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**2017**

# Research Review

University of Ljubljana

Faculty of Computer and Information Science

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**Visual object  
tracking**

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**Ear Biometrics**

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## 2017 Research Review

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## Remarks by the Dean

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Dear reader,

the Faculty of Computer and Information Science at the University of Ljubljana is the leading institution in the field of computer science in Slovenia.

Interest for studies in computer science has never been higher. With 1300 active students, we are the largest Slovenian faculty offering programs in computer science. Many of our professors are world-renowned experts in their fields. Agreements with several top foreign universities and double degree programmes with Technical University Graz, Austria, and Kyungpook National University, South Korea allow our students and teachers to take part in a number of exchange programs.

The faculty is home to active research groups participating in domestic and international research projects. Their diverse research covers some of the most fascinating and rapidly developing disciplines. The faculty has a strong tradition in the field of artificial intelligence, from taking part in establishing its theoretical underpinnings to applying its newest approaches to a wide spectrum of disciplines from computer vision to bioinformatics to network and text mining.

We put theory into practice through collaboration with a diverse set of industrial partners, from adapting data mining tools for a pharmaceutical company to designing a computer vision system for damage inspection of cars to developing a system for video measurements of ski jumping distances.

We invite you to browse through the pages of this booklet with highlights from the past year to get a glimpse into the future.

Prof. Bojan Orel, PhD  
Dean

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# University of Ljubljana

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The University is among the top 3 % universities in the world, according to Webonomics, Times and the Shanghai ranking.

The University of Ljubljana is an institution with a rich history. Opening its doors in 1919 on the foundations of a centuries-long educational tradition in the region, the University of Ljubljana has a reputation for impeccable quality in social sciences, physical sciences, humanities, and technical programmes. The Faculty of Computer and Information Science is a full member of the University.

Research staff and research groups at the University have proved themselves with world-renowned studies and projects in the fields of the arts, science and technology – both at home and abroad.

The University maintains close connections with the Slovenian private sector and with companies from abroad, and its partner institutions include many multi-nationals and some of the most successful domestic enterprises.

**1522**

Doctoral Students

**4060**

Researchers

**5730**

Employees

**428**

EU projects

**361125**

Citations Scopus (2012–2017)

**2820**

Publications

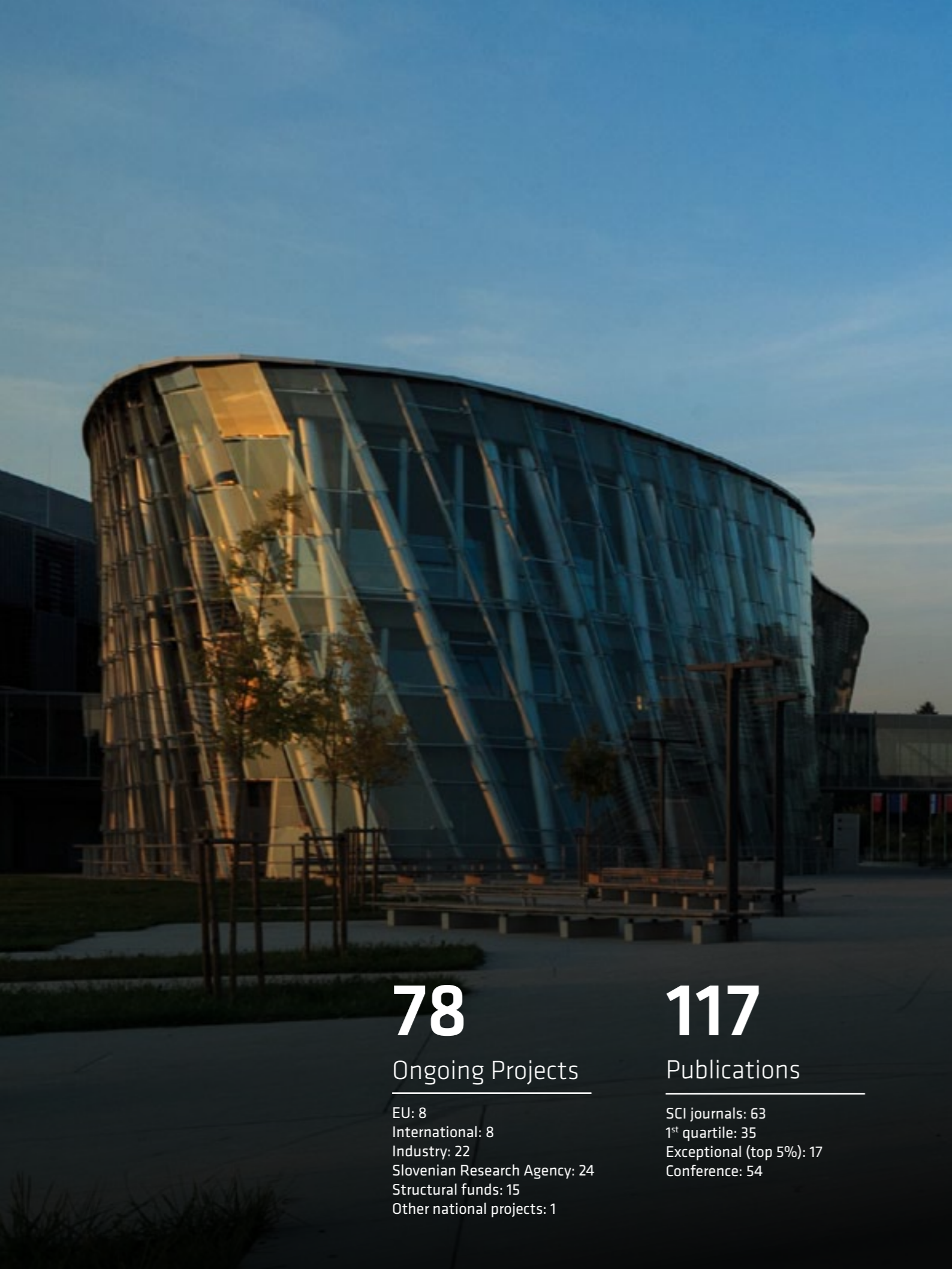
**308155**

Citations WoS (2012–2017)

**53.326.680,00 €**

Revenue for research and development \*

\* data for 2016



**78**

Ongoing Projects

EU: 8  
International: 8  
Industry: 22  
Slovenian Research Agency: 24  
Structural funds: 15  
Other national projects: 1

**117**

Publications

SCI journals: 63  
1<sup>st</sup> quartile: 35  
Exceptional (top 5%): 17  
Conference: 54

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## Faculty of Computer and Information Science

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**33**

Doctoral Students

The Faculty of Computer and Information Science of the University of Ljubljana is Slovenia's leading educational and research institution for computer and information science. The Faculty's main function is educating undergraduate and graduate computer science experts of various profiles, as well as engaging in research work which generates new knowledge and uncovers solutions to contemporary problems.

**123**

Researchers

The Faculty also offers additional educational activities in computer and information science for several professional profiles by hosting lectures and workshops to increase the level of computer literacy in the country. Its public events also serve to popularise ideas about computers, especially among young people.

**168**

Employees

The Faculty was founded in 1996, when the Faculty of Electrical Engineering and Computer Science split into two separate faculties. The study of computer science itself began at the University of Ljubljana back in 1973, first as an elective programme after the 2nd year of electrical engineering study, and has been an independent study programme since 1982. In 2014, the Faculty moved to a new building in Brdo at the outskirts of Ljubljana.

**15 245**

Citations Scopus (2012-2017)

**9 735**

Citations WoS (2012-2017)

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## Slovenia: A Green Country

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Slovenia lies in the heart of Europe, its 20,273 km<sup>2</sup> of land ranking it among the smallest European states. The country's official language is Slovenian. Ethnic Slovenes make up the majority of the 2 million inhabitants, while there are also significant Hungarian and Italian minorities. Since 2004, Slovenia has been a full member of the EU and uses the euro as currency. Life in Slovenia, in comparison to other western countries, is fairly comfortable, and the quality of life is appropriately high.

Despite its small size, the landscape is quite diverse, from the Mediterranean coast to towering alps and the fertile Pannonian plane. A large part of the country is also marked by karstic soil, countless sources of water, and nearly endless forests. Slovenia is among the European countries with the highest percentage of forest, providing a safe haven for a whole zoo of wildlife, including bears, wolves, and lynx, which have disappeared from many other countries. Natural endowments and a safe and peaceful environment bring a number of tourists to the country each year.

Ljubljana is the capital of Slovenia and no visit to Slovenia is complete without a visit to this historic city. With a population just topping 300,000, Ljubljana ranks among medium-sized European cities. It offers everything that larger capitals do, while still giving the cosy feeling of a town, where everything is at your reach. Many of the state institutions are located in the city, as are the most important financial institutions and many major private companies, and of course the largest university in Slovenia.

Students make up a good seventh of the population, giving the city a youthful and lively atmosphere. Numerous cultural events held in the city throughout the year mark its rich tradition, as well as its modern creativeness. By day, the many tourists flocking to the capital are delighted by the cafes and bars along the Ljubljanica river, which winds its way through the heart of the city, while things heat up a bit at night.



**Faculty of Computer  
and Information Science  
is right beside the greenest  
part of Ljubljana.**

# Open to International Collaboration

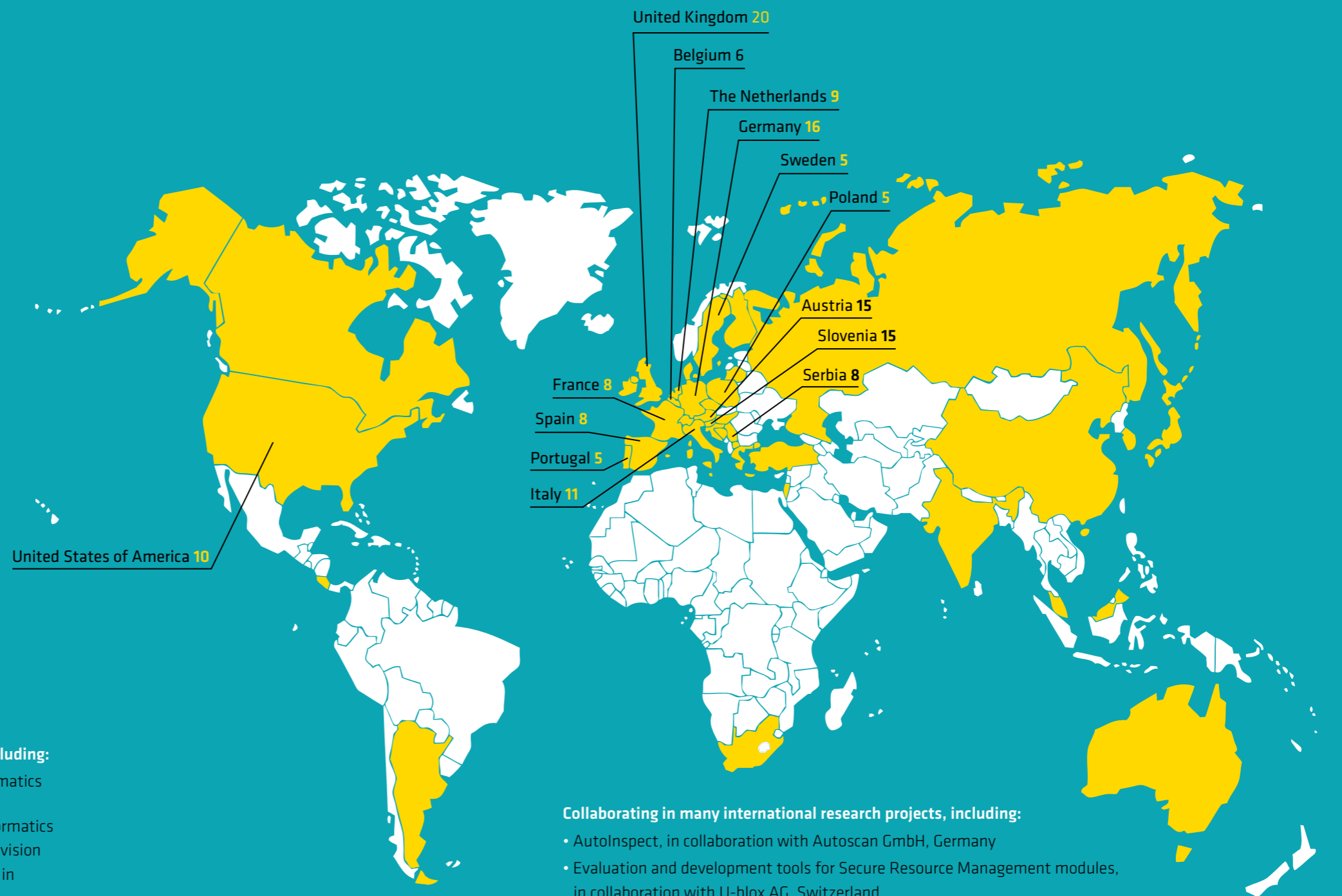
Great diversity and interdisciplinary approaches distinguish the research work of our faculty members. Our research addresses a number of research questions from a wide range of fields concerning computer and information science. Data acquisition and management is an important area of research, as is the integration of systems. Our research addresses a number of other research questions from a wide range of fields concerning computer and information science. Research groups at the faculty are successful in conducting a wide range of national and international projects and programmes. International studies are conducted in collaboration with world-class universities and research centres in Europe, the US and elsewhere around the world. In collaboration with the private sector, which has considered the Faculty an important partner for development, the Faculty conducts numerous applicative studies in computer science. The findings and results of research staff at the Faculty are regularly published in recognised international scientific publications, and its research staff – as world-class experts – participate in professional conferences and actively collaborate in international professional associations in all aspects of computer and information science.

## Collaboration with many world-renowned institutions, including:

- University College London (UK) – joint research in bioinformatics and mobile computing
- Baylor College of Medicine (USA) – joint research in bioinformatics
- DFKI, Saarbrücken (Germany) – joint research in computer vision
- Alpe-Adria University Klagenfurt (Austria) – joint research in compilers and algorithmics
- University of Belgrade (Serbia) – joint research in sport statistics and computational linguistics
- Kyungpook National University (South Korea) – joint research in computer vision and wireless computing, and a double degree study programme in computer science/electronics engineering

**182**  
collaborations

Argentina • Australia • Austria • Belgium • Bosnia and Herzegovina • Canada • China • Costa Rica • Croatia • Czech Republic • Denmark • Finland • France • Germany • Greece • Hungary • India • Ireland • Italy • Japan • Kosovo • Lithuania • Macedonia • The Netherlands • Poland • Portugal • Russia • Serbia • Slovenia • South Korea • Spain • Sweden • Switzerland • Turkey • United Kingdom • United States of America



## Collaborating in many international research projects, including:

- AutoInspect, in collaboration with Autoscan GmbH, Germany
- Evaluation and development tools for Secure Resource Management modules, in collaboration with U-blox AG, Switzerland
- CROSSBOW – CROSS BOrder management of variable renewable energies and storage units enabling a transnational Wholesale market, EU H2020
- DIGITRANS – Digital Transformation in the Danube Region, Danube Transnational Programme
- HUBLINKED – Strengthening Europe's Software Innovation Capacity, Erasmus+

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# Highlights

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“Understand it well as I may,  
my comprehension can only be an infinitesimal  
fraction of all I want to understand.”

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Ada Lovelace

## Large-Scale Computational Models of Liver Metabolism: How Far From the Clinics?

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Assist. Prof. Miha Moškon, PhD  
(miha.moskon@fri.uni-lj.si)

**Collaborating Laboratory:**  
Computer Structures and Systems Laboratory

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“Computational models of liver metabolism are gaining high potential in clinical applications.”

