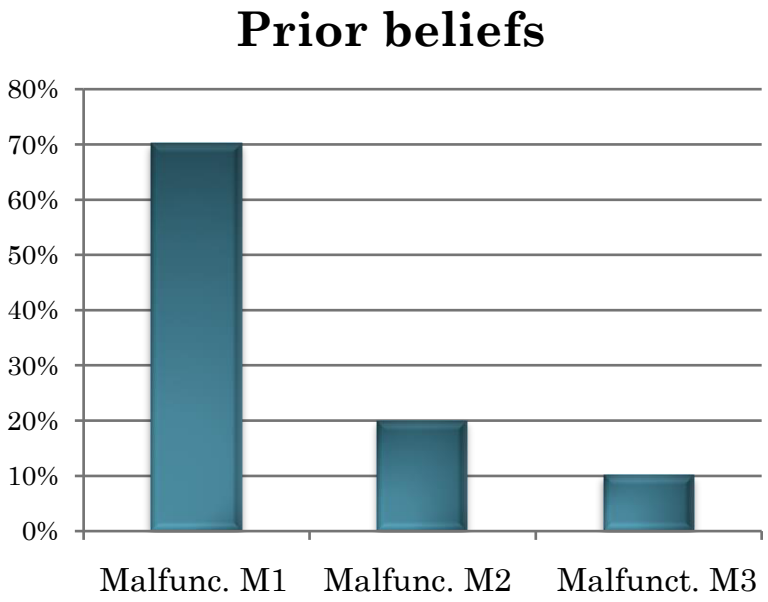
$$P(E) = \sum_i P(M_i)P(E|M_i)$$

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

$$P(M|E) \to P(M)$$

An example of learning with Bayesian inference

- A technician deals with a car engine that has some unusual symptoms that reflect in unusual sounds.
- Technician's prior beliefs are, that 70% of car engines with such symptoms has a malfunction M_1, 20 % a malfunction M_2 and 10 % a malfunction M_3.
- Technician's beliefs about the malfunction can be illustrated by the diagram on the right.



An example of learning with Bayesian inference

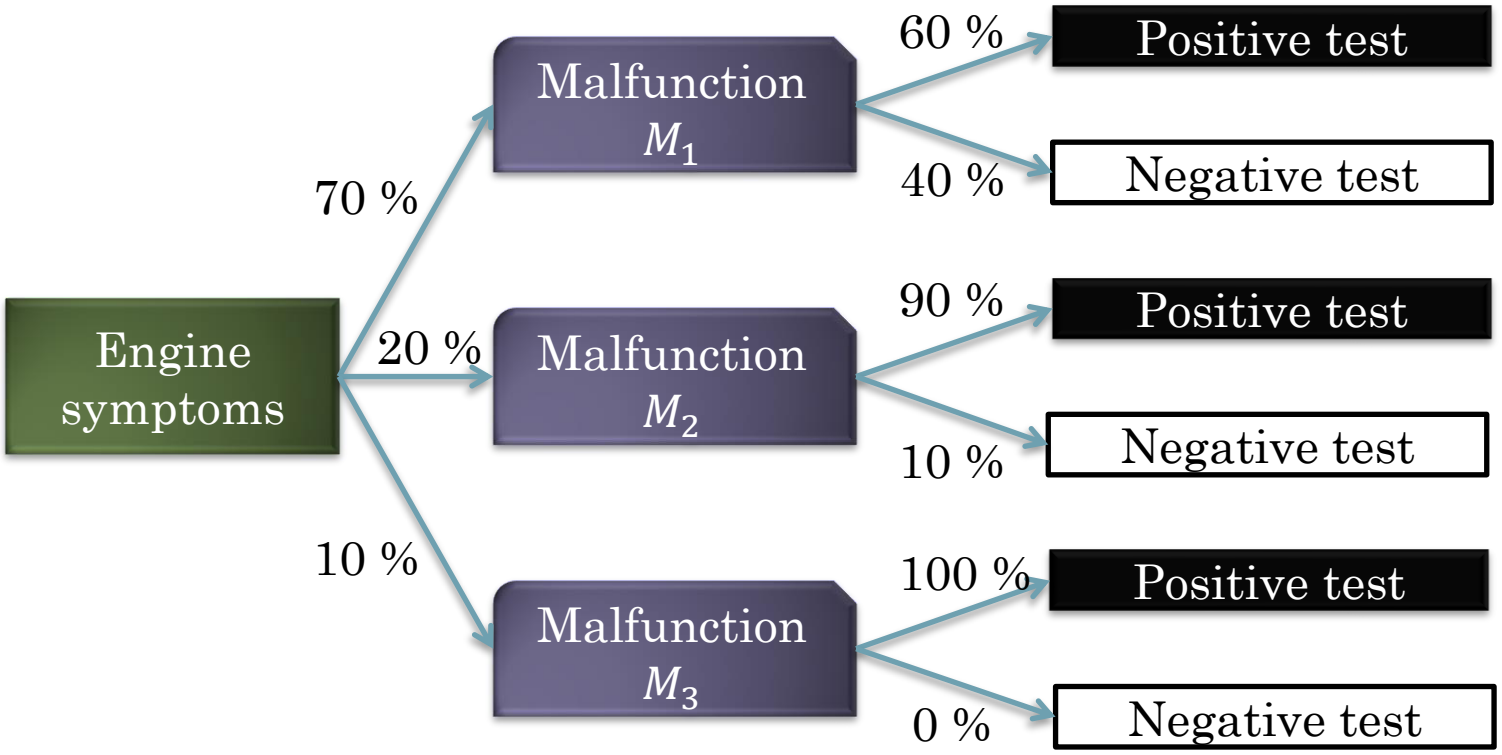
- The technician captures vibration samples of the engine using a special measuring device and analyses them using a special diagnostics application.
- In the specifications of the application, it is stated that 60% of the engines with the malfunction M_1, 90% of the engines with the malfunction M_2 and 100% of the engines with the malfunction M_3 cause the engine vibrations to be above a certain threshold.

