COMPUTATIONAL INTELLIGENCE

Introduction

AGH

Adrian Horzyk

Preface

What do you mean by intelligence?

What should artificial intelligence be doing to be worthy of this name?

What comprises computational intelligence?

Scope of this course

What tasks will we address during this course?

- Efficient Computational Intelligence (CI) models and adaptation methods.
- Construction, self-development, adaptation, and training of various types of Artificial Neural Networks (ANN) and other learning systems, e.g. evolutional and fuzzy.
- Gradient, convolutional, and various deep learning methods and networks.
- Semantic and associative neural systems and memories.
- Linguistic and cognitive neural systems.

We will focus on the most efficient models and methods, but before we can proceed to discuss them, we have to introduce certain fundamentals, elements, and concepts.

Ambitious students are invited to participate in the research and prepare scientific articles, which can be invoked in their C.V.

Basic Challenges of AI and CI

Computers can quite easily solve difficult tasks for humans (like a chess game where the environment and possible moves are exactly and well-defined), but simultaneously they cannot deal with many quite easy tasks for humans which we solve intuitively using abstract thinking or fuzzy knowledge-based concepts.

Such an approach requires a knowledge-based approach to artificial intelligence and is as easy as knowledge modeling in cybernetic systems. Therefore, we still have many troubles to do it because we still search for a solution how to represent and form knowledge in cybernetic systems. Until now no one of the big projects (like CYC) finished with success ☹

Hence, practical scientists limited themselves to some groups of artificial intelligence problems are known under the name of computational intelligence.

Computational Intelligence approaches usually base on construction of computational models using sets of training patterns which describe the solution using samples.

Neural Networks

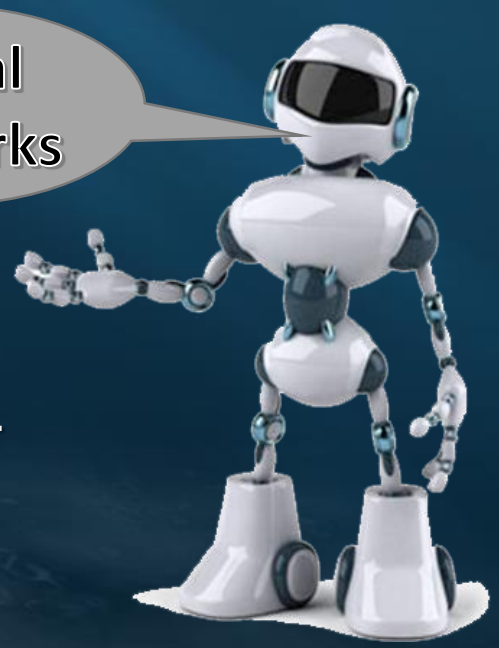
Neural networks are the basis of various computational intelligence approaches, so we will discuss neural networks of four generations:

1. **Generation: The McCulloch-Pitts model of neurons** which implements only the most fundamental mechanisms of the weighted input stimuli integration and threshold activation function leaving aside issues of time, plasticity, and other important factors.

2. **Generation: The model of neurons using non-linear continuous activation functions** enables us to build multilayer neural networks (e.g. MLP) and adapt such networks to more complex tasks and non-linear separable training data.

3. **Generation: The spiking models of neurons** enriched this model with the implementation of the approach of time which is very important during stimuli integration and modeling of subsequent processes in time.

4. **Generation: The associative pulsing model (APN) of neurons** produces series of pulses (spikes) in time which frequency determines the association level. APNs enrich the model with automatic plastic mechanisms which let neurons to conditionally connect and configure an associative neural structure representing data, objects, and their sequences.



Deep Learning

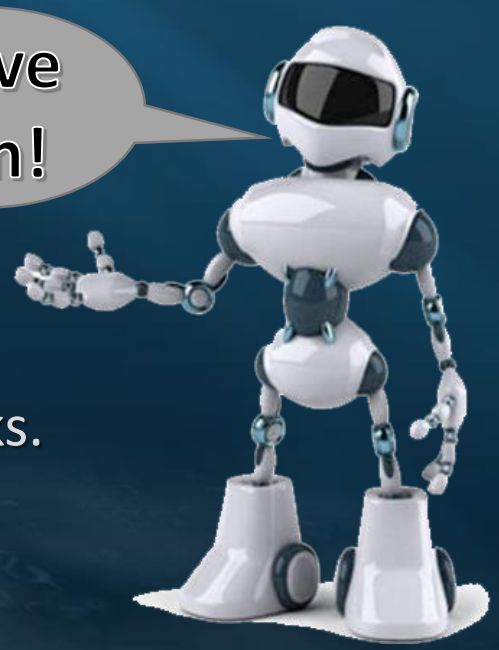
Deep learning, which is today very popular, solves one of the fundamental problems of representation of complex objects using simple features to represent a hierarchy of more complex features which are finally used to solve the problem.
Today, we have many different deep learning systems which will be described and discussed during these lectures and implemented during laboratory and project classes.

Deep learning networks always have a hierarchical structure constructed from various layers, modules or subnetworks. They are not always and not necessarily neural networks.

Deep learning systems are a part of:

- Learning systems
- Representative learning systems
- Hierarchical systems

They use various mathematical approaches to search for solutions to given tasks.



What will be evaluated?

All tasks during laboratory and project classes should end by creation and development of a personal CI system which:

- ✓comprises all realized laboratory tasks and a final project task.
- ✓have a unified common interface for reading input data from text, spreadsheet, xml, and database files containing training data.
- ✓have a unified graphical output interface for presentation of output data, achieved results, structures of neural networks or other models as well as possibly animated intermediate training and evaluation stages to clarify the way of how the structure and parameters are created and modified in the given adaptation process.
- ✓have clearly implemented algorithms and data structures realized with state-of-the-art, good programming practices, rules, and a selected object programming model (MVC, MVVM, etc.)
- ✓Students initiatives will be appreciated.