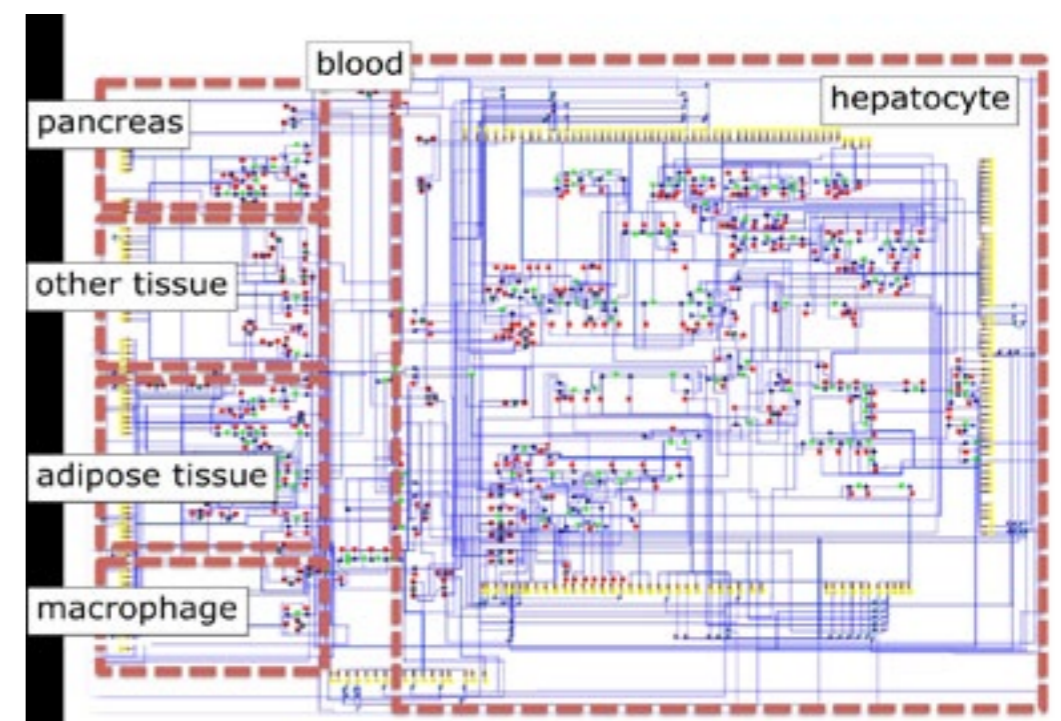
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Computational models of liver metabolism can be used to explain the dynamics of liver diseases, enhance their diagnostics and treatment. These models, however, still must be acknowledged by clinicians for them to be used in daily routine clinical work. The paper titled “Large-scale computational models of liver metabolism: How far from the clinics?” reviews the state-of-the-art computational models of liver cells and describes their value for clinical applications in the diagnosis, treatment and prevention of liver diseases as well as precision medicine in hepatology. We compare these models with the SteatoNet model that was developed at the University of Ljubljana. SteatoNet describes the interactions between the liver and the surrounding tissues and can be adapted to gender or even genome specific data to obtain personalised models. We conducted this research in cooperation with the University of Ljubljana, Faculty of Medicine and the Saarland University Medical Center.

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Tanja Cvitanović, Matthias C. Reichert, Miha Moškon, Miha Mraz, Frank Lammert, Damjana Rozman (2017) Large-scale computational models of liver metabolism: how far from the clinics?, *Hepatology*, 66(4): 1323-1334.

SteatoNet computational model describing the interactions between the hepatocyte (liver cells) and the surrounding tissues.



## A New Performance Evaluation Methodology for Short-Term Trackers

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**Collaborating Laboratory:**  
Visual Cognitive Systems Laboratory

Visual object tracking is a fast-developing field of computer vision, with applications ranging from video surveillance systems to autonomous robots. Several new trackers are published every year at major computer vision venues, and there alone. The lack of standardized performance evaluations makes cross paper comparison of results difficult. In response we have therefore conducted an extensive study of performance measures and proposed a rigorous performance evaluation methodology. The results have been published in major computer vision journals. A Visual Object Tracking (VOT) initiative has been established, and VOT challenges have been conducted for the last five years to test and refine the methodology. The VOT page records over 4,000 monthly visits, while the results paper of the VOT2017 challenge was co-authored by over 100 researchers. The VOT2016 results paper alone reached over 820 views within a single year.

Luka Čehovin Zajc (2017) TraX : the visual Tracking eXchange protocol and library, *Neurocomputing*, 260: 5-8.

Luka Čehovin Zajc, Alan Lukežič, Aleš Leonardis, Matej Kristan (2017) Beyond standard benchmarks: Parameterizing performance evaluation in visual object tracking, *International conference on computer vision 2017, ICCV2017*.

“The Visual Object Tracking (VOT) initiative attracts hundreds of researchers each year.”

The VOT2017 trackers rank list (left) and the VOT community growth (right).



## Smarter Urban Design and Planning

Assist. Martin Vuk, PhD  
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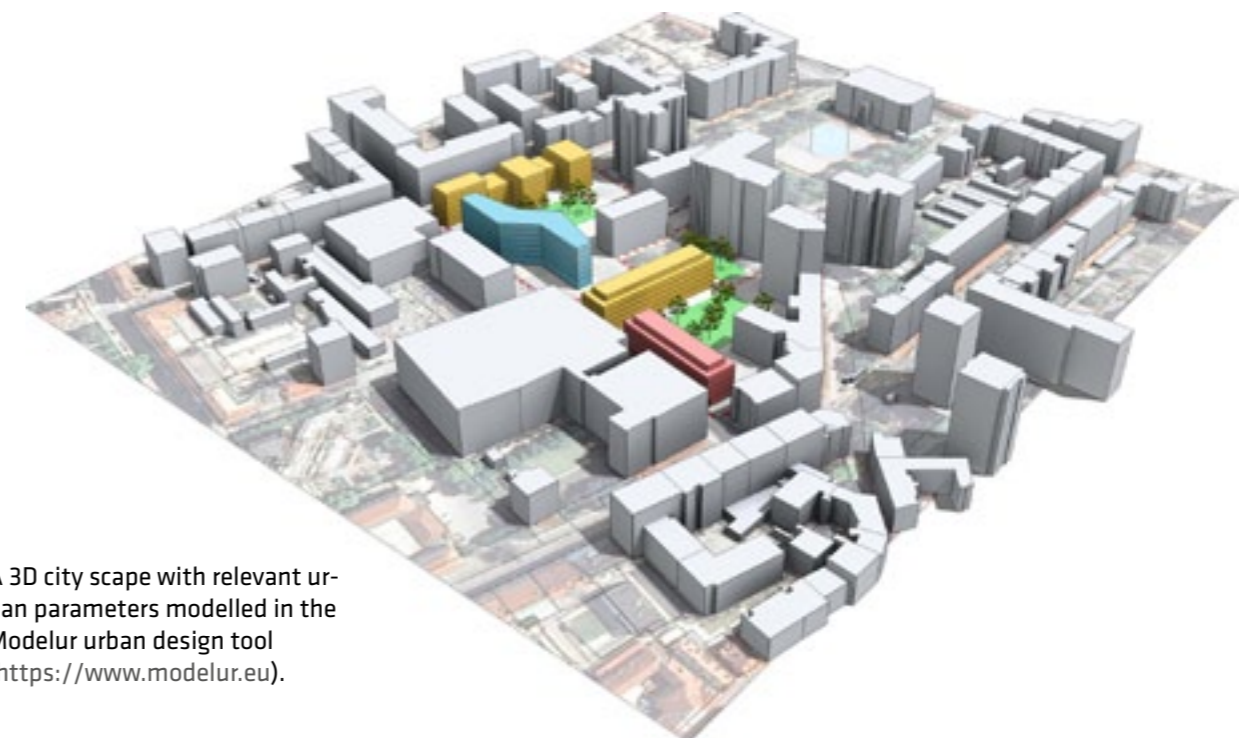
**Collaborating Laboratory:**  
Laboratory for Mathematical Methods in Computer and Information Science

“Interactive 3D zoning allows urban designers to design better cities for everyone.”

Every week cities across the globe gain an estimated 3 million new residents. At the same time, we are facing immense technological, economic and social changes that make urban development nearly impossible to predict. Planning instruments used by municipalities are often obsolete and haven't changed much over the last century, thus lacking the flexibility to respond to the rapid changes cities are facing. They encumber the city development, instead of promoting it.

In collaboration with AgiliCity (Ljubljana, Slovenia) we are developing Interactive 3D zoning, a radically new way of urban planning and design. Interactive 3D zoning converts lengthy and complex city planning documents into an interactive 3D solution space that merges relevant urban parameters with the visual 3D cityscape. These are tightly coupled and make the process of city development more transparent and accessible to the general public and experts.

Jernej Vidmar, Žiga Böhm, Martin Vuk, Žiga Stopinšek. Rector's Award for the best innovation at the University of Ljubljana 2017.



A 3D cityscape with relevant urban parameters modelled in the Modelur urban design tool (<https://www.modelur.eu>).



## Robust Stride Segmentation Based on Inertial-Magnetic Data

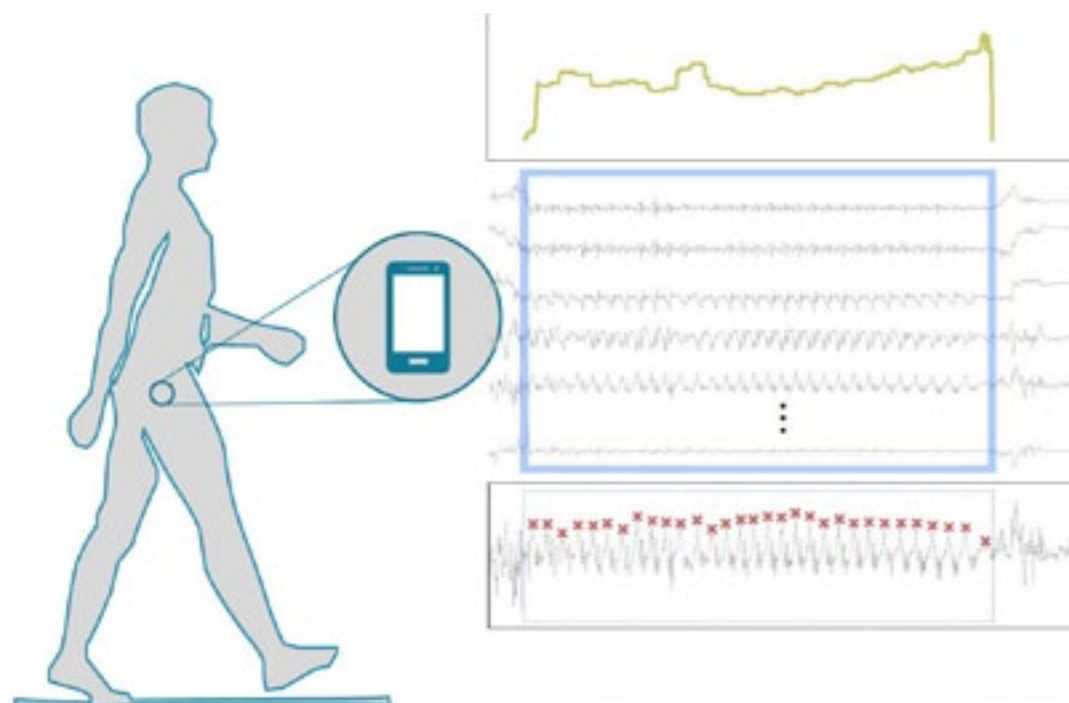
Prof. Matjaž B. Jurič, PhD  
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Assist. Prof. Sebastijan Šprager, PhD  
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**Laboratory:**  
Laboratory for Integration of Information Systems

Effective gait assessment based on data acquired from inertial-magnetic sensors rely on efficient and reliable stride segmentation that also covers accurate detection of gait events. This represents an open problem and big challenge in all communities that deal with movement analysis as proper stride segmentation and gait event extraction from IMU signals significantly affect the performance of gait assessment procedures which rely on the observation of single strides. Especially aggravated situations (i.e. gait transitions, pathologies, free sensor use) are attractive from the perspective of applicability but also very challenging to cope with. We have managed to construct and thoroughly evaluate a robust system for stride segmentation that is able to efficiently assess gait events and extract sequences of consecutive reliable strides. It provides high efficiency and reliability level and it is already practically applied in gait assessment systems. The approach provides an alternative insight into a problem in this domain as it is based on multi-level estimation of local cyclicity.

Sebastijan Šprager, Matjaž B. Jurič (2017) Robust Stride Segmentation of Inertial Signals Based on Local Cyclicity Estimation, accepted for publication in Computers in Biology and Medicine.

“The proposed stride segmentation approach is capable of robust and efficient gait event detection and the extraction of gait sequences in demanding circumstances.”



## Simulating Evolution of Collective Behaviour Under Predation

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**Collaborating Laboratories:**  
Computer Structures and Systems Laboratory  
Laboratory for Cognitive Modeling

Collective behaviour is a scientific field that studies the dynamics in groups of living beings. Since these phenomena are very diverse (Figure) and widespread, the results from these studies are useful to scientists from many different areas of research – from biology, physics, and medicine, to computer science.

We developed a fuzzy logic based model that is suitable for simulating the evolution of collective behaviour in fish schools. During the simulated evolution fish are repeatedly attacked by predators that may use diverse predation tactics. In this hostile artificial world, the simulated fish need to learn how to behave to survive for as long as possible. Our results suggest that diverse predation tactics might be one of the possible reasons for the emergence of multiple regimes of collective behaviour in nature. Our results also suggest that antagonism in predation pressures, where prey are exposed to pressures for which the best response is both grouping and dispersing simultaneously, might be necessary for prey to evolve polarized movement.

Jure Demšar (2017) Evolution of fuzzy animats in a competitive environment, doctoral dissertation, Faculty of Computer and Information Science, University of Ljubljana, Slovenia.

Jure Demšar, Iztok Lebar Bajec (2017) Evolution of collective behaviour in an artificial world using linguistic fuzzy rule-based systems, PLoS One, 12(1).

Jure Demšar, Erik Štrumbelj, Iztok Lebar Bajec (2016) A balanced mixture of antagonistic pressures promotes the evolution of parallel movement, Scientific Reports, 6, Article number 39428.

“Exposure to diverse predation tactics might be the cause for the emergence of multiple regimes of collective behaviour.”



A visualization of various regimes of collective behaviour in fish schools – swarming (bottom left), milling (bottom right), highly polarized motion (top left), and dynamic polarized motion (top right).

## Exploratory Equivalence in Graphs

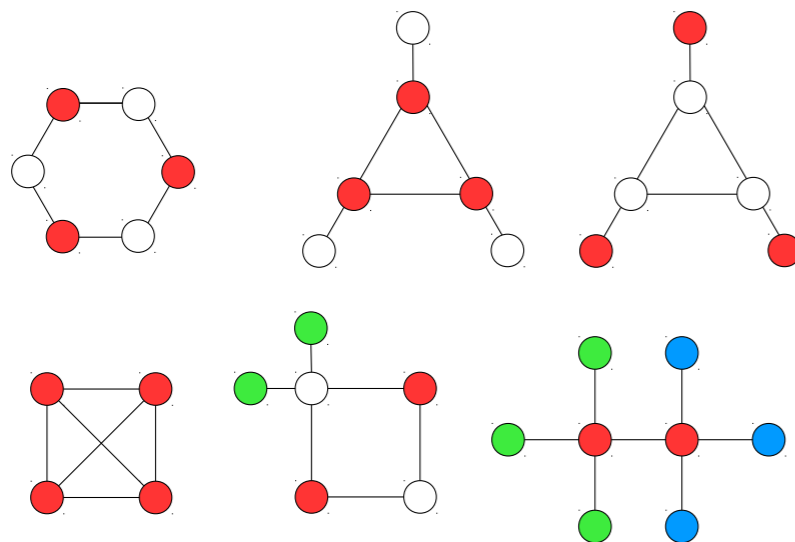
Assist. Uroš Čibej, PhD  
(uros.cibej@fri.uni-lj.si)  
Assist. Luka Fürst, PhD  
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Assist. Prof. Jurij Mihelič, PhD  
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**Collaborating Laboratories:**  
Laboratory of Algorithmics  
Software Engineering Laboratory

In an era of planetary-scale networks, graph theory is becoming increasingly important. The subgraph isomorphism problem – finding the occurrences of a given pattern graph in a given host graph – is particularly relevant. Despite its NP-completeness, backtracking-based algorithms perform reasonably well, unless faced with a pattern graph having many automorphisms (symmetries). We proposed a novel type of graph vertex equivalence, called exploratory equivalence, which can be used to speed up subgraph isomorphism search in case of symmetric pattern graphs. We defined a problem with the goal of finding an optimal exploratory equivalent partition of the graph vertex set, i.e., a partition giving rise to the greatest speed up. Although we showed that this problem cannot be said to belong to NP, we devised an efficient heuristic algorithm for general graphs and exact polynomial-time algorithms for trees and cycles. Recently, we demonstrated that exploratory equivalence can also be used to speed-up general backtracking algorithms.

