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Research Institute
on Artificial Intelligence,
Virtual Reality and Robotics

ARTIFICIAL INTELLIGENCE 4.0 @UBB

FACULTATEA DE MATEMATICĂ ȘI INFORMATICĂ
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EDITORIAL

Computer Science (CS) has proved to be one of the most dynamic and growing fields of research. While the earliest computational tool was the abacus, in the third millennium BC, this started to emerge as an organised discipline during the 18-th century. The technical developments of the 20-th century generated a need to create computational tools and devices to help in our everyday activity.

Part of Computer Science, the essence of Artificial Intelligence (AI) research is to learn from and understand the reasoning methods and models in the nature surrounding us. As we transform these lessons in algorithms and methods and work them out using the computer power and the storage space available today, we return to the real world with our need for experimentation and method validation and contribute to the problem-solving needs of our community. While the whole process appears to the layman as a black box holding some smart magic, this confirms our understanding that the only way forward is cooperation and trust.

The force and effectiveness of our research activity in CS in general and in AI, is best illustrated by a few data. During 1990-2022, out of 146 doctoral theses in CS issued by UBB, 68 (47%) covered topics in AI. During 2016-2022, out of 81 doctoral theses of CS issued in Romania, 32 (40%) were issued by our school. Out of these 32 theses, 25 (78%) covered topics in AI.

Prof. Dr Horia F. Pop, Director
Research Institute on Artificial
Intelligence, Robotics and Virtual Reality

FACULTY OF MATHEMATICS AND COMPUTER SCIENCE
BABEŞ-BOLYAI UNIVERSITY

Universities were created in Europe as early as 11-th century as a framework to introduce scientific investigation and critical thinking as a fundamental way to improve our society. Further away along the path of history, the Humboldtian university model was established in the early 19-th century on the principles of freedom, seminars, and laboratories as the basis for the need to create autonomous individuals, educated as world citizens.

The Babeș-Bolyai University, the *Universitas Claudiopolitana*, long-lasting university of Cluj, takes its strength from the early *Collegium Academicum Claudiopolitanum*, founded in 1581 by Stephen Báthory, prince of Transylvania, with support from the Jesuit order.

The domain of Mathematics was from the very beginning of the modern university one of the major fields of study and research, as the Faculty of Sciences was one of the four original faculties of the university. The Faculty of Mathematics and Computer Science is formed by two complementary sciences. Mathematics, considered the mother of sciences, brings tradition and stability. Computer Science, through algorithmic thinking and heuristic reasoning, brings innovation and novelty.

Our school of Computer Science is one of the most active in Romania, operating with about 80 teaching staff and about 40 PhD students. We benefit of research grants from Romanian and European sources and innovate through cooperations with the IT industry and the academic and scientific community in Cluj and Transylvania, and across the world.

Prof. Dr Anca Andreica, Dean
Faculty of Mathematics and Computer Science

RESEARCH INSTITUTE FOR ARTIFICIAL INTELLIGENCE, ROBOTICS AND VIRTUAL REALITY

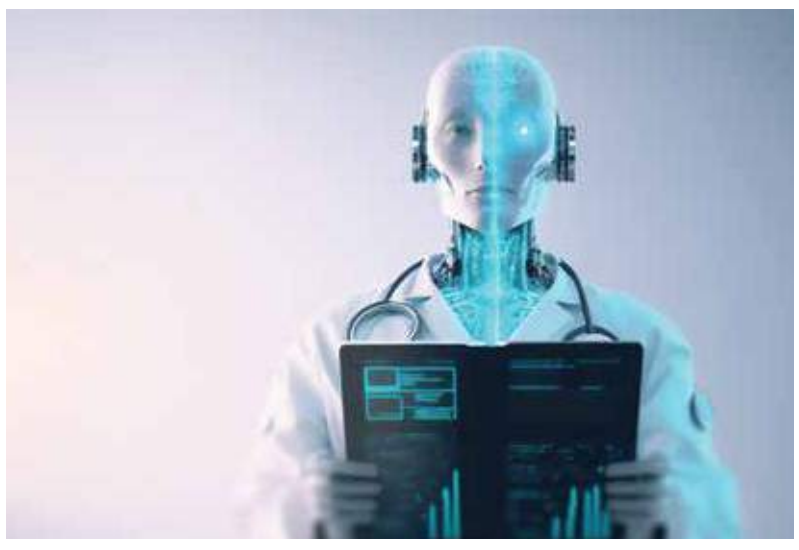
The Research Institute for Artificial Intelligence, Robotics and Virtual Reality is created to support and complement the research efforts in Artificial Intelligence and related areas by the Doctoral School in Mathematics and Computer Science. It counts 27 teaching staff out of which six doctoral supervisors, and seven more professors or associate professors, 32 graduate and PhD students, and four research or associate research staff members. The institute operates on research grants, scientific cooperations and know-how transfer, and is structured on research groups:

- **Computational Intelligence Research Group**
  group leader Prof. Dr Horia F. Pop.
- **Machine Learning Research Group**
  group leader Prof. Dr Gabriela Czibula;
- **Metaheuristics for Complex Systems Research Group**
  group leader Prof. Dr Anca Andreica;
- **Data Mining Research Group**
  group leader Prof. Dr Lehel Csato;
- **Virtual Reality Research Group**
  group leader Assoc. Prof. Dr Rareș Boian;
- **Modelling and Simulation Research Group**
  group leader Assoc. Prof. Dr Andras Libal.

The Institute is accredited by UBB as a research institution since 2013 and has benefitted so far from several (inter)national cooperation agreements, including those with Kyung Hee University, Seoul, Korea (2017), West University of Timișoara, Romania (2018), Martin-Luther Halle-Wittenberg University, Germany (2019).

AI FOR HEALTH

AI is a powerful tool with applications in healthcare, improving patient care, planning capacity and access to healthcare services. AI can boost **clinician productivity**, enhance medical diagnosis and treatment, and optimise the use of available technical and human resources. Chronic diseases, the lack of medical professionals, unsustainability, and healthcare disparities are a few of the major healthcare difficulties and unmet requirements that will benefit from the implementation of AI in medical care.



Healthcare is ripe for disruption, especially where AI and automation can fill in gaps for routine and repeatable tasks. The potential for applying AI in the clinical setting ranges from the automation of diagnostic processes to therapeutic decision making and clinical research. AI, in general, and machine learning, in particular, play a major role in tasks such as **automating image analysis** (e.g., applications in radiology, ophthalmology, dermatology) or signal processing (e.g., electrocardiogram, electroencephalography data analysis). We developed quantitative, non-invasive, and reproducible techniques with minimal user intervention for diagnosis based on medical imaging (e.g., localisation of tumour lesions in breast cancer, staging of prostate cancer, quantification of bladder cancer, identification of cardiac malformations, characterisation of skin cancer). The proposed **integrated intelligent support systems** for tumour identification and staging can reduce the workload of the physicians since the performed predictions tackle the interobserver variability. On long run, a precise tumour staging guides and adapts the therapy selection. Segmentation of

anatomical structures or lesions with limited human interaction was achieved by using both **supervised** (e.g., deep networks) and **unsupervised** (e.g., cellular automata) methods. They enable automatic localisation and delineation of the anatomical structures or lesions in various problems (e.g., breast, prostate, bladder, skin or lung cancer, ophthalmology, cardiac diseases). We are focused on advancing safe, robust, and interpretable AI approaches. The recent AI progress empowers the technologies for adapting decision systems to the specifics of medical investigations.

Our team has developed **human-centric, self-explanatory AI models** and technologies for health management and disease prevention: business intelligence systems for optimising the costs of preparing, running, and monitoring screening programmes; innovative decision-making tools to assist specialists involved in screening programmes through the simultaneous integration of factual and conceptual knowledge. We have explored AI models and big data technologies for monitoring health status and quality of life after treatments or customising the health and disease management.