Final Projects and Grades

All application have to be implemented in one of the top programming object languages: C#, C++, Java, Python, or PHP and if necessary supplemented by the use of a database. Take into account that in the laboratory room there are only MS Visual Studio, Java, and Python available, so if you wish to perform your classes in the other programming language, you are responsible for the possibility to work in it. **Students can also work on their laptops** during these classes if it is more convenient for them.

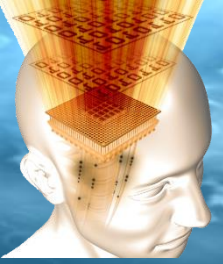
All final projects should be presented to all participants (about 10-15 min.) at the last project classes in the semester. Prepare the final presentation of used methods, data structures, achieved results etc. Draw some valuable conclusions and summaries. Inspire us, give advice and suggestions! Describe abilities of your CI system and show us how it works and develops solutions for some sample training data. Interpret and possibly compare achieved results.

All final complete projects (including the developed CI system with a source code of all modules, a compiled application, training data, databases, presentations etc.) **should be send to the lecturer at the end of the semester** because the lecturer is obligated to store them during at least a year as a proof of the grades given to students.
Hence, only the sent complete projects will be finally evaluated and students will be graded!

Well done projects can be afterward further developed to Master's theses.

Moreover, the students whose projects will be very well done can be recommended to beneficial positions in the interesting business CI and AI projects, e.g.
http://home.agh.edu.pl/~horzyk/research/CooperationJobOffers.php

This course is not an easy one, however, the acquired knowledge and skills should be valuable!



Computational Intelligence in a Chip?

Do point out that:

- Intelligence enables parallel and synchronous processing of many tasks.
- Intelligent creatures can also switch between various tasks and associate their results together developing more complex routines (algorithms).
- The developed routines can be remembered, recalled, and used again in similar situations in the future.
- Such reuse of routines in similar situations or to similar objects we call generalization which is one of the most important factors of intelligence!
- During this process, knowledge is formed, and skills are developed making intelligence more advanced and smart in the areas where these knowledge, skills, and experience had been formed.

Intelligence

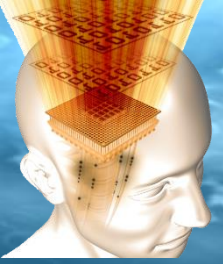
Intelligence is usually defined as:

- the ability to perceive information, and to retain it as knowledge to be applied towards adaptive behaviors within an environment or a context,
- the mental capability of reasoning, planning, solving problems, thinking abstractly, comprehending complex ideas, learn quickly, and use resources efficiently.
- It encompasses processes such as learning, recognizing, classification, understanding, logic, planning, creativity, problem solving, and self-awareness.
- Intelligence is „working” as far as the undertaken actions meet needs of the intelligent entity, because needs propel us to act and think!

Cognition

Cognition means:

- the mental action or process of acquiring knowledge and understanding through thoughts, experience, and the senses which can be used to explore surroundings and find out interesting objects that satisfy needs.
- It encompasses processes such as knowledge, attention, memory, judgment, evaluation, reasoning, problem-solving, decision making, comprehension, production of language, its understanding etc.
- It can be conscious or unconscious, concrete or abstract, and intuitive or conceptual.
- Cognitive processes use knowledge of all kinds and generate new knowledge as well as a result of information processing.
- All processes are analyzed from a different perspective within different contexts.

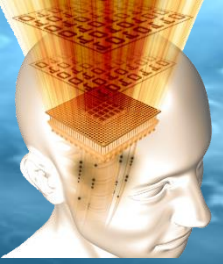


Artificial Intelligence (AI)

Artificial Intelligence should be able to:

- Reproduce and imitate human intelligence.
- Recognize and react to human needs and values.
- Understand human psychology, personality, needs, and aspirations.
- Adapt, learn, remember, and recall objects, facts, rules, and routines.
- Recognize similar objects, facts, rules, and routines and generalize them.
- Classify objects, associate them in different contexts and recall contextually.
- Communicate with people logically and sensitively.
- Cooperate with people.
- Replace people in the frequent or arduous tasks.
- Meet needs of people as well as intelligent machines and define the needs to cooperate to satisfy them.

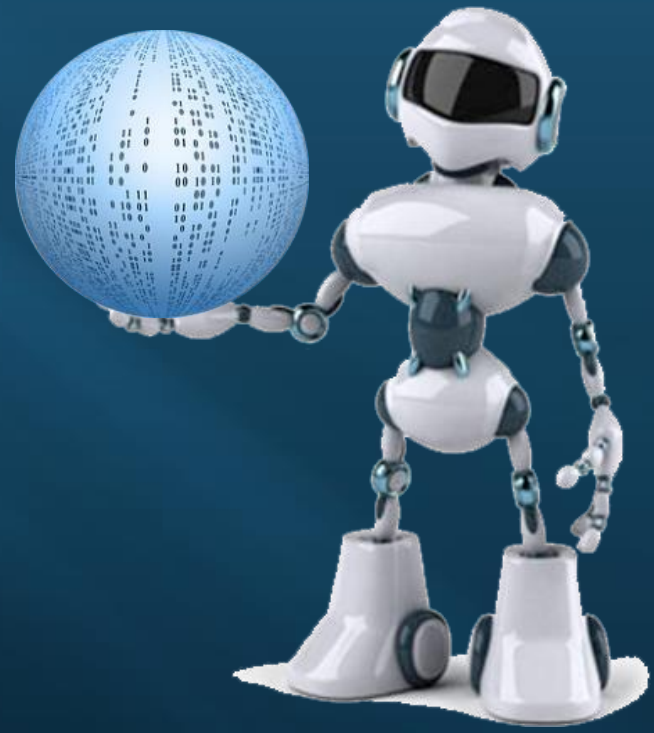
However, what does it technically mean: remember, adapt, learn – is there any difference between these terms?