Luka Fürst, Uroš Čibej, Jurij Mihelič. Maximum exploratory equivalence in trees. FedCSIS 2015, 507-518.

Uroš Čibej, Luka Fürst, Jurij Mihelič. A graph equivalence for symmetry-breaking in backtracking algorithms. Submitted to International Journal of Applied Mathematics and Computer Science (currently under review).



Optimal exploratory equivalent partitions for sample graphs. Each group of vertices having the same colour constitutes an equivalence class. The white vertices are singletons.

“We defined a novel type of graph vertex equivalence that can be used to speed-up subgraph isomorphism search and general backtracking algorithms.”

## Convexity in Complex Networks

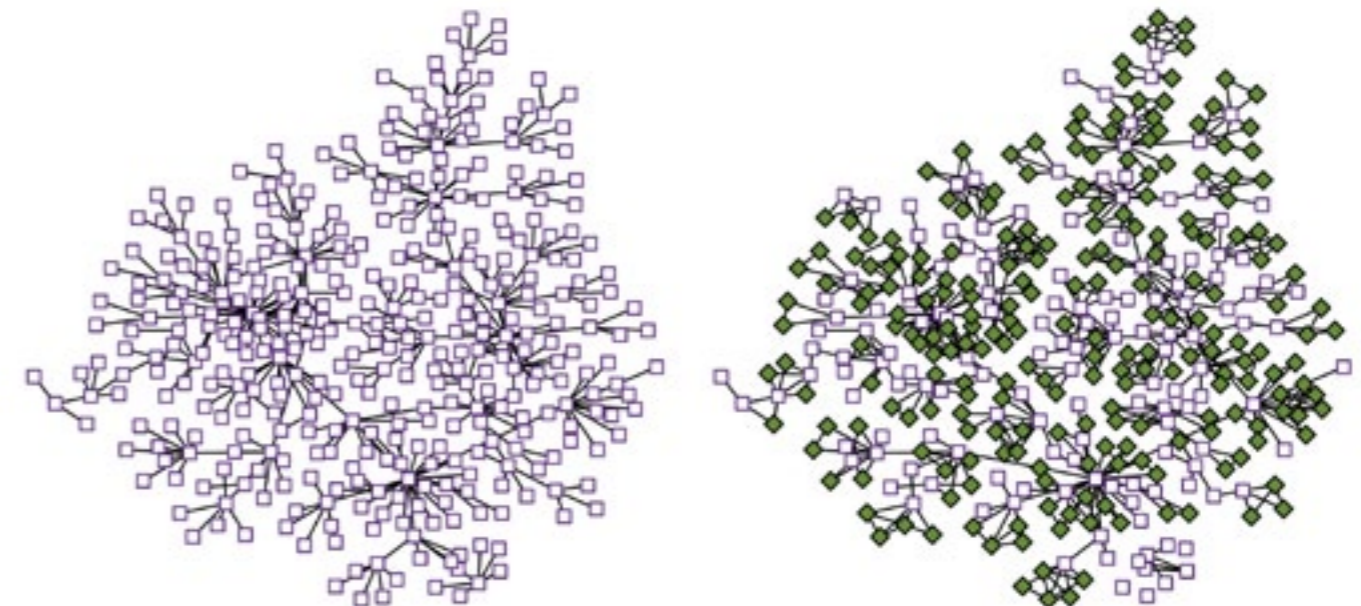
Assist. Prof. Lovro Šubelj, PhD  
(lovro.subelj@fri.uni-lj.si)

**Collaborating Laboratory:**  
Laboratory for Data Technologies

Convexity is a property of a part of a mathematical object that includes all the shortest paths between its units. In the case of graphs or networks, a subgraph is convex if every shortest path between the nodes of the subgraph lies entirely within the subgraph. A convex network can therefore be defined as a network such that every subgraph is convex. We show that convexity is an inherent property of real networks, which was not recognized before. Furthermore, many networks contain a large high-convexity part called a convex skeleton (figure, right). A convex skeleton is a generalization of a spanning tree (figure, left) in which each edge can be replaced by a clique of arbitrary size. We show that convex skeletons retain the most important structural properties of networks. For instance, in the Slovenian computer scientist co-authorship network, a convex skeleton retains the strongest ties between the authors, differently from a spanning tree and other network backbones. A convex skeleton thus represents a simple definition of a network backbone with applications in modelling, visualization, navigation and possibly also elsewhere.

Tilen Marc, Lovro Šubelj (2017) Convexity in complex networks, Network Science, pp. 27, in press. Lovro Šubelj (2017) Convex skeletons of complex networks, arXiv:1709.00255v2.

“A convex skeleton retains the strongest ties between Slovenian computer scientists.”



## Prediction of Aircraft Position

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**Collaborating Laboratory:**  
 Computer Vision Laboratory

Accurate prediction of aircraft position is becoming more and more important for the future of air traffic. Currently, the lack of more precise information about flights prevents ground based applications in air traffic control to fulfil future demands for increased air traffic. In air traffic control, flight data is collected from three sources: radar recordings, flight plan data, and weather data to predict more accurate flight parameters, from which we calculate 4D trajectories. Instead of using static nominal parameters based just on aircraft type, we can predict parameters for each flight individually. These parameters depend also on the flight operator, flight destination, day of the week, etc. The results show that we can predict better performances for current flights based on how similar flights behaved in the past. Based on our published research we have been invited to present this novel approach at an air traffic control users conference, and to become a member of the advisory board of a European project "Advanced prediction models for flexible trajectory-base operations".

Marko Hrastovec, Franc Solina (2016) Prediction of aircraft performances based on data collected by air traffic control centers, Transportation Research Part C: Emerging Technologies, 73: 167-182.

“We predict more accurate aircraft 4D trajectories than current state-of-the-art methods to achieve better airspace throughput in the future.”



## Deep Learning in Biometry

Assoc. Prof. Peter Peer, PhD  
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 Blaž Meden  
 (blaz.meden@fri.uni-lj.si)

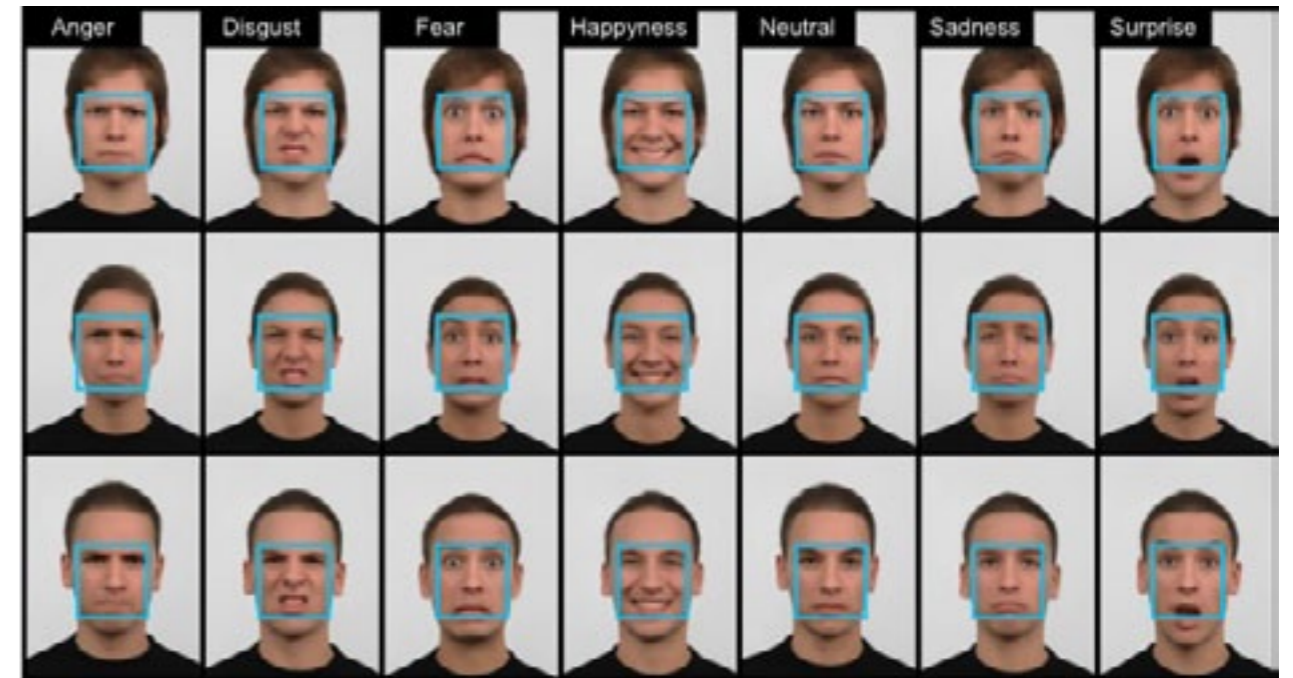
**Collaborating Laboratory:**  
 Computer Vision Laboratory

In the recent years we are witnessing a dominance of deep neural network approaches in computer vision and biometry fields. Although the neural network concept is more than 50 years old, only the recent developments enabled its wide use. Namely, availability of processing power, especially graphical processing units, availability of large databases, and the refined knowledge about the approach itself. Lately, apart from getting very good results in ear detection and recognition with convolutional neural networks, we successfully employed face deidentification (anonymization) with a generative neural network that provides privacy guaranties and, at the same time, retains certain important characteristics (like facial expressions) of the face, even after deidentification.

Blaž Meden, Refik Can Malli, Sebastjan Fabijan, Hazim Kemal Ekenel, Vito-mir Štruc, Peter Peer (2017) Face deidentification with generative deep neural networks, IET Signal Processing, 11(9): 1046-1054.

“Convolutional neural networks work extremely well in privacy aware applications.”

Examples of synthetic images generated by the generative neural network that can produce various facial expressions for every identity in the deidentification pipeline.



## CREA Summer Academy Ljubljana: Developing Business Ideas Through Creativity and ICT

Andrej Brodnik, PhD (andrej.brodnik@fri.uni-lj.si)  
 Assoc. Prof. Matija Marolt, PhD (matija.marolt@fri.uni-lj.si)

### Collaborating Laboratories:

Laboratory for Ubiquitous Systems  
 Laboratory for Computer Graphics and Multimedia

CREA aims to promote ICT development and creativity as new drivers to produce structural changes and arrangements in the European entrepreneurial base, and to influence the future paths of social change and innovation. Furthermore, the CREA project validated a new interdisciplinary European model of the Summer Academy for students who want to develop business ideas with a focus on creativity and ICT, and exploring innovation in advanced fields. The project focused on first steps in product development – from the idea to the business plan and pitching to obtain VC resources. It therefore included training courses, mentoring activities and the incubation program to set-up startup companies that were able to use the opportunities of ICT and Creativity to propose a new business model with a European vision. Each of the two years of the project were organized by the CREA Summer Academy, which took place simultaneously in 6 European cities (Ljubljana, Milan, Newcastle, Stuttgart, Tallinn and Utrecht), concluding with the CREA ICT Business Idea Contest international event. The event was organized to present results to international investors and award prizes. The projects developed at the Ljubljana Summer Academy won the competition both years: the HOMEY first-year team with an application for families to stay on top of their household tasks in a private network, and the TAFR second year team with a robotic solution to help farmers and winegrowers save time and money as well as maintain their health.

“Motivated and innovative students, coached by engaged mentors at CREA Summer Academy Ljubljana, managed to win the international competition CREA ICT Business Idea Contest two years in a row.”



CREA Summer Academy Ljubljana at the Faculty of Computer and Information Science.



## SALUS, Security and Interoperability in Next Generation PPDR Communication Infrastructures

Prof. Denis Trček, PhD (denis.trcek@fri.uni-lj.si)  
 Assist. David Jelenc, PhD (david.jelenc@fri.uni-lj.si)

### Collaborating Laboratory:

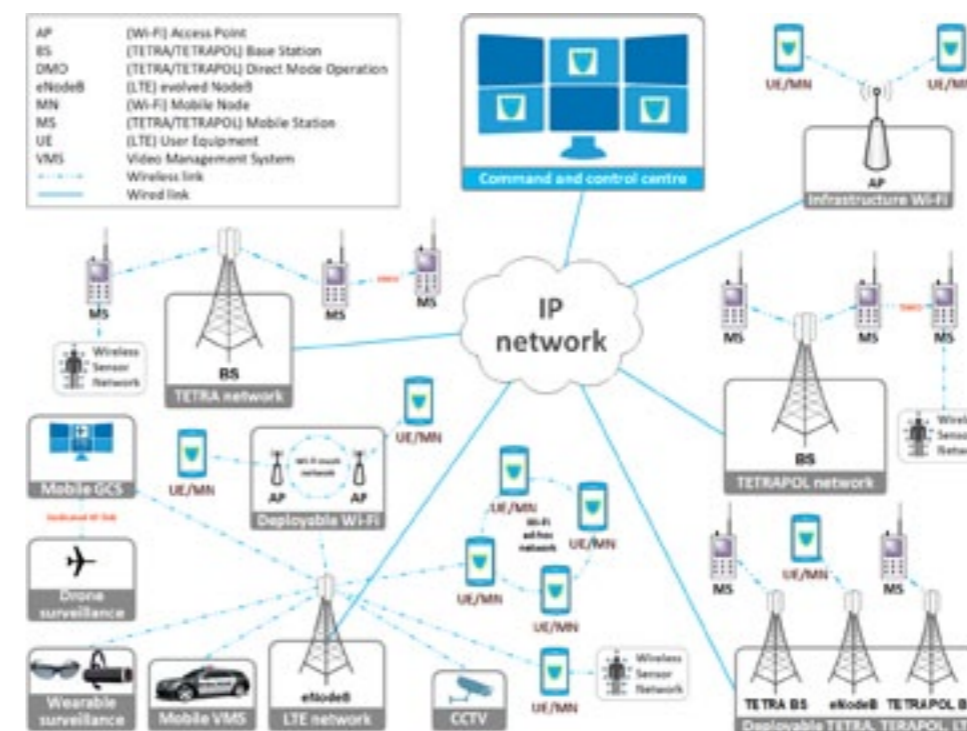
Laboratory of e-media

“An industry awarded research project that designed, implemented and evaluated a new communication infrastructure for public protection and disaster relief (PPDR) agencies.”

Public Protection and Disaster Relief (PPDR) agencies have been relying on digital Private Mobile Radio (PMR) networks for mission-critical voice and data communication. Although these networks are highly resilient and designed to cope with crisis and emergency situations, they are not well secured against monitoring and intrusions and they offer limited interoperability.

The goal of the SALUS project was to design, implement and evaluate a next generation communication network for PPDR agencies by focusing on the integration with and migration to 4G wireless communications developments. The project addressed key research challenges such as enterprise architectures, economic and business analysis, as well as technical aspects concerning quality-of-service, resilience, inter-systems handovers, enhanced security and privacy mechanisms in heterogeneous network infrastructures, and multicast support for broadband PPDR services. The project was recognized by the industry practitioners by awarding it the prestigious International Critical Communications Award.

The consortium comprised 16 partners from industry and academia. The group at the University of Ljubljana contributed by devising the general security architecture and the communication infrastructure for broadband data services.



## Semi-Automatic Creation of a Slovene Thesaurus

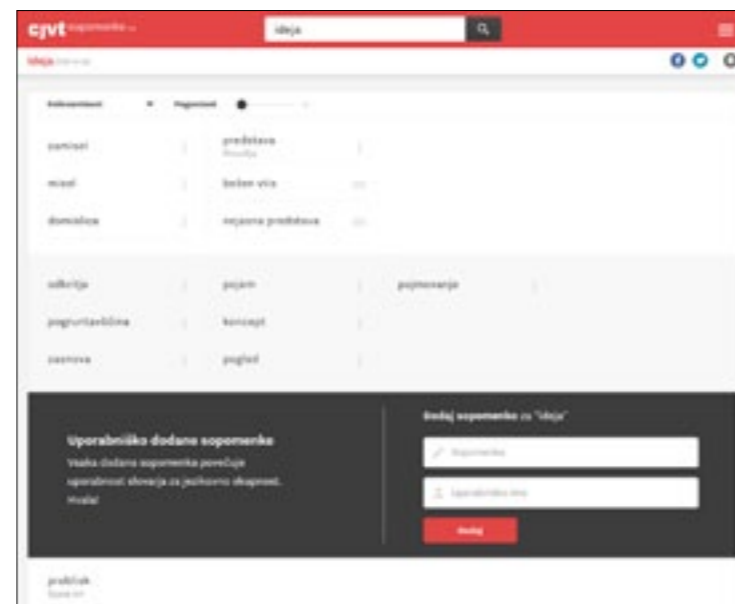
Prof. Marko Robnik-Šikonja, PhD  
(marko.robniksikonja@fri.uni-lj.si)

**Collaborating Laboratory:**  
Laboratory for Cognitive Modeling

Researchers of UL FRI collaborate in the Center for Language Resources and Technologies of the University of Ljubljana (CJVT UL). The recent result of this collaboration is the creation of a thesaurus for the Slovene language, which is open sourced and publicly available at <http://viri.cjvt.si/sopomenke>. We designed a methodology to semi-automatically create a new Slovene thesaurus from the data available in a comprehensive English–Slovenian dictionary, a monolingual dictionary and a corpus. We used a network analysis of the dictionary word co-occurrence graph. The network was enhanced with the distributional thesaurus data available as part of the Sketch Engine tool and extracted from the 1.2 billion word Gigafida corpus as well as information on synonyms from a Slovene monolingual dictionary. The resulting database serves as a starting point for manual cleaning of the information with crowdsourcing techniques in a custom-made online visualization and annotation tool.