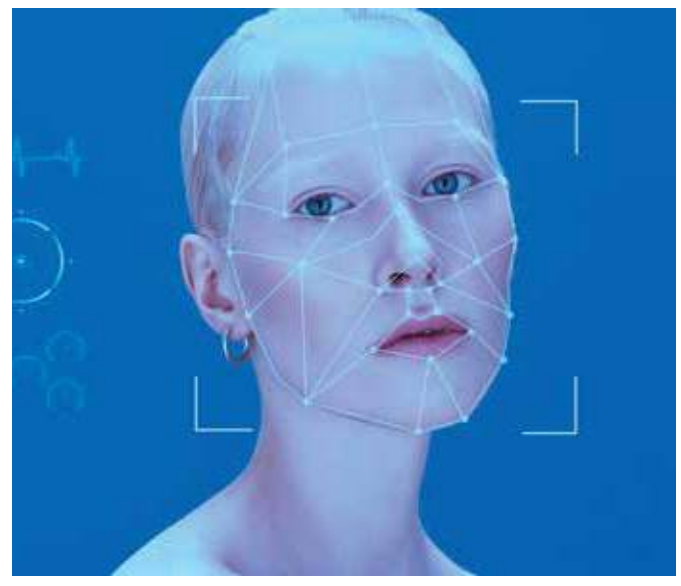
Building innovative and effective solutions for health and well-being requires interdisciplinary approaches that integrate knowledge and expertise from medical, social and natural sciences with the power of computation. New solutions based on AI models represent important advantages related to efficiency and cost in addressing public health problems. *AI will change the face of healthcare and will help the personalised tailoring of the medical act/ clinical routine*.

AI FOR EDUCATION AND PSYCHOLOGY

Educators constantly address and adapt to the changes of how people perceive and process information, which is heavily influenced by technological progress. Psychologists face the same challenges with respect to how people think, learn, memorise information, or solve problems. Improvements of the education system require psychology insights. However, there is a large diversity of factors that influence the way people learn and interact with technology, and AI is optimal in

dealing with such challenges. Many complex problems that arise in fields like **emotion recognition** or building **intelligent assistants** cannot be solved by standard methods but by AI-based tools and algorithms, able to generate efficient and intelligent solutions using limited resources.

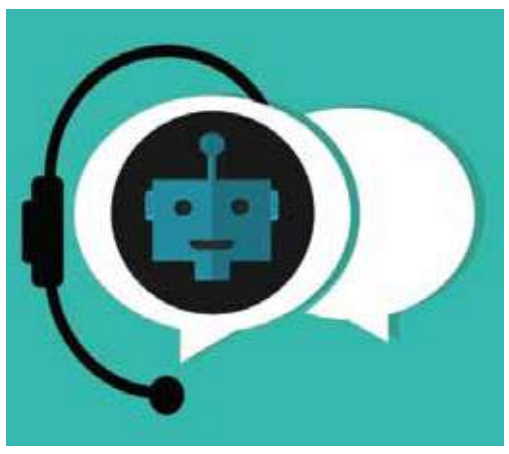
Recognising human emotions is a difficult task even for humans. Still, it is a very important task as emotions influence the performance of humans, and their decisions. Identifying human emotions or predicting them would provide relevant information in education and psychology. We have addressed the automatisation of this challenging task based on multiple modalities used by humans to express emotions, including facial expression, body posture, voice, text or physiological signals (e.g., body pressure, heart rate). The proposed **emotion detection algorithms** are based on the facial expression as the main source and the identification of micro-expressions. Applying these methods for pre-schoolers (3-6 years old) is particularly



challenging due to low attention span of the child as well as the scarcity of specialised training data.

Extracting the emotions from voice and textual data is another application area explored by our research teams. Recognising emotions in speech requires separating the speakers, converting voice to text, and then applying the same techniques used for text emotion recognition. We have developed a **Romanian emotion lexicon**, thus opening the perspectives for new Romanian language processing research. The biometrical effects of emotions differ qualitatively, quantitatively, and temporally from one person to another. We therefore created algorithms able to extract emotions from **biometric data** by processing the information acquired from multiple sensor channels. The fused streams of data provide a multitude of accurate measurements, that were mapped to emotions using **machine learning** and **data mining** algorithms