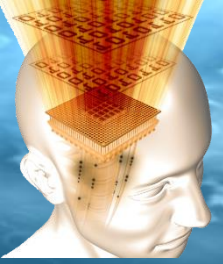


Computational Intelligence (CI)

Computational Intelligence:

- is a set of nature-inspired methodologies and approaches to address complex real-world problems to which mathematical modeling is useless or not efficient enough,
- usually refers to the ability of a computer to learn specific tasks from data or experimental observations,
- is focused on solving engineering tasks using adaptive mathematical models modeled on a human way of thinking or other biological processes,
- does not reproduce human intelligence sufficiently, but models intelligent ways of solving problems using nature-inspired mechanisms, data structures, and systems,
- encompasses artificial neural networks, fuzzy logic, evolutionary computations, genetic algorithms, and various probabilistic methods,
- is used to recognize, classify, group (cluster), predict, or approximate efficiently in order to make decisions without human assistance or help people in the decision processes,
- can be perceived as an important component of artificial intelligence.





Important factors of CI

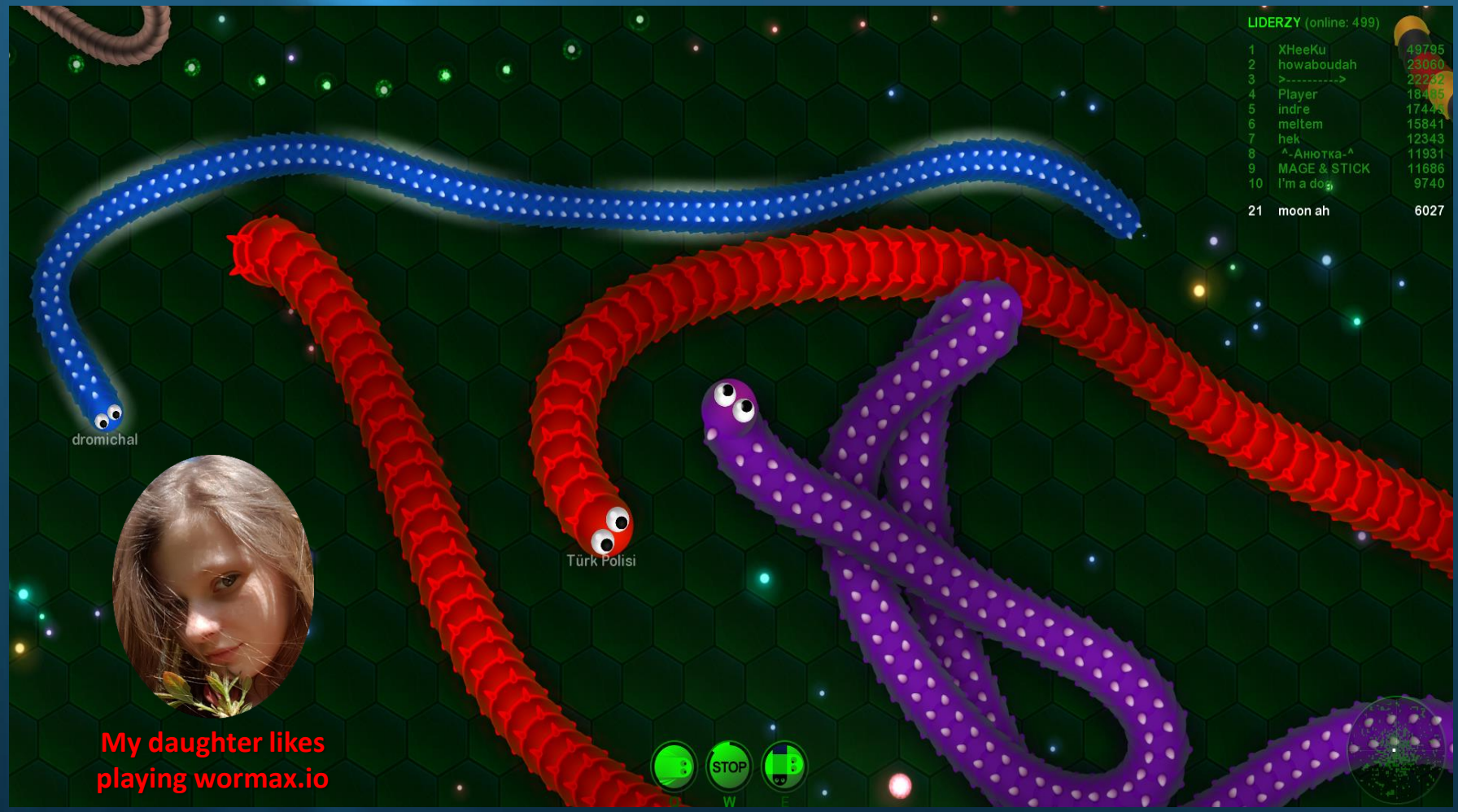
What is important when using computational intelligence methods?

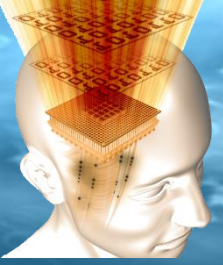
- The Senses or Sensors – which enable the given AI or CI system to explore given or any surroundings and retrieve data from the environment to process them or use for learning.
- Exploration Ability – the ability to explore any given surroundings to find out interesting objects in order to try to use them to satisfy needs or achieve goals.
- Generalization – how well will the model generalize input data?
  Generalization is usually treated as an approximation process.
- Ability to Combine and Join together the developed and known solutions.
- Adaptability – the ability to adapt the model to trustworthy solve a given task and find a solution with satisfactory accuracy.
- Accuracy – defines how precisely the given model can be adapted
  and how accurate are the obtained results?
- Adaptation Period – how long it takes to adapt the given model?
- Evaluation Time – how fast it works when the model is developed?
- Memory – how much memory does the model need to work well?