Simon Krek, Cyprian Laskowski, Marko Robnik Šikonja (2017) From translation equivalents to synonyms: creation of a Slovene thesaurus using word co-occurrence network analysis, *Electronic lexicography in the 21st century: proceedings of eLex 2017 Conference, Lexical Computing*, 93-109.

“Sophisticated computational methods allow for a fast and reliable curation of the Slovene language.”



## Publication Boost in Web of Science Journals of Science Journals

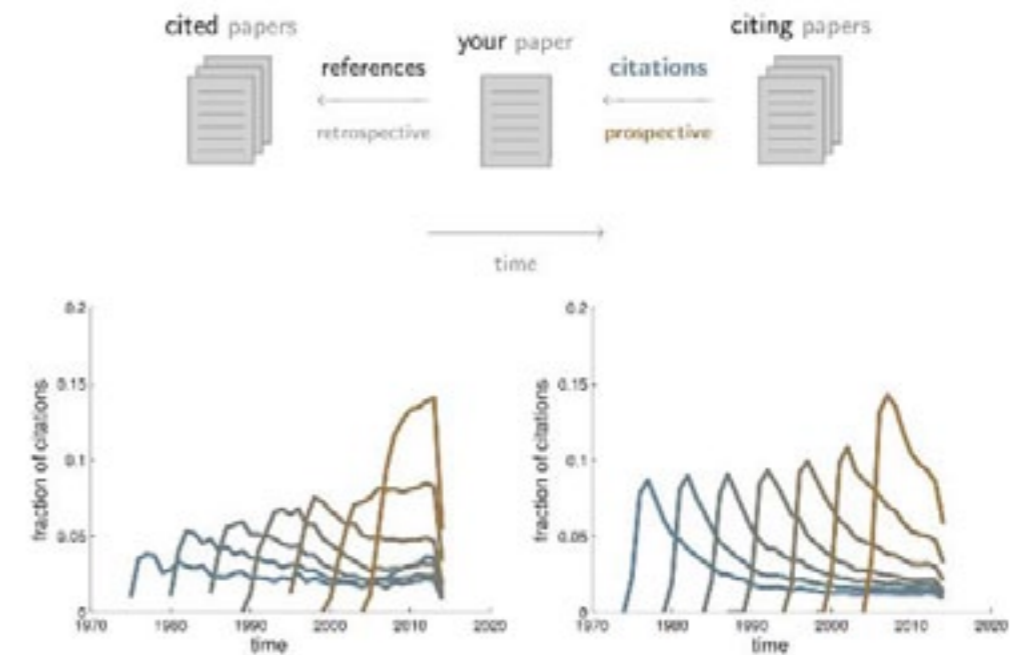
Assist. Prof. Lovro Šubelj, PhD  
(lovro.subelj@fri.uni-lj.si)

**Collaborating Laboratory:**  
Laboratory for Data Technologies

“The number of citations to recent computer science papers is increasing each year.”

It is well known that scientific production has increased dramatically in recent decades with more and more papers published, referenced and cited each year. The question is whether this growth is accompanied by some novel trends in how scientific papers cite one another. We conduct a longitudinal study of distributions of papers’ citations as in the Web of Science database (top figure). We show that the citation distributions of computer science papers have changed notably after around the year 2000 as opposed to e.g. physics (bottom figure left and right, respectively). Although the references from the more recent papers generally cover a longer time span, the newer papers are cited more frequently than the older ones, with the number of citations increasing each year. We show that this effect is due to the growing number of computer science journals in the Web of Science database, whereas the citation behaviour of computer scientists does not appear to have changed.

Lovro Šubelj, Dalibor Fiala (2017) Publication boost in Web of Science journals and its effect on citation distributions, *JASIST* 68(4): 1018-1023.



## Investigating the Impact of Notification Delivery Strategy on the Usage of a Smartphone-Based Stress Management Intervention

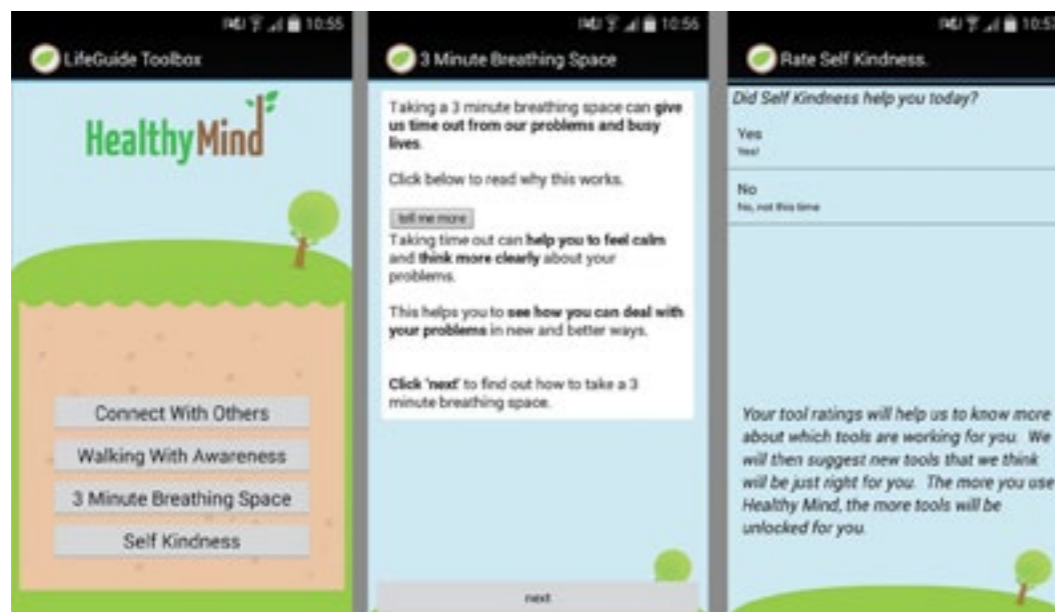
Assist. Prof. Veljko Pejović, PhD  
(veljko.pejovic@fri.uni-lj.si)

**Collaborating Laboratory:**  
Computer Structures and Systems Laboratory

Several key health and well-being problems, such as diabetes, stress, obesity, substance abuse and similar issues, can be tackled through changes in patients' behaviour. Yet, changing one's behaviour is difficult and in the traditional psychological practice is done through one-on-one advising sessions requiring tremendous human and material resources. We harness a new opportunity for administering large-scale behaviour change interventions via ubiquitous smartphones. We develop a framework for building mobile interventions that can deliver context-relevant advising information to elicit positive behavioural change. However, simply pushing patronising messages to users' phones is unlikely to translate to the desired change in behaviour. In our work, published at PLOS One, we examine how the frequency and timing of messages impact users' engagement with Healthy Mind, a smartphone-based stress management intervention we developed.

Leanne G. Morrison, Charlie Hargood, Veljko Pejović, Adam W. A. Geraghty, Scott Lloyd, Natalie Goodman, Danius T. Michaelides, Anna Weston, Mirco Musolesi, Mark J. Weal, Lucy Yardley (2017) The Effect of Timing and Frequency of Push Notifications on Usage of a Smartphone-Based Stress Management Intervention: An Exploratory Trial, PLoS ONE 12(1).

“Changing one’s behaviour is difficult, and the right timing is crucial for changes to stick.”



“How to use sculptures to preserve memories for future generations?”

## 3d Visualizations of the Women Writers Database

Assoc. Prof. Narvika Bovcon, PhD  
(narvika.bovcon@fri.uni-lj.si)

**Collaborating Laboratory:**  
Computer Vision Laboratory

“What kind of input produces a structure or an organization of coordinates that travel from a library to a database and re-enter the world as an object? [...] The transmutation of literary archives, lost texts through time, into delicate artefacts produced by a database of fragile connections that keep a trace of their source and become fragments for the future.” Nicole Hewitt, Janez Strehovec, Srečo Dragan for the “ZDSLJ Salon 2017” jury award.

The sculptures (Literary Authors, A Quotation, A Lake and Cloth) were conceptualized as diagrams of relations in the Women Writers database. Designed as computer models they were 3D printed and cast in silver. The miniatures are fragments of a narrativized archive, a vessel of memory for a future archaeology. (The sculptures were produced as part of the “Travelling Texts 1790-1914” HERA research project at the University of Nova Gorica in collaboration with Aleš Vaupotič.)

Narvika Bovcon, Aleš Vaupotič. 3d visualizations of the Women Writers database. 2017. Installation view, Salon ZDSLJ '17, National Museum, detail: Literary Authors, silver, 1 x 3.5 x 0.3 cm.

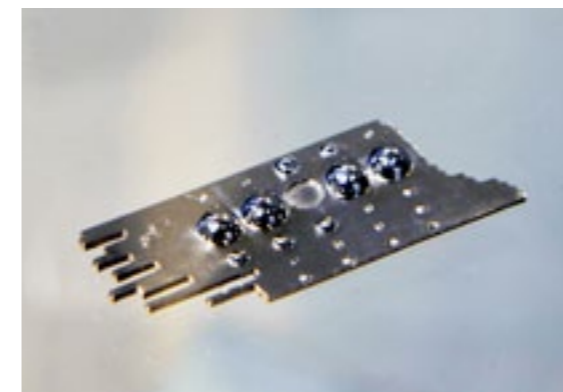
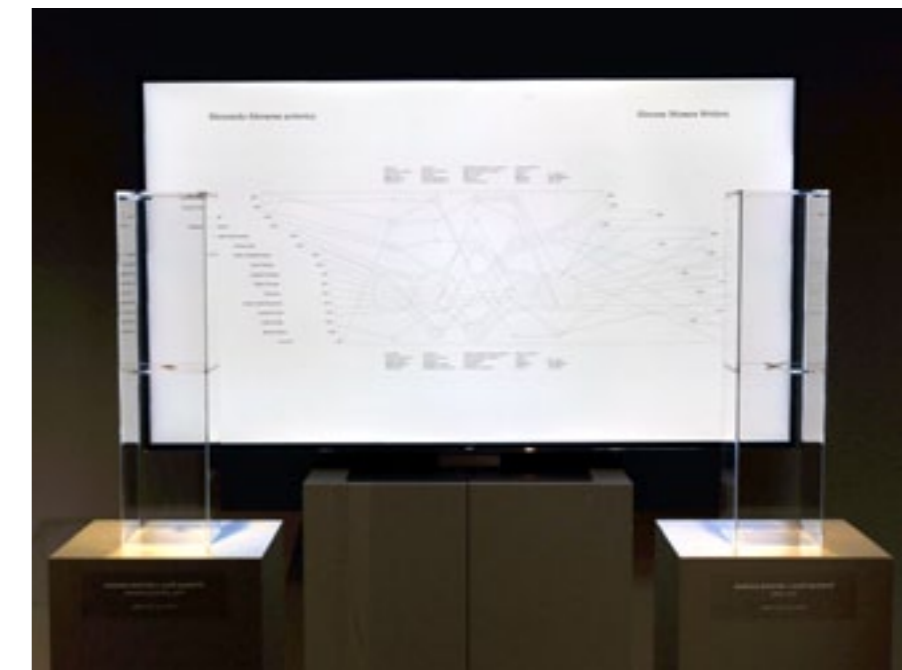


Photo: Miha Benedičič



## CodeQ – Intelligent Tutoring System for Programming

Assist. Timotej Lazar (timotej.lazar@fri.uni-lj.si)  
 Assist. Prof. Aleksander Sadikov, PhD (aleksander.sadikov@fri.uni-lj.si)  
 Prof. Ivan Bratko, PhD (ivan.bratko@fri.uni-lj.si)  
 Assist. Martin Možina, PhD (martin.mozina@fri.uni-lj.si)

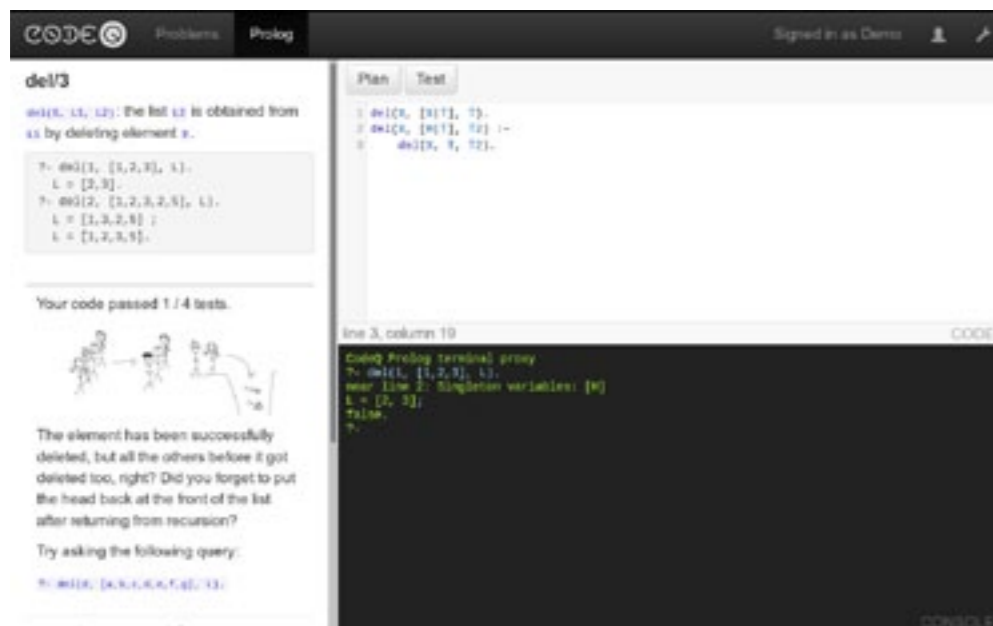
**Collaborating Laboratory:**  
 Artificial Intelligence Laboratory

CodeQ is an intelligent tutoring system for learning the basics of programming. Currently, the system contains learning materials and programming problems for the languages Prolog and Python, and Mindstorms robot programming. CodeQ is suitable for classroom use, as well as for individual study. The system helps the learner by presenting individual hints to the student depending on the specific errors in the student's submitted programs. Some hints are predefined in the system by the instructors. But in the cases when none of the predefined hints is appropriate for the student's submission, CodeQ is capable of automatically generating a completely new suitable hint. CodeQ automatically discovers new types of frequent student errors by learning from the database of student submissions.

Timotej Lazar, Aleksander Sadikov, Ivan Bratko (2017) Rewrite rules for debugging student programs in programming tutors. IEEE Transactions on Learning Technologies 99, pp. 12.

Timotej Lazar, Martin Možina, Ivan Bratko (2017) Automatic Extraction of AST Patterns for Debugging Student Programs. AIED 2017: Artificial Intelligence in Education, 162-174.

“The tutoring system learns from students' mistakes and generates hints for better programming.”



CodeQ is freely available (<https://codeq.si>) and is currently used in programming courses at three faculties of Ljubljana University (Faculty of Computer and Information Science, Faculty of Chemistry and Chemical Technology, and Faculty of Pedagogy).