$$P(E|M_1) = 0{,}6 \qquad P(E|M_2) = 0{,}9 \qquad P(E|M_3) = 1{,}0$$

- Let as assume that the application gave the positive test result (evidence E – vibrations are above the threshold).
- What are now technician's beliefs in what malfunction is causing the unusual engine symptoms.

An example of learning with Bayesian inference

- A tree with possible causes and facts with their probabilities



An example of learning with Bayesian inference

- A joint probability that we have a technician dealing with an engine that has one of the malfunctions (M_1, M_2, M_3) and the test is positive (E), is thus,

$$P(\mathrm{E}, \mathrm{M}_1) = P(M_1) \cdot P(E|M_1) = 0{,}7 \cdot 0{,}6 = 0{,}42$$
$$P(\mathrm{E}, \mathrm{M}_2) = P(M_2) \cdot P(E|M_2) = 0{,}2 \cdot 0{,}9 = 0{,}18$$
$$P(\mathrm{E}, \mathrm{M}_3) = P(M_3) \cdot P(E|M_3) = 0{,}1 \cdot 1{,}0 = 0{,}1$$

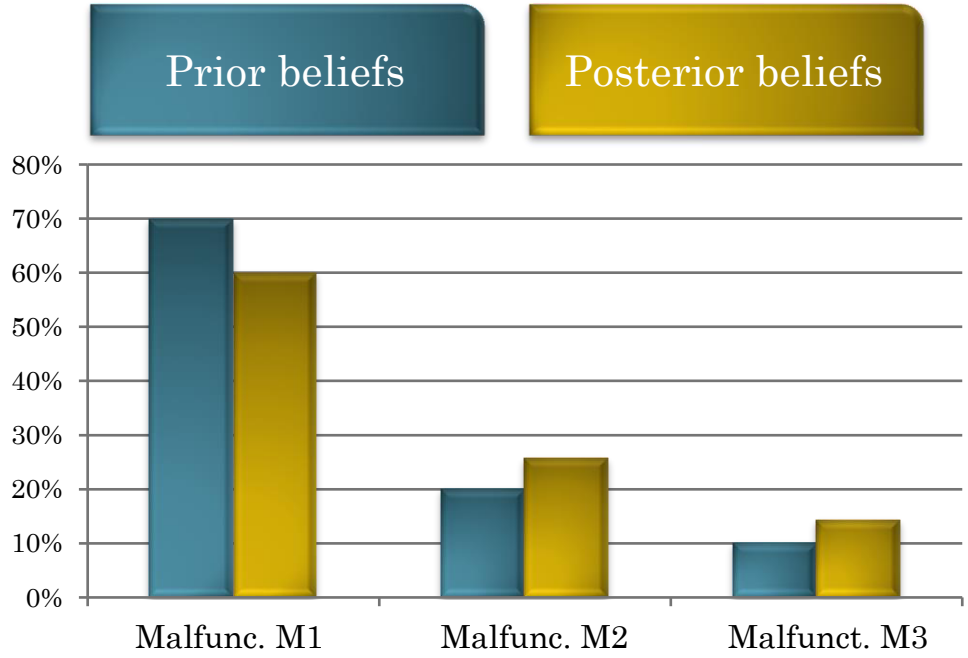
- Technicians‘ prior beliefs after the positive test thus changes to the posterior beliefs

$$P(E) = \sum_i P(M_i)P(E|M_i) = \\ = 0{,}42 + 0{,}18 + 0{,}1 = 0{,}7$$

$$P(M_1|E) = \frac{0{,}42}{0{,}42+0{,}18+0{,}1} = 0{,}6$$
$$P(M_2|E) = \frac{0{,}18}{0{,}42+0{,}18+0{,}1} = 0{,}257$$
$$P(M_3|E) = \frac{0{,}1}{0{,}42+0{,}18+0{,}1} = 0{,}143$$

An example of learning with Bayesian inference

- Technician's beliefs were thus changed, however, he would still decide that most probably the engine has the malfunction M_1, despite the fact that all the engines with the malfunction M_3 normally have positive test result.



Questions

- What is machine learning?
- What are the types of natural learning?
- What are the basic principles of machine learning?
- What are the main machine learning methods?
- Give an example of machine learning with Bayesian reasoning.