How does intelligence work? Case study!

Simple environments, rules, and control capabilities can be found in various games, e.g. wormax.io, where players should rescue its worm before the impact with other worms and eat as much food as possible to grow longer and faster.

The feeding can be faster if the worm will make other worms impact and eat their remains, so the strategy is not very complex but requires composure, perceptiveness, mastery, and skill.





Fundamentals of INTELLIGENCE!

The fundamental question is how to develop (artificial) intelligence and skills? How do they develop in nature? How this development is stored and where?

In order to find a solution to these questions, we can look at the human way of thinking in a simple artificial environment of a sample game.

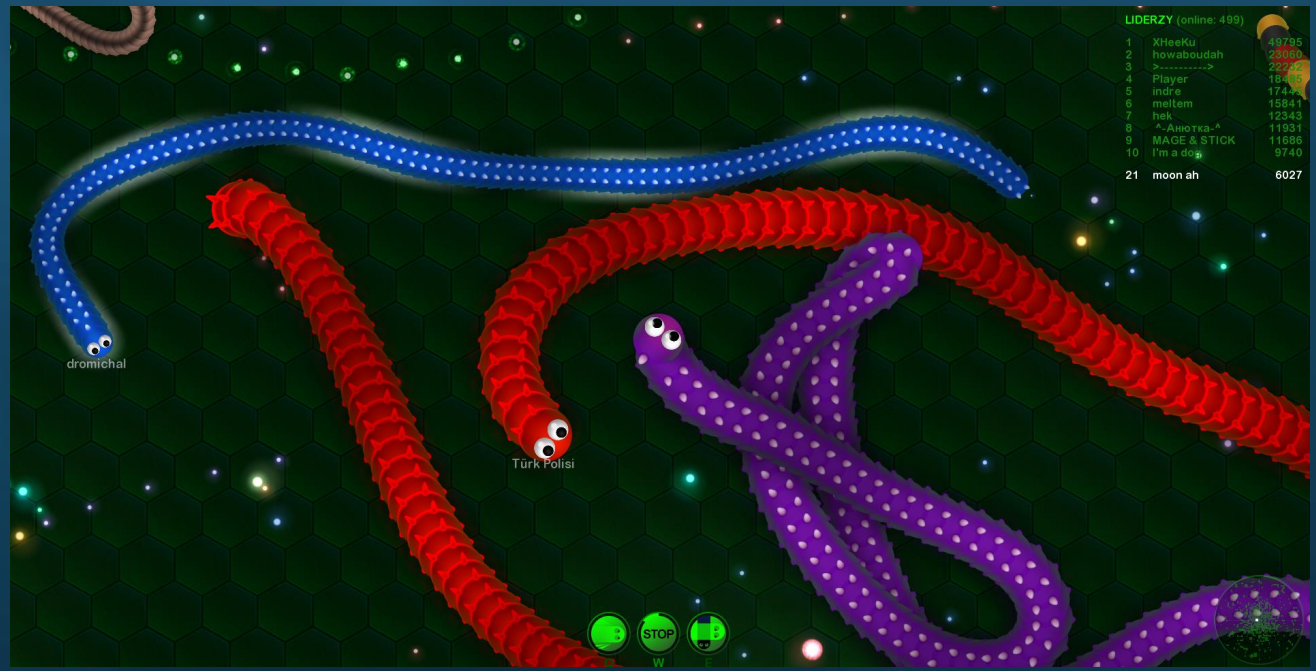
What are the steps which people usually perform to master a game and develop their game intelligence?

Intelligent strategy guidelines:

- ✓Minimizing costs, effort, danger, risk, time to achieve desired results or goals.
- ✓Maximizing advantages, incomes, profits, satisfaction, or fulfillment of needs.
- ✓Focus on efficiency and multi-parameter optimization of all important processes.