## Orange, Data Mining Fruitful & Fun

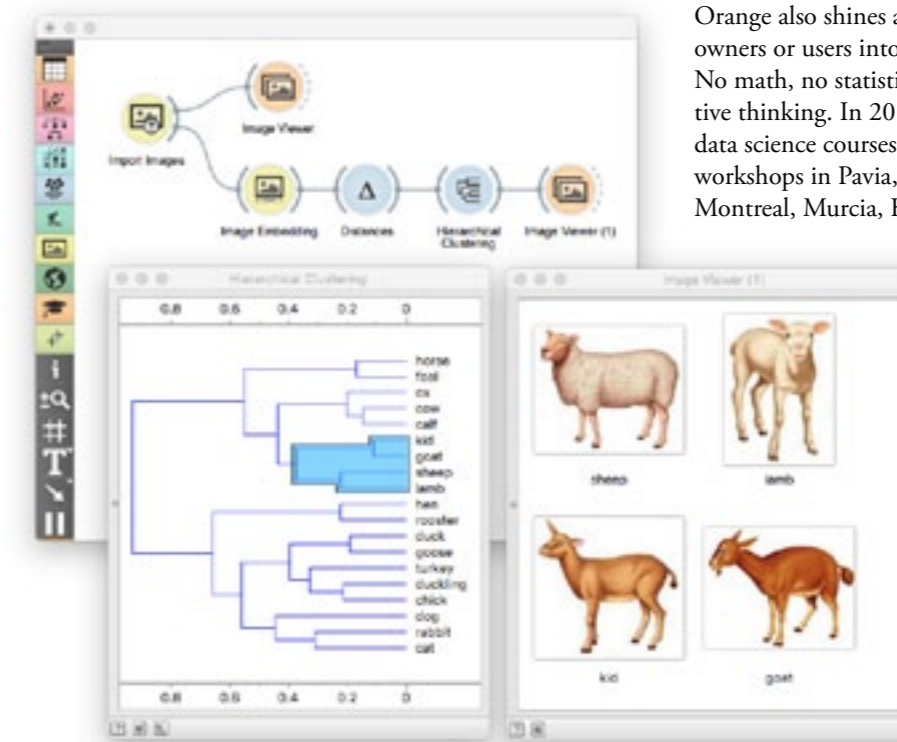
**Benevolent Dictators:**  
 Prof. Janez Demšar, PhD (janez.demsar@fri.uni-lj.si)  
 Prof. Blaž Zupan, PhD (blaz.zupan@fri.uni-lj.si)

**Laboratory:**  
 Bioinformatics Laboratory

“Orange Data Mining turns data owners into data scientists.”

Orange is a free, open-source environment for data science, in which users compose data mining workflows from a collection of components — widgets. With over 100 widgets for data management, visualization, and modelling, Orange can perform any data mining task, from simple data exploration and visualization to powerful modelling. Orange's unique feature is its interactivity: every action or selection in visualizations of data or machine learning models propagates through the data analysis workflow.

With a combination of widgets in a workflow, Orange users can devise attractive tools for data exploration. Consider, for example, the workflow from the figure. We loaded the drawings of domestic animals, measured their differences using deep neural networks, and then used hierarchical clustering to organize them into a dendrogram. We can now select a particular branch of the dendrogram and display the related images in a separate widget. Any change of selection will update the image list.



Orange also shines as a training tool that can turn data owners or users into data scientists in a couple of days. No math, no statistics, no programming - just intuitive thinking. In 2017, we have been perfecting our data science courses and delivered them at hands-on workshops in Pavia, Luxembourg, Ljubljana, Otočec, Montreal, Murcia, Houston, Liverpool, and Kolkata.

# Research Laboratories

Research at the Faculty of Computer and Information Science at the University of Ljubljana (FRI) is conducted in 19 research laboratories. These provide a creative space for knowledge transfer and the flow of ideas between established researchers, students, companies and the wider society.

## Laboratory for Biomedical Computer Systems and Imaging

The laboratory conducts research in the field of biomedical signal and imaging data. Our research includes describing physiological phenomena, modelling physiologic relationships, graphically displaying anatomic details and physiologic functions, visualising biomedical signals, developing standardised databases, developing detection and recognition techniques, evaluating the performance of recognition techniques, analysing bioelectric patterns, and developing performance measures and protocols, biomedical information technologies and software, dynamic web-interface creation, responsive web design, responsive information visualization.



Prof. Franc Jager, PhD  
franc.jager@fri.uni-lj.si

## Laboratory for Cryptography and Computer Security

We focus on cryptography and computer security, discrete mathematics, coding theory and statistical design. We have extensive experience in applied cryptography, especially public key cryptosystems (elliptic curve cryptosystems), cryptographic protocols (AKC) and their implementations in restricted environments, such as smart cards (including HSM and FPGA). We also study algebraic combinatorics (distance-regular graphs, association schemes, finite geometries, codes, finite fields and the like), probability and statistics.



Prof. Aleksandar Jurišić, PhD  
aleksandar.jurismic@fri.uni-lj.si

## Laboratory for Computer Graphics and Multimedia

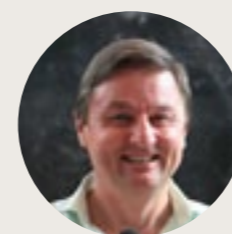
The laboratory performs R&D in the fields of multimedia technologies, human-computer interaction and computer graphics. Our main focus is on audio processing and music information retrieval (audio understanding, organisation of music archives), interactive 3D visualisation and 3D graphics (medical imaging, games), and e-Learning (learning for people with disabilities, gamification). We have extensive experience in developing software solutions for desktop, mobile and web, are active in the development of visualizations and didactic simulations. We collaborate with partners in national, EU and industrial projects.



Assoc. Prof. Matija Marolt, PhD  
matija.marolt@fri.uni-lj.si

## Laboratory for Ubiquitous Systems

The prime area of research interest is efficient data handling in distributed pervasive environments, which store terabytes of data that present a challenge in at least two areas: the efficient storage and handling of the data. The distributed environment is inherently capable of parallel processing and requires a proper data and work distribution. Currently our research is concentrated on four areas: unstructured text handling, environmental data processing, biomedical signal processing, and online streaming data processing. The work performed also overlaps with the area of Computer Science Education.



Andrej Brodnik, PhD  
andrej.brodnik@fri.uni-lj.si

## Laboratory of e-media

The laboratory focuses on advanced (lightweight) communications (e.g. the Internet of Things), security, privacy, e-business, and human factor modelling. Our research devotes particular attention to the analysis and design of advanced systems (from PKI to critical infrastructures), cryptographic protocols, advanced security and privacy analytics (e.g., big data methods for searching for precursory signals), and the quantitative treatment of the human factor. We have patented lightweight cryptographic protocols and developed practical (industry relevant) food supply chain management solutions based on RFIDs.



Prof. Denis Trček, PhD  
denis.trcek@fri.uni-lj.si

## Laboratory for Cognitive Modelling

The laboratory pursues research in machine learning, neural networks, statistics, image, text and data mining. Recent research has been related to the generation of semi-artificial data, the analysis of big data with the MapReduce approach, learning from data streams, incremental data fusion, recommender systems, automated essay evaluation, network mining, text summarisation using archetypal analysis, web-user profiling, applying evolutionary computation to data mining, spatial data mining with multi-level directed graphs, bottom-up inductive logic programming, combining deep neural networks with matrix factorization, heuristic search methods in clickstream mining, multi-view learning, and readability analysis.



Prof. Igor Kononenko, PhD  
igor.kononenko@fri.uni-lj.si

## Laboratory for Data Technologies

Areas of interest include data acquisition, management, integration, analysis and visualisation, all within the framework of information system development, management and governance. Special interest is devoted to internet of things, big data, real-time data management, the analysis of large networks, data streams, information extraction, etc. We work closely with industry partners in developing and testing new technologies and approaches.



Prof. Marko Bajec, PhD  
marko.bajec@fri.uni-lj.si

## Laboratory for Adaptive Systems and Parallel Processing

Our research topics include development of adaptive algorithms in areas of artificial neural networks, data clustering, data mining, information-theoretic modelling and reinforcement learning, and design of computer systems, ranging from high performance computing to on-chip designs. We are mainly focused on problems where the lack of theoretical knowledge prevents exact solutions and where special software and hardware are demanded for efficient processing. One of our main current areas encompasses efficient hardware implementations of deep neural networks. We are also involved in digital logic design of arithmetic circuits, processing on GPUs, smart wireless sensor networks, experimental research in the field of wireless networks, radio-based localization and software-defined radio.



Prof. Branko Šter, PhD  
branko.ster@fri.uni-lj.si



### Laboratory for Algorithmics

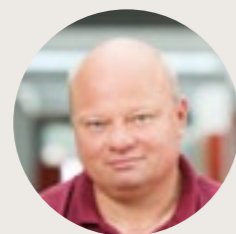
We conduct research in the areas of approximation and randomised algorithms, linear algebra (matrix multiplication), combinatorial optimisation (routing, problems on graphs, issues regarding the robustness of a facility location), parallel computation (algorithm mapping and scheduling, algorithms in parallel systems, hardware supported multithreading, dataflow computing), algorithm engineering and experimental algorithmics (boosting algorithm efficiency in practice), compiler design (parsing methods, attribute grammars), operating system design, grid computing (data replication on data grids), as well as computability and complexity theory.



Prof. Borut Robič, PhD  
borut.robic@fri.uni-lj.si

### Information Systems Laboratory

The focus of the research here includes software development methodologies and business process evaluation. We offer efficient approaches to the evaluation of information systems, specific information solutions and specific IT related processes. The approaches break down IT products or IT processes into key elements and evaluate them through a comprehensive set of criteria. We have excellent references in the areas of information system strategic planning and context aware applications, where we have developed a context engine prototype.



Assist. Prof. Rok Rupnik, PhD  
rok.rupnik@fri.uni-lj.si

### Computer Vision Laboratory

We research the capture, processing and interpretation of 2D and 3D visual data, machine learning in computer vision, and the use of images in computer-human interactions. We work in the following specific areas: interactive visual signage systems, 3D documentation in archaeology and cultural heritage, interpretation of images in biometry, medicine, geology and meteorology, the forensic analysis of images and video, virtual and augmented reality, as well as in the production of computer games and in new media art installations (in cooperation with the Academy of Fine Arts).



Prof. Franc Solina, PhD  
franc.solina@fri.uni-lj.si

### Laboratory for Integration of Information Systems

The laboratory has established strong foundation in service computing, cloud computing, digital transformation and Blockchain technologies. It conducts research in the field of the integration and interoperability of applications, cloud-native architectures, microservices and APIs, blockchain and smart contracts, devices, information systems, architectures and platforms. We focus on software architectures, platforms, design patterns. We work on technologies for the execution, monitoring and optimization of business processes and on IoT integration and mobility issues, including localization, authentication and gait analysis algorithms.



Prof. Matjaž Branko Jurič, PhD  
matjaz.juric@fri.uni-lj.si

### Visual Cognitive Systems Laboratory

The laboratory is involved in basic and applied research of visually enabled intelligent systems addressing various research problems from the fields of computer vision, machine learning, and cognitive robotics. We have extensive experience with visual object tracking, object detection and categorization, incremental visual learning, as well as with systems for human-robot interactive learning and development of computer vision solutions for smart mobile devices and visual inspection. Our experience has been accumulated in collaboration with a variety of research partners in a number of EU, national and industry funded projects.



Assoc. Prof. Danijel Skočaj, PhD  
danijel.skocaj@fri.uni-lj.si

### Software Engineering Laboratory

The laboratory is involved in teaching and research in the areas of software engineering and information systems, with an emphasis on agile software development methods (i.e. factors affecting successful adoption, agile project management, performance evaluation, the introduction of lean concepts, and similar), graph grammars and graph algorithms (parsing graph grammars, etc.), model driven development (reverse engineering, domain specific languages), and web data mining (stochastic models for user behaviour analysis, separating interleaved web sessions, etc.).



Prof. Viljan Mahnič, PhD  
viljan.mahnic@fri.uni-lj.si

### Bioinformatics Laboratory

The laboratory carries out research in data mining, machine learning, data visualization, big data analysis and data fusion. We apply computational methods to solve practical problems and focus on systems biology, biomedicine and natural sciences. The laboratory is developing Orange (<https://orange.biolab.si>), a comprehensive data mining suite that uses visual programming to merge machine learning and interactive data visualisations.



Prof. Blaž Zupan, PhD  
blaz.zupan@fri.uni-lj.si

### Computer Structures and Systems Laboratory

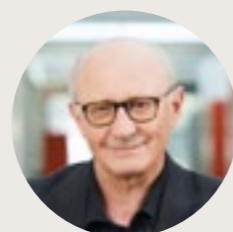
The laboratory is focused on the computational methods for modelling, simulation and analysis of three fundamentally different system families. Their applications are directed towards computational approaches in systems and synthetic biology, towards the analysis of coordinated behaviour in biological systems and towards the design of Quantum-dot Cellular Automata processing structures. Laboratory therefore consists of three groups, i.e. the Computational Biology Group, the Collective Behaviour Group and the Quantum-dot Cellular Automata group.



Prof. Nikolaj Zimic, PhD  
nikolaj.zimic@fri.uni-lj.si

### Artificial Intelligence Laboratory

The laboratory carries out research in machine learning (particularly argument based machine learning, inductive logic programming, robot learning), qualitative reasoning with robotics applications, intelligent robotics (planning, learning for planning), machine learning in medicine, and intelligent tutoring systems (ITS for programming and game playing, automated hint generation and the automatic assessment of the level of difficulty of problems for humans).



Prof. Ivan Bratko, PhD  
ivan.bratko@fri.uni-lj.si

### Computer Communications Laboratory

Our research is focused on communication networks and protocols, cloud architectures and services, cloud and network security, virtualization and containerization, ICT sustainability. We have researched the orchestration of complex virtual environments, examined SDN / NFV and single packet authorization as well as their use in IoT and cloud environments, and developed our own virtual cloud laboratory. Our latest project focuses on carrier-grade container solutions for large telco providers.



Assoc. Prof. Mojca Ciglaric, PhD  
mojca.ciglaric@fri.uni-lj.si

### Laboratory for Mathematical Methods in Computer and Information Science

We are involved in research in various spheres of continuous and discrete mathematics. On the one hand our research topics include commutative algebra, linear algebra, nonlinear dynamical systems, Brownian motion, martingales, algebraic topology, computational topology, topological data analysis and scientific computing. On the discrete side of the mathematical spectrum, however, we deal with problems in graph theory, particular the structural and colouring problems of graphs, which are also connected with problems in computational geometry.



Assoc. Prof. Polona Oblak, PhD  
polona.oblak@fri.uni-lj.si

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# Research Projects

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Research work at the Faculty is funded by the European Commission, the Slovenian Research Agency, industrial partners and other funding agencies.

## Industrial projects

The Faculty is participating on more than 20 projects funded by different institutions and industry partners, including: University College London • Autoscan GmbH • Slovenian Environment Agency • Armasuisse • Slovenian Ministry of Infrastructure • Lek d. d. • Marand Ltd • NERVteh Ltd. • Garex Adria Ltd. • U-blox AG • Agency for communication networks and services of the Republic of Slovenia • Ministry of Public Administration of the Republic of Slovenia • Visual Assistant Ltd • Slovenia control, Slovenian Air Navigation Services, Ltd • Iskratel Ltd • Mladinska Knjiga Založba Ljubljana d.d. • Kolektor Group d.d. • Post of Slovenia • Nielsen lab Ltd • Research and development center NELA • Centre of Excellence for Biosensors, Instrumentation and Process Control • District Court of Ljubljana and others.



## Projects funded by the European Commission

FLEXICIENCY – Energy Services Demonstrations of Demand Response, Flexibility and Energy Efficiency Based on Metering Data • SWITCH – Software Workbench for Interactive, Time-Critical and Highly Self-Adaptive Cloud Applications • CREA – Network of Summer Academies for Improving Entrepreneurship in Innovative Sectors • MONROE RICERCANDO – Rapid Interpretation and Cross-Experiment RootCause Analysis in Network Data with Orange: Ricercando • CROSSBOW – CROSS BOrder management of variable renewable energies and storage units enabling a transnational Wholesale market • DIGITTRANS – Digital Transformation in the Danube Region • HUBLINKED – Strengthening Europe’s Software Innovation Capacity • GETM3 – Global Entrepreneurial Talent Management.