The limited availability of trained professionals for psychological assistance or process automation has been tackled by innovative interactive systems. Our research teams have developed **chatbots** and **virtual assistants** to provide support in problems such as psychological screening, academic scheduling, and bullying. We work closely with specialists in psychology and education, applying our **natural language processing** and **process automation** expertise to build machine learning models and architectures able to understand a user's free-text statements through **intent understanding** and **sentiment analysis.**



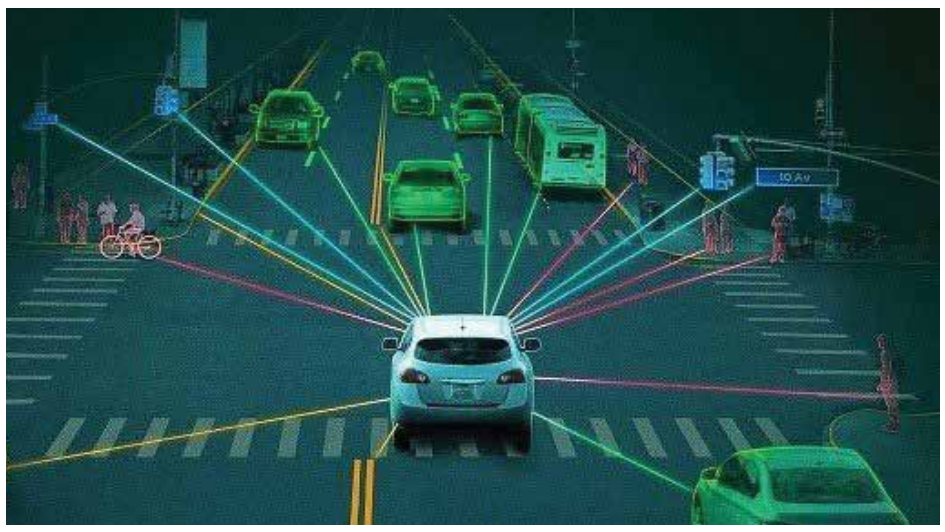
AI FOR ECONOMIC SCIENCES

Economic application domains are known to gravitate around large data lakes rich with hidden patterns that can be explored and uncovered by AI algorithms. Many complex problems that arise in fields like **transportation, logistics, supply chain management, business** or **finance** cannot be solved exactly by standard algorithms due to very large search spaces that need to be covered, while AI offers powerful tools and algorithms able to generate efficient and intelligent solutions using limited resources.

From optimisation problems in transportation for terrain, rail, or air vehicles to classification problems related to driving systems, our team has successfully developed and trained AI techniques such as **neural networks, deep learning** and **explainable AI models** to enable highly performing solutions to these complex problems. We have developed image processing techniques and AI algorithms to understand and generate meaning from road images, traffic sign images or railway videos. Interpretability of deep neural network models is a major concern when applied in safety-critical environments such as driver assistance and autonomous driving systems. Our research teams are committed to tackle multiple challenges in this context, including the constraints imposed by hardware accelerators of embedded systems on the network architectures and the use of explainable AI models for tasks such as object detection, semantic segmentation, and depth prediction.

Route optimisation and **traffic assignment** are challenging problems for which AI support in the generation of solutions facilitates the integration and consideration of many variables such

as traffic conditions, vehicle, and driver profiles. We have designed state-of-the-art **evolutionary algorithms** and **nature-inspired optimisation techniques** to find the best routes in terms of financial or ecological cost savings in different traffic environments, to compile the optimal schedule for trains or airplanes, or to detect and understand traffic signs, promote safety, and facilitate the driving experience.



We work closely with specialists in **finance** and **business** to apply our knowledge in order to address problems of **predicting business indicators** or **forecast** risk factors for **credit scoring** or **investing.** Our team has built various AI architectures that accurately predict data points further translated to business intelligence by our collaborators. Interdisciplinary projects implemented in cooperation with our industrial partners focus on developing AI solutions to support **business process automation** based on **machine learning** and **natural language processing** techniques.

Using **complex network theory** and **big data technologies**, we modelled various financial systems as **networks**, applied network science tools to extract the important nodes and analyse network dynamics, developed AI optimisation models to detect the network communities and designed algorithms to **detect fraud** or perform **financial engineering** on the invoices or transactions existing in the economy of the systems.