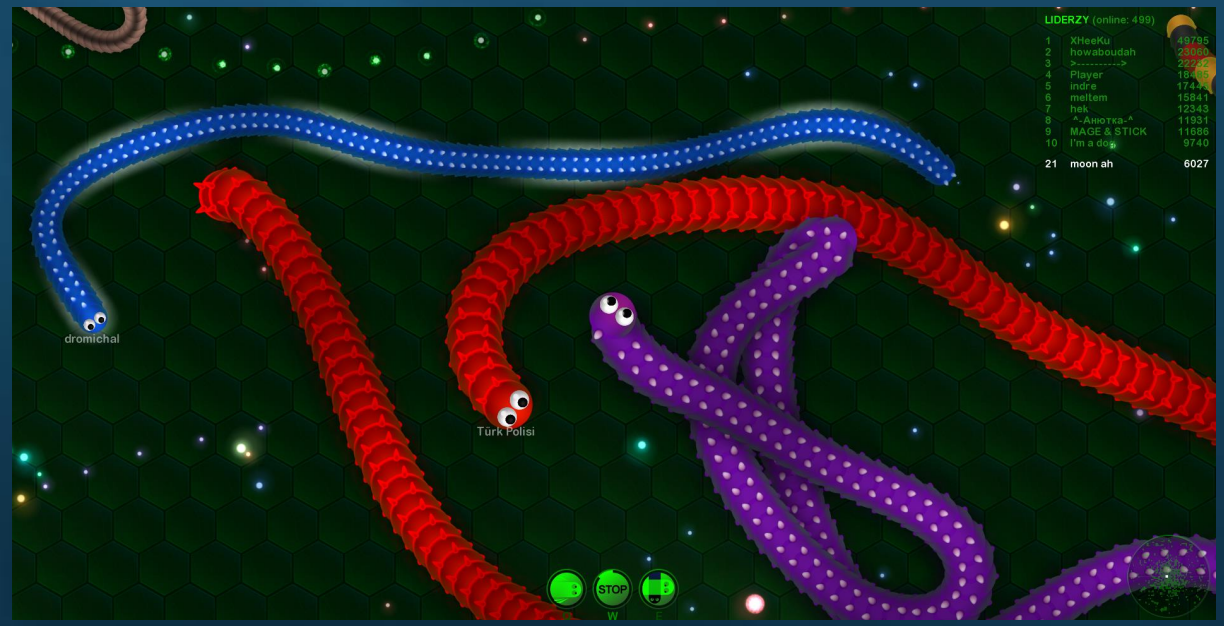
Needs and Goals

- Needs are the fundamentals of the development of human intelligence.
- They are great motivation factors that many times take control of us.
- Intelligence has no reason to develop if there are no need, no goal, and no motivation factors. The more needs have the intelligent entity, the faster its intelligence can develop if it has the possibility to interact and impact on the environment.
- They force us to define goals and look for strategies to achieve them.
- We live in given environment and can have a certain impact and control over it throughout our actuators: muscles, body language, sounds, speech etc.
- Our memory capabilities enable us to remember objects, their relations, possible actions, impact on them, conditions of taking control over them, and routines that define sequences of actions that must be undertaken to achieve desired goals and satisfy the needs.
- The variability or fulfillment of needs temporally change targets and focus to satisfy other needs.



Environment and Control

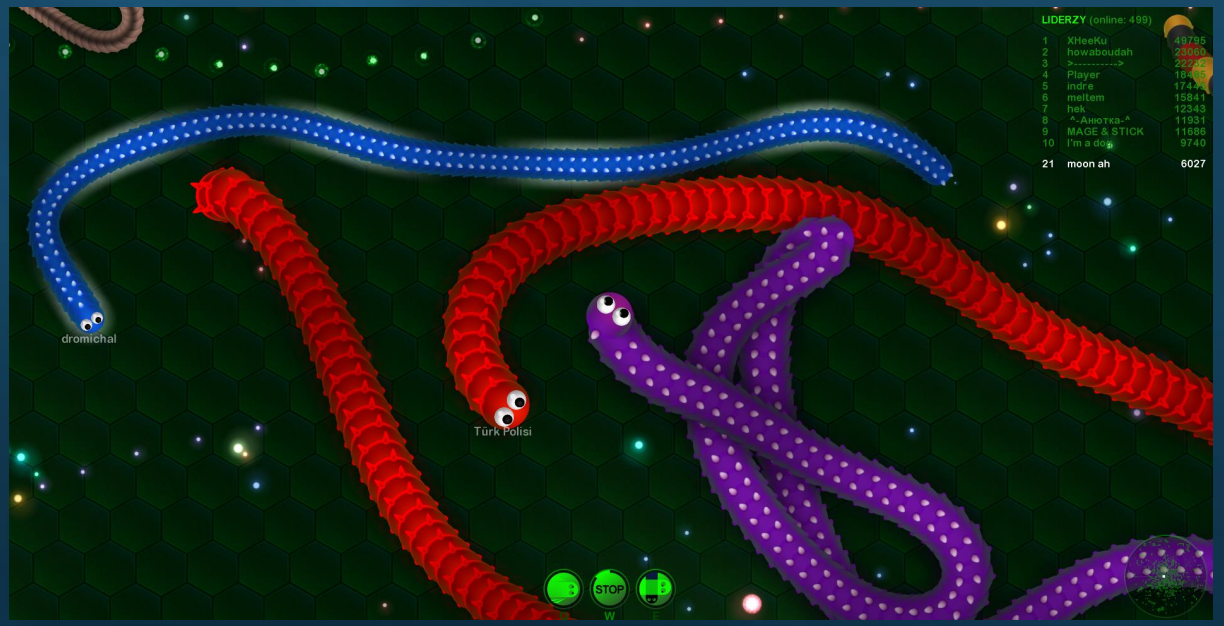
- The environment can be real or artificial, e.g. in games or simulators.
- Each environment can be controlled directly or indirectly.
- Direct influence is usually carried out by touch, body signs, sounds, or speech.
- Indirect influence can be achieved using various tools, other objects in the scene, or other performers who can be influenced and controlled.
- Thus, the environment must be looked through and inspected for possible objects that can be controlled and find out how they can be controlled and by whom?
- Do we have appropriate actuators to control them and do it efficiently enough?
- What is necessary to take efficient control over interesting objects or other performers?



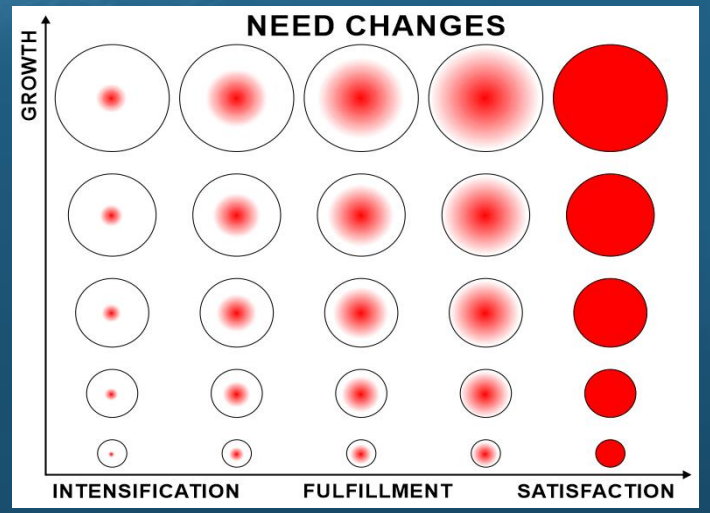
Environment and Objects

Recognize important objects in the given environment:

- Distinguish between static and moving objects.
- Find out similar objects after their appearance and behavior.
- Specify all important capabilities of other objects and performers in the environment
- Check how you can interact with them and influence them to change their behavior or state in which they are.
- Try to use them to satisfy your needs directly or achieve define goals.
- Check other available options and look for improvements or limitation of involved resources if the direct control has satisfied.
- Try to combine available options and find out an indirect way of achieving goals.