## Current Structural funds and other national projects

BioPharm.SI: Next Generation of Biologics • EkoSMART – a Smartcity Ecosystem • GOSTOP – Building Blocks, Tools and Systems for the Factories of the Future • SocioPower • Towards quality of Slovene textbooks • Reading Literacy and Development of Slovenian Language • Natural Science and Mathematical Literacy: Promoting Critical Thinking and Problem Solving • Video Distance Measurement of Ski Jumping • Waste separation on a mobile device • InfoGen: Information system for tracking, analysis and management of laboratory samples in functional genomics • API development for the digital transformation and API economy • Computer vision and intelligent robotics for advanced forms of communication • Central European Olympiade in Informatics (CEOI) • Computer vision on smart phone for augmenting tourist and educational content in local environment • Cryptogram – a portal for cryptography and computer security • Upgrade of Corpuses Gigafida, Kres, ccGigafida and ccKress.

## Current programmes, basic research and applied projects, bilateral and other projects funded by the Slovenian Research Agency

Artificial Intelligence and Intelligent Systems • Computer Vision • Synergy of the Technological Systems and Processes • Pervasive Computing • Parallel and Distributed Systems • Maintenance of Large Databases Based on Visual Information Using Incremental Learning • Designed Cellular Logic Circuits • Trust Management and Reputation Systems • Metabolic and Inborn Factors of Reproductive Health, Birth • Open Information Extraction for Slovene and Serbian Languages • Intelligent Computer Techniques for Improving Medical Detection, Analysis and Explanation of Human Cognition and Behaviour Disorders • Automatic Detection and Localization of Ischemia by the use of Data Mining Algorithms • Representations of Quantum Groups via Computational Linear Algebra • Signal and Information Processing Systems in Sensor Networks • Intelligent Agile Method Framework (iAMF) • Graph Optimisation and Big Data • Advanced sensing technologies and modelling for sulfur compounds in food cold chain traceability • Development of an open-source platform for multivariate analysis of FTIR data • Data Fusion in Systems Biology of a Social Amoeba Dictyostelium • Advancement of Computationally Intensive Methods for Efficient Modern General-Purpose Statistical Analysis and Inference • Multiobjective discovery of driving strategies for autonomous vehicles • Centre for Language Resources and Technologies of University of Ljubljana • New grammar of contemporary standard Slovene: sources and methods



The project is cofinanced by the Republic of Slovenia and by the European Union through the European Regional Development Fund.



The project is cofinanced by the Republic of Slovenia and by the European Union through the European Social Fund.





## EkoSMART, A Smartcity Ecosystem

**Project Type:**  
Structural Funds Project

**Project Coordinator:**  
Marand Ltd, Slovenia

**Principal Investigator at FRI:**  
Prof. Marko Bajec, PhD  
(marko.bajec@fri.uni-lj.si)

**Project Duration:**  
2016–2019

**Collaborating Laboratories:**  
Laboratory for Data Technologies  
Laboratory for Ubiquitous Systems  
Artificial Intelligence Laboratory  
Computer Communications Laboratory  
Visual Cognitive Systems Laboratory  
Laboratory for Integration of  
Information Systems

The purpose of the EkoSMART programme is to develop a smart city ecosystem with all the support mechanisms required for the efficient, optimised and gradual integration of various smart city areas into a unified and well-connected system of value chains. The programme focuses on three key pillars for smart cities (health, active life and mobility) and is strategically linked with municipalities and other important smart city domains, such as energy, smart buildings, citizen involvement and engagement and smart communities. EkoSMART introduces a universal architecture for a smart city that is based on self-learning and self-optimising agents which can find a common Nash equilibrium between heterogeneous sources. This architecture allows for the realisation of smart city concepts such as interoperability, adaptability, self-configurability, open data, semantic interoperability and the integration of social capital. In economic terms, the vision of the EkoSMART programme is to enable Slovenian smart city innovations and products to enter the global market. This vision will be achieved through the following key approaches: the concentration of critical mass of knowledge and experience; a focus on the user; evolutionary development; and flexible architecture.

The EkoSMART programme differs from other initiatives in the following ways: • there is an emphasis on electronic and mobile health and mobility as the pillars of smart cities; • it introduces modular, self-configurable, self-optimising, flexible, adaptable and intelligent universal architecture; • there is an intensive focus on the development and implementation of new ICT methods and concepts such as the Internet of things and artificial intelligence for the continued development of technology and human society; • is based on a high-quality consortium of advanced partners, and is therefore also strategically linked to smart home and health programmes; • it puts strong emphasis on smart specialisation, i.e. the introduction of interconnected citizen, technology and market value chains.



## BioPharm.SI, Next Generation of Biologics

**Project Type:**  
Structural Funds Project

**Project Coordinator:**  
Centre of Excellence for Biosensors,  
Instrumentation and Process Control, Slovenia

**Principal Investigator at FRI:**  
Prof. Blaž Zupan, PhD  
(blaz.zupan@fri.uni-lj.si)

**Project Duration:**  
2016–2020

**Collaborating Laboratory:**  
Bioinformatics Laboratory

Biologics are one the latest and perhaps the most complex achievements of medicine. Biologics are specific, with fewer side effects, enabling treatment of previously incurable diseases. Slovenia has achieved great successes in this field: the first biosimilar approved in US was developed by the Slovenian company Lek and by the National Institute of Chemistry. Manufacturing of biologics is mainly challenged by the complexity of the molecules (proteins) produced by genetically modified cells in precisely controlled environments-bioreactors. Yet small modifications of producing cell line, production environment or conditions might impact product quality and efficacy. In Bioinformatics Laboratory we are collaborating with Lek and other partners of BioPharm.SI to develop data science infrastructure to monitor, store, organize and mine the data from the production. Our aim is to relate production parameters with quality estimates and to optimize the production process. To achieve this, the Bioinformatics Laboratory is adapting its data mining suite Orange, developing data access components, and designing new data visualization and mining tools to address specific data types and observations and to model the processes.



## GOSTOP, Building Blocks, Tools and Systems for the Factories of the Future

**Project Type:**  
Structural Funds Project

**Project Coordinator:**  
The Jožef Stefan Institute

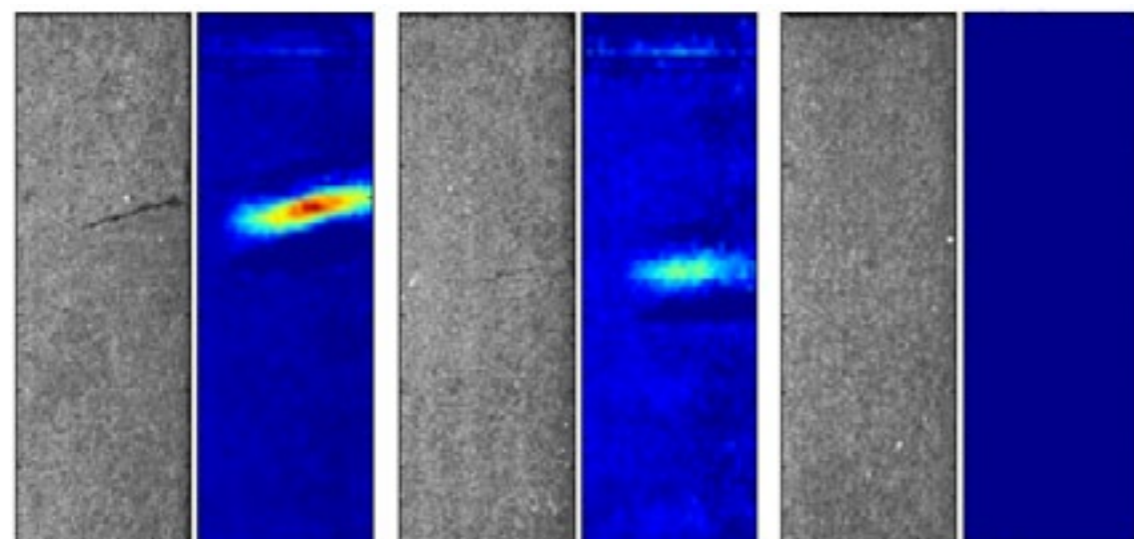
**Principal Investigator at FRI:**  
Assoc. Prof. Danijel Skočaj, PhD  
(danijel.skocaj@fri.uni-lj.si)

**Project Duration:**  
2016–2020

**Collaborating Laboratory:**  
Visual Cognitive Systems Laboratory

The aim of the proposed GOSTOP programme is to accelerate the development of the Factories of the Future concept in Slovenia and to provide solutions to the current needs of Slovene industry. In GOSTOP, a total of 13 companies and 6 research organisations which had compatible research and development programmes in the Factories of the Future concept joined forces to push forward its development. Four areas were identified in which decisive breakthroughs could be achieved in Slovenia in the near future: control technologies, tooling, robotics, and photonics.

Faculty of Computer and Information Science is collaborating with other partners in the area of robotics. The main goal is to develop flexible and adaptable technologies that would allow for fast and simple adaptation to a new product in the production process. One of the mayor enabling technologies in this respect is machine vision. Our goal is to develop efficient machine vision algorithms, coupled with machine learning approaches, which would allow for fast and flexible adaptation of visual inspection systems to be able to deal with novel quality control problems. We base our research on latest developments in deep learning and develop novel algorithms that are able to replace the need for handcrafting solutions for individual problem domains with a more general approach based on learning a solution by observing a number of exemplar images.



## FLEXICIENCY, Energy Services Demonstrations of Demand Response, FLEXibility and Energy efficiency Based on Metering Data

**Project Type:**  
EU project – H2020

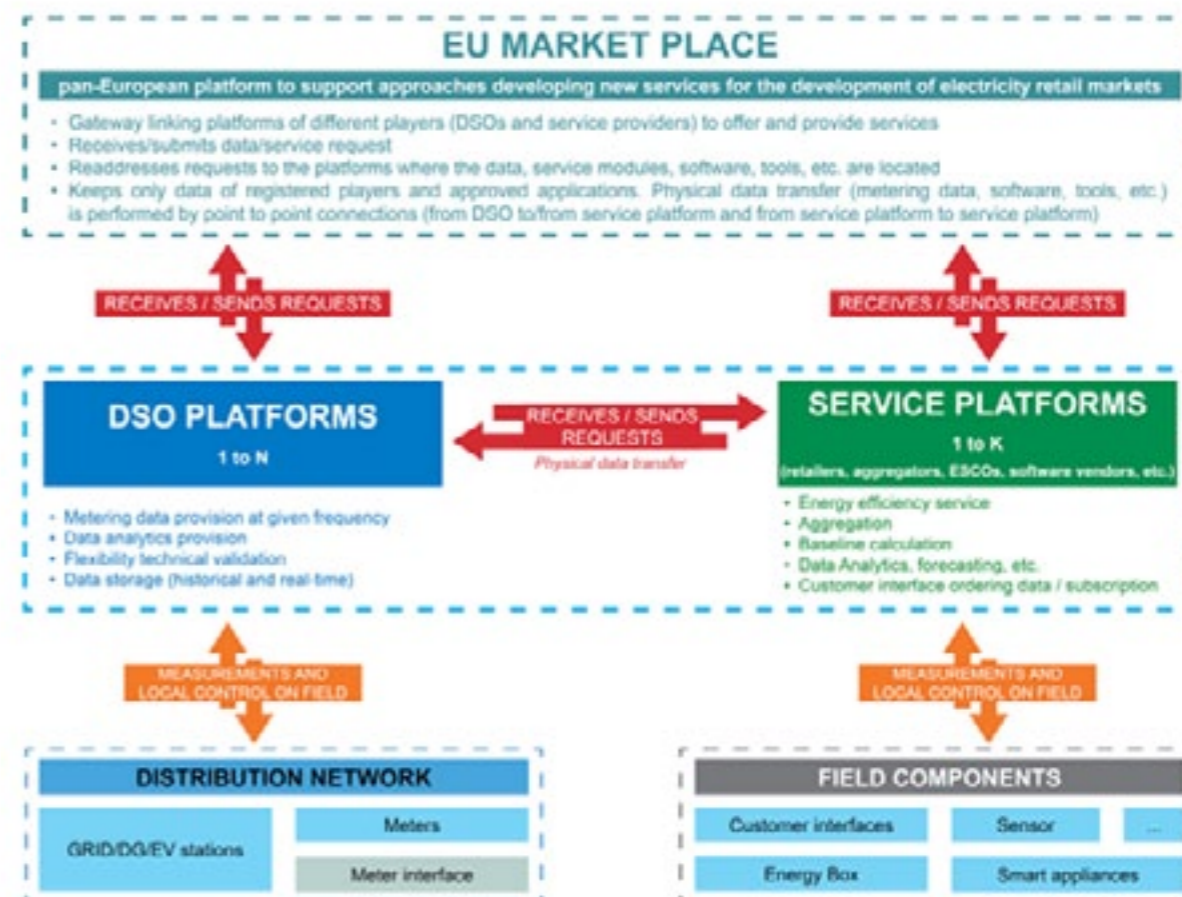
**Project Coordinator:**  
Enel Distribuzione s.p.a., Italy

**Principal Investigator at FRI:**  
Prof. Matjaž Branko Jurič, PhD  
(matjaz.juric@fri.uni-lj.si)

**Project Duration:**  
2015–2019

**Collaborating Laboratory:**  
Laboratory for Integration of Information Systems

The aim of FLEXICIENCY project is to address flexibility and efficiency within the European energy market, putting focus on consumers and making use of data from smart metering. More specifically, the project's mission is to create new opportunities for energy business and expand the DSO's market facilitator role for new services. As neutral players in the market, they can support the creation of new business opportunities and innovative services for end users, based on consumer data collected by smart meters. The initiative marks an important step towards the achievements of 2020 energy consumption and CO2 emissions targets through the development of advanced energy services and the implementation of new policies and market regulations that promote the creation of smart grids. The activities in 2017 covered research and development activities on EU Market Place – management of regulated and nonregulated services, integration between EU Market Place and Market Player platforms for an effective data exchange as well as management of service activities.





## CROSSBOW, CROSS BOrder Management of Variable Renewable Energies and Storage Units Enabling a Transnational Wholesale Market

**Project Type:**

EU project – H2020

**Project Coordinator:**

ETRA Investigación y Desarrollo S.A., Spain

**Principal Investigator at FRI:**

Prof. Matjaž Branko Jurič, PhD  
(matjaz.juric@fri.uni-lj.si)

**Project Duration:**

2017–2021

**Collaborating Laboratory:**

Laboratory for Integration of Information Systems

CROSSBOW project aims at the successful deployment of a set of technological solutions which will enable to increase the shared use of resources to foster transmission networks cross-border management of variable renewable energies and storage units. This will enable a higher penetration of clean energies whilst reducing network operational costs and improving economic benefits of RES and storage units.

The project will demonstrate a number of different technologies offering TSOs increased grid flexibility and robustness through: a better control of cross-border balancing energy at interconnection points; new storage solutions – distributed and centralized-, offering ancillary services to operate Virtual Storage Plants (VSP); better ICT and Communications – i.e., better network observability, enabling flexible generation and Demand Response schemas and the definition of a transnational wholesale market, proposing fair and sustainable remuneration for clean energies through the definition of new business models supporting the participation of new players and the reduction of costs.



## SWITCH, Software Workbench for Interactive, Time Critical and Highly Self-Adaptive Cloud Applications

**Project Type:**

EU project – H2020

**Project Coordinator:**

Universiteit van Amsterdam, The Netherlands

**Principal Investigator at FRI:**

Prof. Marko Bajec, PhD  
(marko.bajec@fri.uni-lj.si)

**Project Duration:**

2015–2018

**Collaborating Laboratory:**

Laboratory for Data Technologies

The SWITCH project addresses the urgent industrial need for developing and executing time critical applications in Clouds. Time critical applications such as disaster early warning, collaborative communication and live event broadcasting can only realise their expected business value when they meet critical requirements for performance and user experience. The very high requirements on network and computing services, particularly for well-tuned software architecture with sophisticated data communication optimisation, mean that development of such time critical applications is often customised to dedicated infrastructure, and system performance is difficult to maintain when infrastructure changes. This fatal weakness in the existing architecture and software tools yields very high development cost, and makes it difficult fully to utilize the virtualized, programmable services provided by networked Clouds to improve system productivity. SWITCH aims at improving the existing development and execution model of time critical applications by introducing a novel conceptual model: application-infrastructure co-programming and control model, in which application Quality of Service (QoS)/Quality of Experience (QoE), together with the programmability and controllability of the Cloud environments, can all be included in the complete lifecycle of applications. Based on this conceptual model SWITCH provides: • a SWITCH Interactive Development Environment (DRIP) - an interactive environment for developing applications and controlling their execution, • a Distributed Real-time Infrastructure Planner (DRIP) - a real-time infrastructure planner for deploying applications in Clouds, and • an Autonomous System Adaptation Platform (ASAP) - for monitoring and adapting system behaviour. The SWITCH consortium has well-balanced partners with complementary expertise from both academic and industrial backgrounds. By demonstrating the software using diverse use cases, the consortium specifically aims at exploitation of the business potential of the SWITCH results.