AI FOR BIOINFORMATICS AND ENVIRONMENT

Many problems in **bioinformatics** are too complex for traditional methods and algorithms, but **Machine Learning (ML)** techniques are well suited for such tasks, as they may be dynamically adapted to new daily generated biological data, as well as account for noisy or erroneous data. Our research teams provide AI based solutions for challenging problems such as **protein** structure prediction, **DNA** fragment assembly and promoter identification, multiple sequence alignment, temporal ordering of biological data, **gene expression** data analysis, gene clustering, and protein-protein interaction.

Environment. In a world of continuous climate change, where the intensity and number of severe weather events is increasing, crisis management and risk assessment become essential. Meteorological institutes keep enormous historical data sets that can be used by ML algorithms to analyse and predict meteorological phenomena in time for the public and authorities to take measures. Our ongoing projects tackle environment issues via ML and big data approaches, for **accurate weather forecasting and nowcasting**, wildfire prediction or identification and classification of environmental factors that have significant effects on flora and fauna. Other AI based contributions to environment related problems refer to water quality analysis of the Danube river, coals analysis and comparison, classification of mineral waters, scheduling and identification of households' shiftable energy consumption.

Agriculture. Data mining and computational intelligence techniques applied for the thorough analysis of agriculture-related data collected by smart sensors facilitate decision making for farming activities such as crop planting, irrigation, soil management, disease, and pest identification, aimed to support and optimise food production. We developed ML solutions for problems such as estimation the seasonal harvest, identification of the optimal sowing schedule, optimisation of maintenance and harvesting processes, early detection of pests and diseases. AI and ML methods are used by our researchers to also process aerial and ground-level images and to create effective models that provide innovative solutions for farmers.

Chemistry. Statistical modelling has been applied in chemistry for decades. Novel soft computing methods, recent data availability, and increased computational power allowed us to significantly contribute to the field. We successfully tackled chemistry problems such as intramolecular interactions and catalyst modelling, droplets detection and segmentation in surface sciences, optimal selection of solvent systems or classification of chemical elements.

Archaeology. The versatility of ML has led to its rapid adoption by archaeologists. Bioarchaeology studies the organic remains on archaeological sites to infer knowledge about our ancestors' health, nutrition, evolution, and societies. Our research results refer to characterisation of Roman pottery and automation of processes of determining characteristics based on osteological analysis.

AI FOR COMPUTER SCIENCE

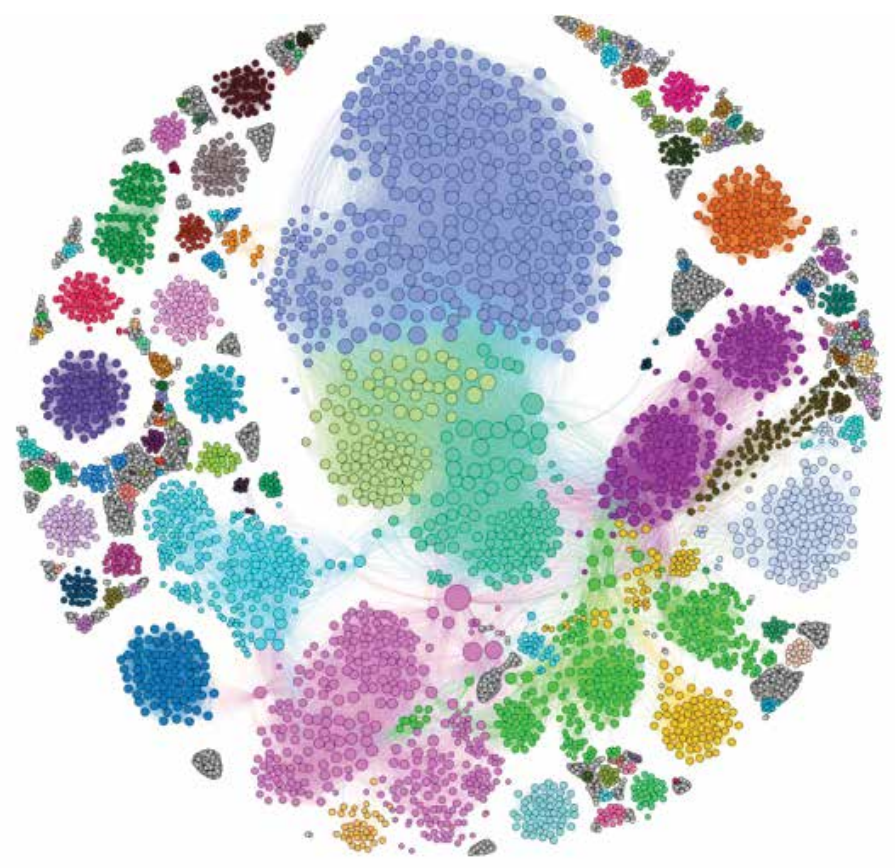
Approaching **software engineering** issues as **search** problems, allows solving them using computational intelligence and consequently benefits from the advantages offered by AI. **Metaheuristics** have successfully been applied for software engineering activities with balancing competing (and sometimes inconsistent) constraints, where perfect solutions are either theoretically impossible or practically infeasible. Some of the software engineering activities tackled by our research teams are software **quality** evaluation, change and defect management, prediction and detection of software **defects**, test case ordering, **cost and effort estimation**, component selection.