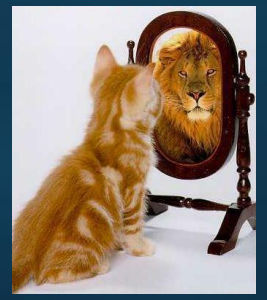


Explore a New Environment



Try to explore a new (selected by you) environment and write down your findings:

1. Choose a new unknown environment (e.g. in any computer game, but not very difficult or complex for the beginning).
2. Identify all objects that could be interesting from the game point of view and your needs.
3. Assign names to these objects and divide them into two categories:
   - Passive – that have to be found during an exploration process and your movement in this environment
   - Active – that move or try to interact with you
4. Recognize which objects are friendly or useful and which are dangers or useless.
5. Consider your own needs that can stand behind your will to play and designated goals using any known systematics or typology of personalities, e.g. the 10x10 Character Systematics. Plan to meet the future needs that predictably appear in the future because you know that many of the known needs will grow again after some time. Predict this growth and schedule your behavior to prepare for fulfilling your future needs more efficiently!
6. Answer the questions:
   - Why do I want to be in this environment (to play this game) and how far I will do it?
   - What can make me to stop being there or playing the game?
   - When this environment (game) will start boring me?
   - Does it make sense to stay in this environment (play this game) anyway? Why? Why not? Verify all your identified needs.
7. Define what your needs are the most important in what situations in the environment (game) and what is the hierarchy of your needs and goals. Notice how fulfilling of each need influences the further strategy and how the goals change.
8. Develop your strategies to satisfy your needs in the selected environment (game) and watch your mind how it develops these strategies, what you combine or divide apart – track your intelligence and describe how it is influenced by your needs!



Strategy Construction

To construct an intelligent strategy to satisfy needs it is necessary to:

- Define goals which achievement will satisfy them. There can be many alternative ways of course.
- Define what actions should be undertaken by you, other performers, or objects to make you closer to the defined goals or at least partially fulfill your needs.
- Reveal which behaviors or actions are the most prospective, under your easy control, or require small costs or effort to achieve some of the defined goals.
- Remember these behaviors and actions and use them in the following steps.
- Select the most important goals that can be at least partially achieved by a known method.
- Try other options, various alternative combinations or sequences of possible behaviors to satisfy other needs or achieve other goals. If profitable, remember them for the following steps.
- Evaluate these behaviors and actions, their combinations, and sequences and associate them with needs that are satisfied as an effect of their occurrence.
- Combine and join prospective combinations and sequences or check similar behaviors to the prospective once to develop more complex actions which satisfy needs faster, cheaper, or more efficiently.
- Select these goals which are currently the most profitable or necessary to satisfy at first or the most severe needs and start to act and control actions of other performers or objects to satisfy your needs and achieve your goals. Do not stop to experiment with other similar actions do develop your skills and intelligence.

Advanced Strategy Construction

To further develop intelligent strategy it is necessary to use similarities or opposites to identify them:

- Find opponents that are trying to prevent or frustrate plans
- Find strengths and weaknesses of the opponents
- Try to prevent, resist a potential attack, protect from harm or danger, and defend against their strength
- Try to use their weaknesses to defeat or discourage opponents to attack, assault or fall on you
- Try to use available objects or take control over other performers to achieve goals indirectly, i.e. the goal which are beyond your reach or could be achieved easier in this way.
- Develop strategies that make you closer or faster to the designated goals.

Try to supplement the above list with your ideas or suggestions.

Genius is the exceptional intellectual ability to put facts together in new creative and original ways such that they form new important values, knowledge, understanding, or experience.

Genius requires being open-minded, open to new experiences and associations, be ready do create them, and try to put things or actions together or subsequently in new original ways.

Many times it is activated by the uncommon and extraordinary environment or experiences.

Our minds require new context to create innovative solutions.

Use Similarity in your Strategies

To make the development process faster and cheaper use the observation of other similar performers:

- Find out similar performers who behave like you or have similar features or needs.
- Discover, remember, and use similar strategies as other performers if they have been successful.
- Track their behavior and imitate those who were successful in satisfying similar needs to yours.
- Remember successful behaviors and use them in the future in similar situations or to similar objects.
- Try to use also the reverse actions to the opposite objects.
- Everything that is moving can be interesting or dangerous because movements require sources of energy that must be obtained so the moving object or performer can be your opponent or competitor as well.
- Try to notice and remember the clever strategies of your opponents that were successful.
  Learn from the mistakes of all other performers as well.
- Strategies can be described by a certain sequence of combined actions and can be used in a special context created by objects and performers in the given environment.
- Remember and associate all successful behaviors with such a strength that is according to the satisfaction level of your needs or achievement of the defined goals.
- Try to generalize strategies by means of similarity and combination of simpler rules and strategies.

Conclusions about Learning

„Learn something” - What does it really mean?