## MONROE RICERCANDO, Rapid Interpretation and Cross-Experiment Root-Cause Analysis in Network Data with Orange: Ricercando

**Project Type:**  
EU project – H2020

**Project Coordinator:**  
Simula Research Laboratory, Norway

**Principal Investigators at FRI:**  
Assoc. Prof. Fabio Ricciato, PhD  
(fabio.ricciato@fri.uni-lj.si)  
Assist. Prof. Veljko Pejović, PhD  
(veljko.pejovic@fri.uni-lj.si)

**Project Duration:**  
2016–2018

**Collaborating Laboratories:**  
Laboratory for Adaptive Systems and  
Parallel Processing  
Bioinformatics Laboratory  
Computer Structures and Systems  
Laboratory

Mobile broadband (MBB) networks have revolutionised the way we communicate, yet our understanding and means of troubleshooting such complex systems remain modest. The EU project MONROE (Measuring Mobile Broadband Networks in Europe) will design, deploy and operate the first European transnational open platform for independent, multi-homed, large-scale monitoring and assessment of performance of MBB networks (<https://www.monroe-project.eu>). Within the MONROE framework, project RICERCANDO (Rapid Interpretation and Cross-Experiment Root-Cause Analysis in Network Data with Orange), led by the Faculty of Computer and Information Science of the University of Ljubljana aims to advance tools for integrative exploration, visualization and interpretation of MBB data and meta-data across multiple experiments. The integration of these data with advanced data mining and interactive data exploration features will support human experts in the process of detecting and understanding the root-cause of the network problems and performance degradation. A distinguishing feature of RICERCANDO is the interdisciplinary composition of the project team that includes established data mining experts (Prof. Zupan) working together with networking experts (Prof. Ricciato, Prof. Pejovic).

## Evaluation and Development Tools for SRM Module

**Project Type:**  
Industrial project

**Principal Investigator at FRI:**  
Prof. Marko Bajec, PhD  
(marko.bajec@fri.uni-lj.si)

**Project Duration:**  
2017–2018

**Collaborating Laboratory:**  
Laboratory for Data Technologies

We evaluated and developed tools for the Secure Resource Management (SRM) platform, a new generation of Internet of Things (IoT) modules. They follow modern development practices and secure standards, as they bring a REST API interface to the physical interfaces of sensors and actuators (GPIO, I2C). To make them even more approachable by application developers, we developed three applications and organized the hackathon BajtaHack 2017. SRMEasyConfig is a development tool for quick interaction, configuration and debugging of SRM modules. SRMScriptEditor is a development editor for editing, running, and managing configuration scripts on SRM modules. SRMDataPlatform is a IoT data platform for collecting data from SRM modules. BajtaHack 2017 was the first two-day hackathon with this technology oriented towards creative innovations on the field of IoT, and automation of home and surroundings, that took place on November 25-26.

## SocioPower

**Project Type:**  
Structural Funds Project

**Principal Investigator at FRI:**  
Neli Bagus, PhD  
(neli.blagus@fri.uni-lj.si)

**Project Duration:**  
2017-2020

**Collaborating Laboratory:**  
Laboratory for Data Technologies

In the past decade, social media became important part of everyday life. The employment of different social applications changes the way we communicate, collaborate, gather information and consequently perceive the world around us. Therefore, social media, forums and the Web in general represent a valuable source of opinions, that enables a deeper understanding of society. In our project, we are developing the SocioPower platform for capturing, aggregating and analysing data from different social media. The platform will provide a wide range of information on topics that emerge in society and their intensity, as well as the insight into the thinking of individuals and different society groups. Thus, the service users could use the information to recognize the attention of the society and to identify its problems. The main objectives of the project are providing improved information for the needs of the decision-makers, and achieving greater involvement and interaction with society. Example of the use of the Sociopower platform in the smart city.

Example of the use of the Socio-power platform in the smart city.



## DIGITRANS, Digital Transformation

**Project Type:**  
EU project – Interreg Danube Transnational Programme

**Project coordinator:**  
MFG Innovation Agency Media and Creative Industries Baden-Württemberg, Germany

**Principal Investigator at FRI:**  
Prof. Matjaz Branko Jurič, PhD  
(matjaz.juric@fri.uni-lj.si)

**Project Duration:**  
2017-2019

**Collaborating Laboratory:**  
Laboratory for Adaptive Systems and Parallel Processing

Digital technologies such as IoT, big data and cloud computing are dramatically changing the way business is being done. Transformation based on those technologies enables more comprehensive and systematic business models, while simultaneously lowering overall costs to companies. One of the biggest challenges SMEs and start-ups face is the effective transition from current business models to new, technologically advanced and user-friendly ones.

Its goal of the project is to adapt business models, activities and processes in an efficient way and make use of the opportunities digital technologies provide. This will be achieved by: developing an appropriate innovation method which will enable SMEs to create competitive digital business models; establishing incubator premises in the partner regions based on the newly developed DIGITRANS method; developing online learning content and a method toolbox integrated into online learning platform; teaching SMEs the skills needed to handle the transformation process. This will be done by providing appropriate trainings.







## Improving the Quality of Slovene Textbooks

**Project Type:**  
Structural Funds Project

**Project Coordinator:**  
University of Ljubljana,  
Faculty of Education, Slovenia

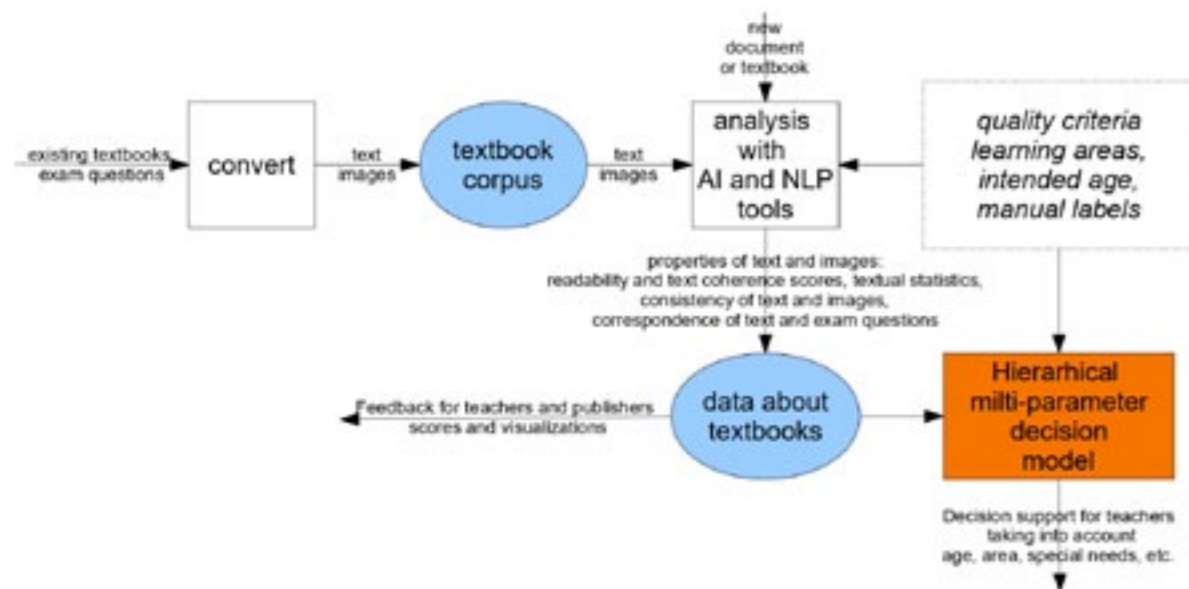
**Principal Investigator at FRI:**  
Prof. Marko Robnik-Šikonja, PhD  
(marko.robnikskonja@fri.uni-lj.si)

**Project Duration:**  
2017-2019

**Collaborating Laboratory:**  
Laboratory for Cognitive Modeling

The goal of the project is to develop quality metrics for Slovene primary and secondary school textbooks to be used during their certification and evaluation. The research group will develop a prototype of the automatic web-based tool, which will allow evaluation of textbooks based on their textual and pictorial properties. The tool will support decision-making process for selection of appropriate textbook.

UL FRI researchers will adapt, develop and implement several readability metrics for the Slovene language. They will use techniques from natural language processing, machine learning, and image recognition to assess readability and text coherence. The decision support will be implemented through a hierarchical multi-parameter decision model, which will be flexible enough to capture requirements of different areas (social, humanistic and natural sciences), different age groups, education levels, special needs of pupils etc. The developed tool will be calibrated and evaluated on a sample of human evaluated textbooks. The tool will be open-sourced and publicly available and will provide feedback on readability and text coherence.



## AutoInspect

**Project Type:**  
Industrial project

**Principal Investigator at FRI:**  
Assoc. Prof. Matej Kristan, PhD  
(matej.kristan@fri.uni-lj.si)

**Project Duration:**  
2016-

**Collaborating Laboratory:**  
Visual Cognitive Systems Laboratory

The project goal is development of a system for damage inspection of cars. In collaboration with a company, a rich sensory system of proximity sensors and cameras was designed and optimized to scan the car as it drives through a scan tunnel. Advanced computer vision solutions have been developed to perform partial 3D reconstruction of the car's hull and segment the car into parts. We have made several innovations on sensor-based glass detection on cars, robust real-time fringe pattern detectors that do not assume a static scene and novel computer vision methods for identifying defects by spatial frequency analysis. Particular attention has been dedicated to ensuring higher than real-time processing of all streams from five cameras, delivering accurate and short scanning times.





## HUBLinked, Strengthening Europe's Software Innovation Capacity

**Project Type:**  
EU project - Erasmus+

**Project coordinator:**  
Dublin Institute of Technology, Ireland

**Principal Investigator at FRI:**  
Assoc. Prof. Mojca Ciglaric, PhD  
(mojca.ciglaric@fri.uni-lj.si)

**Project Duration:**  
2017-2019

**Collaborating Laboratory:**  
Computer Communications Laboratory

By creating a sustainable strategic network of major European ICT hubs, the goal of HubLinked is to strengthen Europe's software innovation capacity by learning from regions of proven ICT strength and sharing that knowledge will all regions. HubLinked will improve: the effectiveness University-Industry (U-I) linkages between computer science faculty and different types of companies; develop global software innovator graduates that can work in any sector; upskill academic and industry staff to engage in U-I linkages for software innovation. Although the ICT sector is a major economic sector in Europe, HubLinked also includes SMEs in the non-software sector to provide a 'low-cost low-commitment' mechanism to prototype software innovations. An established partnership of large, industry-focused computer science faculties has come together with a representative mix of industry partners (large multinationals, SMEs in both the software and other sectors and start-up companies). All partners are located in regions identified as ICT Poles of Excellence.

HubLinked has six deliverables: • effective U-I linkages specific between computer science faculties and different types of company; • the CSI4 curriculum framework for industry-oriented, internationalised, innovation-focused and interdisciplinary computer science degrees; • four Global Labs modules whereby international teams of students work together across time zones, supervised by industry mentors, to turn real-world problems from any sector into 'experience-appropriate' prototypes; • a portal of study and placement opportunities for students and staff in major international software hubs; • an online professional development for academic and industry staff; • form the HubLinked Association with a long-term goal of including a partner from each EU country.

To maximise sustainability and impact, HubLinked aligns the strategic development of major computer science faculties in the HE partners, operates at faculty level, works across the three Bologna levels (Bachelors, Masters and Doctorate including LLL). In addition to the four major industry partners, each higher education partner also brings with them an extensive network of industry partners, campus incubation units and other higher education partners. We estimate the HubLinked partnership can directly reach over 3,000 companies, 12,000 students and 400 staff during the lifetime of the project. HubLinked will create a network of European ICT professionals that will increase the innovation capacity and competitiveness of European software hubs and help underpin education, research, innovation, trade and economic development for years to come.

## Multiobjective Discovery of Driving Strategies for Autonomous Vehicles

**Project Type:**  
Post-doctoral applied research project  
funded by the Slovenian research agency  
and industry partner

**Principal Investigator at FRI:**  
Erik Dovgan, PhD  
(erik.dovgan@fri.uni-lj.si)

**Project Duration:**  
2016-2018

**Collaborating Laboratory:**  
Artificial Intelligence Laboratory



Autonomous vehicle driving consists of monitoring the vehicle and its surroundings, taking decisions about actions and applying the selected actions. This is a continuous process that optimizes several objectives such as the traveling time and the fuel consumption. An important objective is also the acceptability of vehicle behaviour by the passengers, which can be defined as the similarity to human driving behaviour. We developed a multiobjective optimization algorithm for discovering human-like driving strategies that mimics human driving behaviour and at the same time minimizes the traveling time and the fuel consumption. The results show that the fuel consumption of human driving can be reduced by as much as 20 % within the same driving style and time constraints. This project has been financially supported by the Slovenian Research Agency and NERV7EH.

Erik Dovgan, Jaka Sodnik, Ivan Bratko, Bogdan Filipič (2017) Multiobjective discovery of human-like driving strategies, Proceedings of the Genetic and Evolutionary Computation Conference (GECCO).





## GETM3, Global Entrepreneurial Talent Management 3

**Project Type:**  
EU project – MSCA

**Project coordinator:**  
University of Northumbria at Newcastle,  
United Kingdom

**Principal Investigator at FRI:**  
Assist. Prof. Tomaž Hovelja, PhD  
(tomaz.hovelja@fri.uni-lj.si)

**Project Duration:**  
2017–2020

**Collaborating Laboratory:**  
Information Systems Laboratory

GETM3 focuses on young talent as a key driver of future development, developed through co-operation of 3 stakeholders: employers (including MNC & SME), universities and students/graduates. Despite a widely recognized importance of young talent (e.g. Europe 2020), its potential remains largely untapped. They are educated and entrepreneurial and yet experience instability in employment. At the same time, employers report skills mismatch and difficulties with attracting, managing and retaining young talent. To tackle this paradoxical situation, an innovative, multi-perspective approach is needed, reinforced by our 15-partner consortium; comprising of a transnational, inter-disciplinary, inter-generational, gender balanced and inter-sectorial research team.

The main objective of GETM3 is to improve employability and future global talent management to support economic development by capitalizing on entrepreneurialism as a key characteristic of the young. To achieve this objective, the project is divided into six work packages. Three WPs focus on in-depth research of specific issues from each of the stakeholder perspectives. The Integration and Innovation WP, essential for impact, aims to integrate research outputs and develop GETM3 across dimensions: generations, genders, disciplines, countries, sectors and stakeholders. The overall design of the project builds impact through researcher mobility in two ways: researchers will gain first hand and in-depth insights on specific issues from various perspectives, and will develop their skills through networking and training incorporated into mobility with sandpit events.

Higher-education partners on the project GETM3.



Industry partners on the project GETM3.