Cybersecurity is answering a problem of central importance in a world that relies on technology more than ever before. Although information security has always been of major concern, the emergence and progress of social media and mobile applications has changed the speed and extent of access to data and information. As such, Internet users are nowadays more exposed to malicious software. By proposing novel methods for analysing malicious software, detecting fake news and intentional deception, or recognising malicious web links, using AI approaches, we have improved the reliability and efficiency of current systems.

Robotics research has become an interdisciplinary topic at intersection between computer science and engineering. We aim at developing machinery to aid or replace humans in carrying out

complex or difficult tasks (e.g., in high-precision manufacturing processes or in dangerous environments). Our research projects concentrate on coordinating multiple autonomous agents in different environments to avoid obstacles and collisions. Examples include warehouse management for the optimal placement and delivery of packages, rescue robots sent into an earthquake affected landscape, or nanorobots delivering nutrients or drugs passing through biological barriers. The proposed robust AI algorithms (evolutionary approaches, swarm intelligence, neural networks) provide a strong theoretical framework for further experimentation.

Complex networks emerge in almost every domain, including scientific, economic, or social applications displaying extensive relations between constituent units (e.g., people, computer programmes, stock markets). We developed methods to assess the nodes importance via centrality measures, search for recurrent and significant network motifs,



determine influential nodes that maximise the spread of information in a network, and critical nodes that, once removed, would degrade such an interlinked system. Other applications concern the spreading of (mis/dis) information in social networks, study of epidemic spreading, de-structuring of criminal networks, analysing bank transactions, finding influential authors in co-authorship networks, as well as inspecting stock market networks to determine critical stocks.

THE FUTURE OF AI

The childhood phase of AI is about to end, as the research concerns tend to mature. We are assessing here what we feel are major issues in AI research and philosophy for the time to come.

Intellectual property issues. The legal decision concerning machine recording of personal information placed privacy responsibility onto the actual human user. AI devices generate new information out of large quantities of already available data. The legal property over automatically produced data must be assessed.

Human trust issues. By definition, the AI methods achieve results considered intelligent by humans. They are not required to follow human logic. Therefore, research must concentrate on explainable methods and on the need to formally prove and justify the results.

Software quality issues. The software programmes are usually sold with an “as-is” guarantee. Of course, such a procedure is inadequate for AI software.

Legal liability of the AI entity. In every case a human based activity is replaced by an AI entity, a legal liability issue will be raised. The impersonal nature of AI will generate difficulties.

Healthcare issues. Further research will naturally be dedicated to AI-augmented individuals. Issues such as eye and bones replacement, or brain support for member paralysis will lead to questions on the moral acceptability of AI-based improvements.

Out-of-the-box thinking. While this is the driving force behind human advances throughout our history, AI methods are not able to capture it in a satisfactory manner... *Is this good or bad?*

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