- At first sight, the answer seems to be easy and intuitive.
- At the second sight, we can notice that many things are not easy to learn and master by people.
- Finally, we can conclude that „learning” is a very complex process that we do not understand enough to model it sufficiently in artificial intelligence learning systems!
- Computational intelligence is limited to algorithms that try to remember and generalize training samples.
- **Is that enough to model learning processes?**
- Deep learning architectures can learn more precisely complex tasks represented by training samples, but they cannot construct thinking processes that add together various routines etc. That is indispensable for intelligent processes and human-like learning using similarities and opposites.
- **What characterizes the human way of learning?**
- **How can we learn complex procedures, methods, algorithms, think and solve difficult tasks?**
- **What makes our intelligence intelligent?**

Similarity

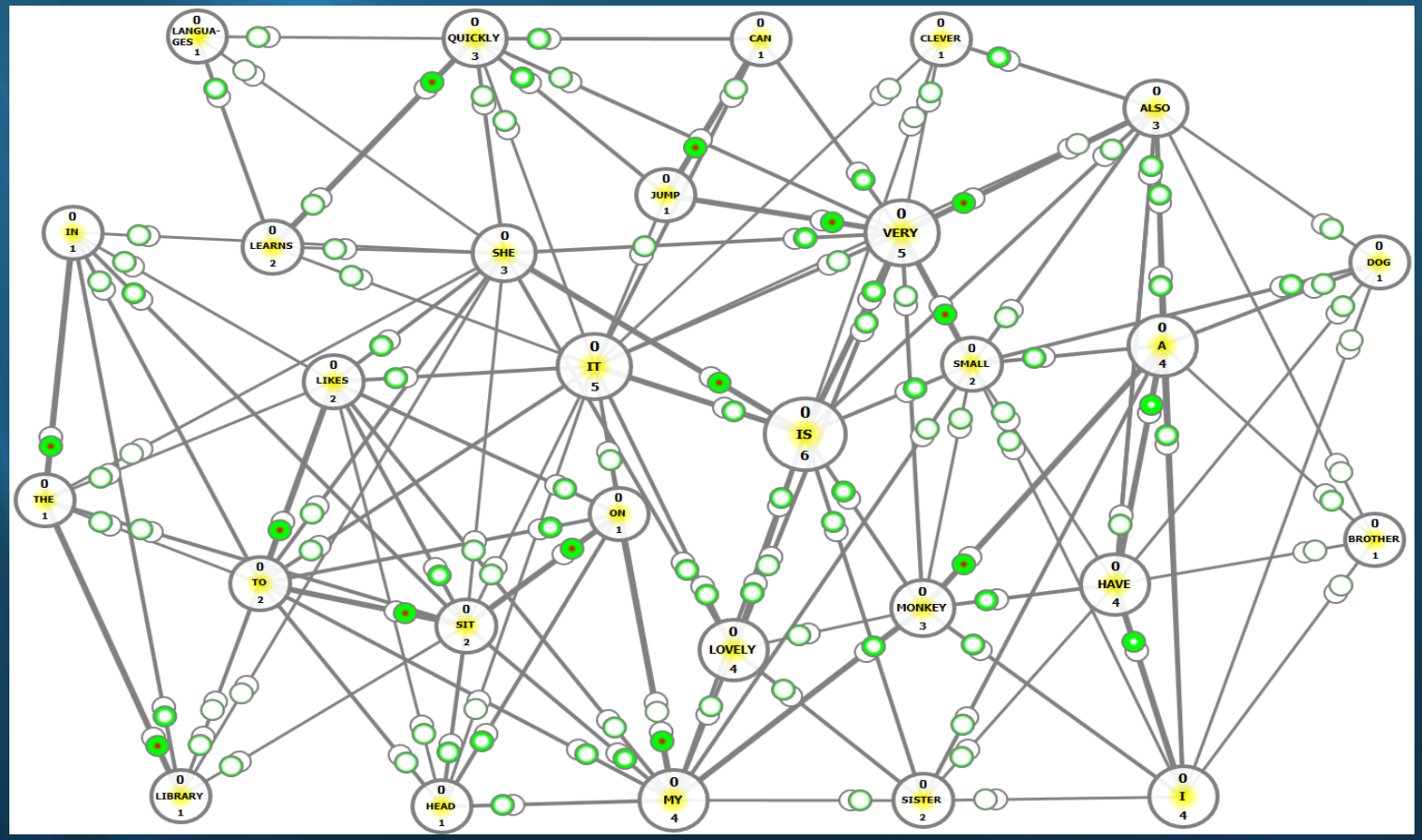
How do we learn rules, complex procedures, routines, and algorithms?

- The ability to remember is an important factor of learning, but it is not enough!
- People learn from watching and imitating others if things they do can satisfy their needs.
- People learn from their successes as well as from the successes of other people (i.e. competitors as well as cooperators)
- People learn from their mistakes as well as from the mistakes of other people (i.e. competitors as well as cooperators)
- People learn things that are somehow associated with their needs and goal (motivation factors)
- People learn to generalize and think by addition, removal, subtraction, joining, combining, or splitting things together or apart.
- People use the context of environment, in which they are, or the context of things, which they should use or process, to recall previously associated (learned) rules, procedures, routines, or algorithms
- The previously learned routines can be used and generalized thanks to the similarity of things, actions, or environment. Moreover, these routines can be added, joined, combined etc.
- Thus, learn means not only to remember but also to use similarity of various kinds to adapt known solutions to similar objects, actions, or environment.
- **How do human brains find similar objects, actions, or environment and use it contextually?**

Succession

Rules, complex procedures, routines, and algorithms can be described by succession:

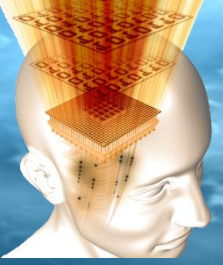
- The successions of objects and actions define all procedures, routines, methods, and algorithms.
- The observation and remembering are enough for robots to be able to imitate them.
- The observation and contextual associating are necessary to generalize them and be creative.
- Succession is a kind of relations that can associate whatever objects in a whatever context.
- Thus, succession lets us learn and remember whatever sequence of data, objects, or actions.
- In result, we can gain knowledge that is true as well as false!



Creativity

Creativity is a certain change in view of the contemporary knowledge, skills, or experience.

- To be creative something (not everything) has to be changed intelligently!
- How to make intelligent changes in what you know or deal with?
- Use the new or modified context of thinking (recalling associated objects) by changing: things, actions, or surrounding in the context of things or actions you try to be creative.
- We shall discuss these things later when talking about associations and associative neural systems.



Computational Intelligence

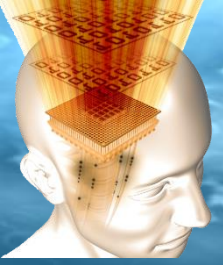
Computational Intelligence is not equipped with needs. It models a very limited part of intelligent processes and strategies. It is generally used for:

- Clustering – creating groups of similar objects or processes,
- Classification – checking whether an object or process does belong to a given group,
- Recognition – evaluating whether the object or process is already known,
- Approximation – modeling of simple decision rules based on various functions,

but it cannot self-develop, self-transform, or define new rules and strategies.

Despite the above-mentioned limitations, it is still very useful and practical because it allows us to solve various tasks for which the solution is unknown, but it can be constructed a model on the basis of training samples automatically.

We shall also try to model more complex routines and advanced learning approaches using similarity, succession, and association to make our systems more intelligent!



Theory and Practice!

Theory is indispensable to successfully implement computational intelligence methods with understanding and consciousness of the ways they work and process data.
The practical theory will be the matter of all following lectures until the end of this term.

- We shall start with models of neurons and their networks.
- The fundamentals of artificial neural networks will be presented.
- The variety of neural networks models will be presented.
- The methods of boosting the training process and other parameters will be discussed.
- Next, we will address modern deep learning strategies and networks.
- The idea of associative neural systems and advanced adaptation methods will be presented and explained.
- The final topics of laboratory projects will be proposed.
- Practical programming and implementation issues will be also presented and discussed.

Bibliography and References

ACADEMIC WEBSITE - ADRIAN HORZYK, PhD, DSc.

AGH University of Science and Technology in Cracow, Poland
Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering
Department of Biocybernetics and Biomedical Engineering, Field of Biocybernetics

Dossier | Research | Publications | Courses | Graduates | Consultations | Contact

AGH

LECTURES

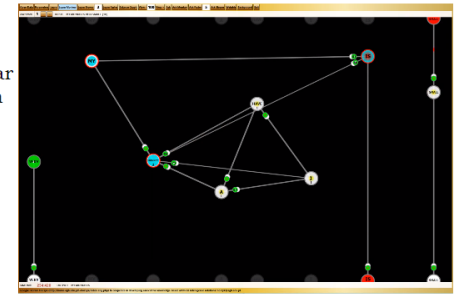
(will be renewed and expanded during the semester)

- Introduction to Artificial and Computational Intelligence
- Artificial Neural Networks, Multilayer Perceptron MLP, and Backpropagation BP
- Radial Basis Function Networks RBFN
- Unsupervised Training and Self Organizing Maps SOM
- Recurrent Neural Networks
- Introduction of Final Projects and Description of Requirements
- Associative Neural Graphs and Associative Structures
- Deep Associative Semantic Neural Graphs DASNG
- Associative Pulsing Neural Networks
- Deep Learning Strategies and Convolutional Neural Networks
- Support Vector Machines SVM
- Fuzzy Logic and Neuro-Fuzzy Systems
- Motivated and Reinforcement Learning
- Linguistic, Semantic Memories, and Cognitive Neural Systems
- Psychological Aspects of Intelligence, Human Needs, and Personality
- Writing Journal Papers

COMPUTATIONAL INTELLIGENCE

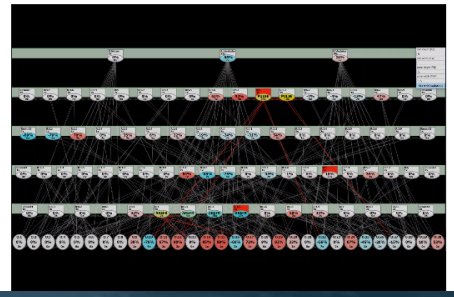
This course includes 28 lectures, 14 laboratory classes, and 14 project classes.

What is this course about?



This course is intended to give students a broad overview and deep knowledge about popular solutions and efficient neural network models as well as to learn how to construct and train intelligent learning systems in order to use them in everyday life and work. During the course we will deal with the popular and most efficient models and methods of neural networks, fuzzy systems and other learning systems that enable us to find specific highly generalizing models solving difficult tasks. We will also tackle with various CI and AI problems and work with various data and try to model their structures in such a way to optimize operations on them throughout making data available without necessity to search for them. This is a unique feature of associative structures and systems. These models and methods will allow us to form and represent knowledge in a modern and very efficient way which will enable us to mine it and automatically draw conclusions. You will be also able to understand solutions associated with various tasks of motivated learning and cognitive intelligence.

Lectures will be supplemented by laboratory and project classes during which you will train and adapt the solution learned during the lectures on various data. Your hard work and practice will enable you not only to obtain expert knowledge and skills but also to develop your own intelligent learning system implementing a few of the most popular and efficient CI methods.



Expected results of taking a part in this course:

- **Broad knowledge** of neural networks, associative and fuzzy systems as well as other intelligent learning systems.
- **Novel experience** and **broaden skills** in construction, adaptation and training of neural networks and fuzzy systems.
- **Ability to construct** intelligent learning systems of various kinds, especially deep learning solutions.
- **Good and modern practices** in modelling, construction, learning and generalization.
- **Own intelligent learning system** to use in your life or work.
- **Satisfaction** of enrollment to this course.

http://home.agh.edu.pl/~horzyk/lectures/ahdydci.php