## Robust Computer Vision Methods for Autonomous Water Surface Vehicles

**Project Type:**  
Basic research project funded by the Slovenian research agency

**Principal Investigator at FRI:**  
Assoc. Prof. Matej Kristan, PhD  
(matej.kristan@fri.uni-lj.si)

**Project Duration:**  
2017–2020

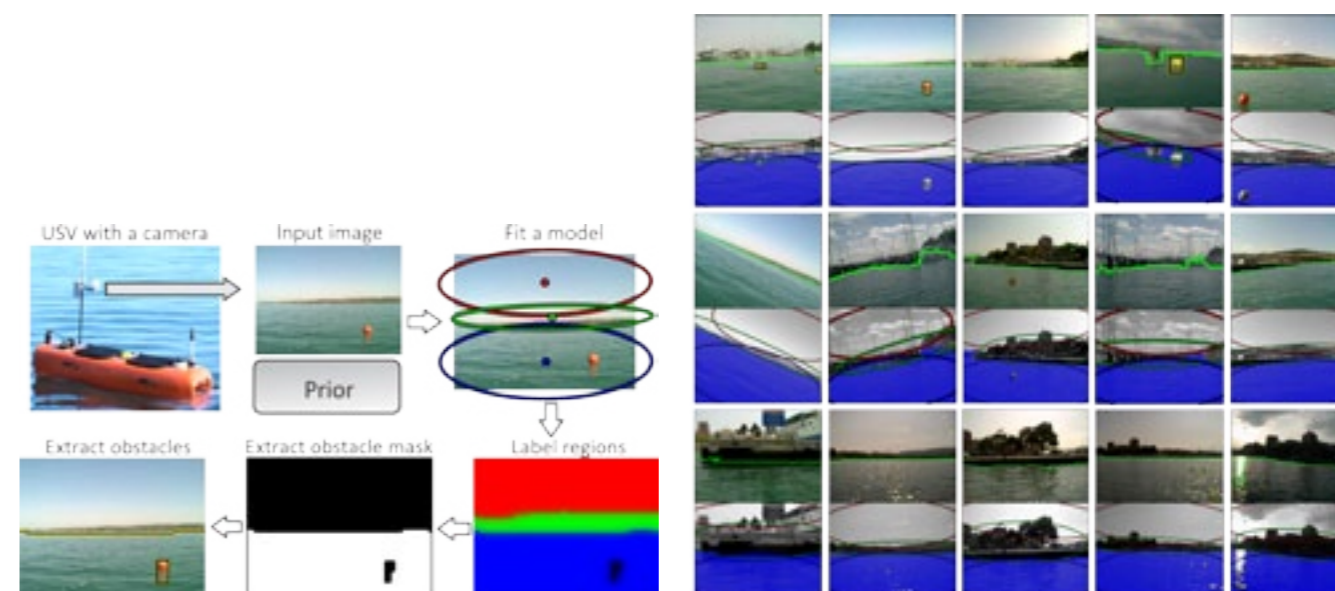
**Collaborating Laboratory:**  
Visual Cognitive Systems Laboratory

Over the last decade the research in “field robotics” has resulted in development of small-sized (~2m long) unmanned surface vehicles (USVs) that can be manually guided or used to follow a pre-programmed path. Due to their portability and ability to navigate relatively shallow waters and narrow marinas, their potential use is indeed large, ranging from coastal water and environmental surveillance, to inspection of man-made structures above and below water surface.

The project overarching goal is to develop functionalities required for robust autonomous navigation of USVs in uncontrolled environments, primarily relying on the captured visual information. The objectives are to develop efficient and robust computer vision approaches for obstacle detection, long-term tracking and fusion with other sensors and camera modalities. A critical requirement of the approaches will be real-time performance, environment adaptation and long-term robustness to temporary failures of sensory information and visual uncertainties.

Matej Kristan, Vildana Sulić Kenk, Stanislav Kovačič, Janez Perš (2016) Fast image-based obstacle detection from unmanned surface vehicles, IEEE transactions on cybernetics, 46(3): 641-654.

Borja Bovcon, Rok Mandeljc, Janez Perš, Matej Kristan (2017) Improving vision-based obstacle detection on USV using inertial sensor, 10th International Symposium on Image and Signal Processing and Analysis, ISPA 2017.



## Natural Science and Mathematical Literacy: Promoting Critical Thinking and Problem Solving

**Project Type:**  
Structural Funds Project

**Project Coordinator:**  
National Education Institute, Slovenia

**Principal Investigators at FRI:**  
Assoc. Prof. Matija Marolt, PhD  
(matija.marolt@fri.uni-lj.si)  
Assist. Martin Vuk, PhD  
(martin.vuk@fri.uni-lj.si)  
Prof. Aleksandar Jurišić, PhD  
(aleksandar.juriscic@fri.uni-lj.si)

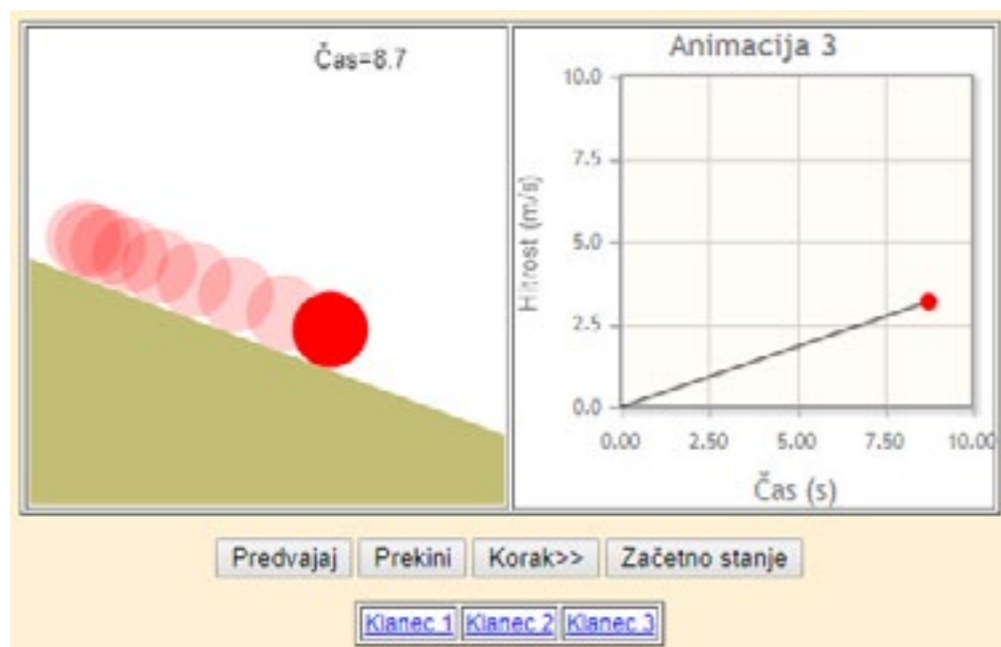
**Project Duration:**  
2017–2019

**Collaborating Laboratories:**  
Laboratory of Computer Graphics  
and Multimedia  
Laboratory for Mathematical Methods  
in Computer and Information Science  
Laboratory for Cryptography  
and Computer Security

The project Natural Science and Mathematical Literacy: Promoting Critical Thinking and Problem Solving aims to develop and test pedagogical approaches, strategies and flexible forms of learning, which will, also through the integration of new technologies, contribute to the integrated and continuous vertical development of natural science, mathematical and other literacy (financial, digital, media...) of children from kindergartens to secondary schools.

Following the project goals, the Laboratory for Computer Graphics and Multimedia will contribute with the development of a series of interactive online physical simulations for solving authentic problems through ICT.

An interactive online simulation: investigating motion on a sloping surface.



## Reading Literacy and Development of Slovenian Language

**Project Type:**  
Structural Funds Project

**Project Coordinator:**  
National Education Institute, Slovenia

**Principal Investigator at FRI:**  
Assoc. Prof. Matija Marolt, PhD  
(matija.marolt@fri.uni-lj.si)

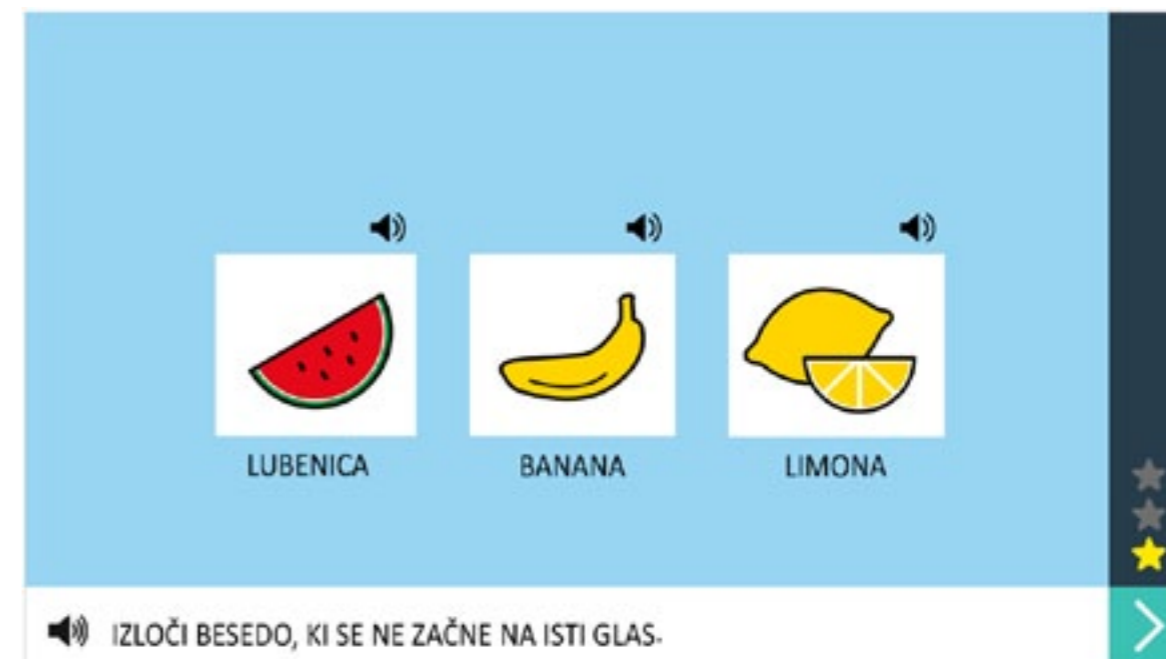
**Project Duration:**  
2017

**Collaborating Laboratory:**  
Laboratory of Computer Graphics  
and Multimedia

The project Reading Literacy and Development of Slovenian Language aims at raising the reading literacy level for better learning achievements of pupils at all levels of education.

The Laboratory for Computer Graphics and Multimedia will participate in the project with the preparation of an online platform for supporting development of children's pre-literacy abilities in the early school period. As part of the project, two specific educational games will be developed and integrated in the online platform for distribution of educational applications. The games aim to support the set goals for aiding the development of auditory perception in the child.

The game Intruder aims at raising the phonological awareness of a child.



## CJVT UL, Center for Language Resources and Technologies of University of Ljubljana

**Project Types:**  
Infrastructure program funded by the Slovenian research agency, other national project funded by the Slovenian Ministry of Culture and Basic research project funded by the Slovenian research agency

**Principal Investigator at FRI:**  
Prof. Marko Robnik-Šikonja, PhD  
(marko.robniksikonja@fri.uni-lj.si)

**Project Duration:**  
2015–2020

**Collaborating Laboratory:**  
Laboratory for Cognitive Modeling

Researchers of UL FRI collaborate in the Center for Language Resources and Technologies of University of Ljubljana (CJVT UL). This interdisciplinary research unit is aimed at scientific research, development, and maintenance of key digital language resources and language technologies for contemporary Slovene. Two projects of the Center are described below.

Gigafida is a reference corpus of Slovene language containing Slovene texts from daily newspapers, magazines, books, web pages, parliamentary speeches etc., all together around 1.2 billion words in 40,000 documents. Currently, Gigafida and corpora extracted from it (Kres, ccGigafida and ccKres) contain documents created until 2012. The project has three goals: collecting new materials, machine processing of new and existing documents, and public availability of upgraded corpora.

The project “New grammar of contemporary standard Slovene: sources and methods” aims to explore linguistic methodological foundations of a complex analysis of written and spoken Slovene. Resulting methodology and data will provide a foundation for the empirical description of Slovene and will enable several language technology applications. This analysis represents the first step towards the new descriptive corpus-based grammar of Slovene.



**Project Type:**  
Applied research project funded by the Slovenian research agency and industry partners

**Principal Investigator at FRI:**  
Assoc. Prof. Danijel Skočaj, PhD  
(danijel.skocaj@fri.uni-lj.si)

**Project Duration:**  
2014–2017

**Collaborating Laboratory:**  
Visual Cognitive Systems Laboratory

## VILLarD, Maintenance of Large Databases Based on Visual Information using Incremental Learning

We live in the era of information abundance. However, rather than quantity, the central concern has become the quality and credibility of the acquired data. This is especially true for visual information databases. In this project, we aspire to combine computer-based automation of image interpretation that is necessary for database maintenance as well as suitable introduction of a human verifier into the loop. Such a combination is of central importance for developing a methodology suitable for semiautomatic maintenance of traffic signalization records, which is partially our project’s practical goal. Even the database of such records only for state roads in the Republic of Slovenia may contain more than 250,000 entries along with additional information. Automation is therefore crucial for continuous maintenance of such databases. The main goal of the project is to develop a framework for semi-supervised incremental learning as well as specific methods for visual learning and recognition that will increase the quality and efficiency of large visual information databases maintenance.



# Creative Path to Practical Knowledge

A successful measure which connects knowledge and experience for a successful transition from the educational system into work environment is carried out by support of the Public Scholarship, Development, Disability and Maintenance Fund of the Republic of Slovenia and financed by the European Social Fund and the Slovenian Ministry of Education, Science and Sport.

This program is aimed to increase employability of youth and to support the cooperation between universities and private companies. Students take the central role as experts in small scale projects from all academic fields and use their theoretical knowledge and apply it towards research and practical solutions. With the help of academic and practical mentors, the students are solving individual businesses and society challenges which are the most actual at the moment, using specific theoretical knowledge from educational process and business work approach with the support of their infrastructure.

In 2017 our researchers were involved in several projects, out of which, in 5 they were also principal investigators. In the rest of these projects, they collaborated as academic mentors.

## Waste Separation on a Mobile Device

**Principal Investigator:**  
Assoc. Prof. Zoran Bosnić, PhD  
zoran.bosnic@fri.uni-lj.si

Within the student project Po kreativni poti do znanja 2016/2017 we developed a mobile game FriCycle that employs gamification to teach its users how to correctly separate different waste into appropriate waste bins. The game itself was developed for the Android platform. It features different play modes and contains instructional videos that are also equipped with a sign language for the deaf and hearing-impaired users. As such it aims to achieve the improved ecological and environmental awareness of the pupils and general public. Eight students from various 1st and 2nd cycle study programmes at UL FRI participated within the project. The FriCycle was developed in cooperation also with company Celtra, razvoj informacijskih tehnologij, d.o.o., and with Zveza društev gluhih in naglušnih Slovenije.

## Computer Vision and Intelligent Robotics for Advanced Forms of Communication

**Principal Investigator:**  
Assist. Prof. Luka Čehovin Zajc, PhD  
luka.cehovin@fri.uni-lj.si

The main goal of the project was to study the possibilities of using computer vision and mobile robotics methods for advanced forms of communication with consumers/users. The project was a cooperation between the Faculty of Computer and Information Science, Infinum d.o.o., a high-tech company, specialized in development of mobile applications, and the Technical Museum of Slovenia. Within the project, we examined the usefulness of three different sensory-robotic platforms, a multitouch surface, a mobile robot and a camera of a smartphone in different communication scenarios. In addition to extending these systems with functionalities for interactive communication with users we have also analysed the usefulness of platforms from the perspective of user acceptance and economic viability.

## InfoGen: Information System for Tracking, Analysis and Management of Laboratory Samples in Functional Genomics

**Principal Investigator:**  
Assist. Prof. Miha Moškon, PhD  
miha.moskon@fri.uni-lj.si

During experimental work, researchers acquire large number of samples. Managing these samples and the data they represent has become a big issue within the research community. In the project, we designed and implemented an information system as a support system for tracking, analysis and management of animal and/or human samples acquired in the biochemical research laboratories and/or clinical environment. The interdisciplinary nature of the project required the collaboration of seven students from three different fields of study, i.e. computer and information science, biochemistry and cognitive science. We divided the information systems in three different segments devoted to three different types of samples, namely samples obtained from animal models, samples obtained for the diagnosis of Alzheimer disease and samples obtained from suicide victims.

## API Development for the Digital Transformation and API Economy

**Principal Investigator:**  
Assist. Prof. Sebastijan Šprager, PhD  
sebastijan.sprager@fri.uni-lj.si

Companies and organizations face the need to transform business, redefine business models, products and services and use the opportunities brought by digital technologies. In the project, general purpose mechanisms and architecture were designed to allow automatic linking of user service devices to the software APIs that the institutions expose. This enables direct engagement of users of services in defined business processes (customer engagement).

## Video Distance Measurement of Ski Jumping

**Principal Investigator:**  
Assoc. Prof. Matjaž Kukar, PhD  
matjaz.kukar@fri.uni-lj.si

Great successes of Slovenian ski jumpers in recent years incited a lot of public interest for active ski jumping, especially in junior categories. Competitions with 100 - 200 jumpers that last up to 8 hours are no rare events. Distance measuring in junior categories is performed manually by three to six umpires. Only in highest level competitions (World cup, Continental cup) video recordings are used for this purpose. In the project we developed an affordable system for video measurements of ski jumping distances. We focused on using commercially available technologies (video camera, external microphone, portable computer) to support and (in the future) automatically measure jumping distances. We developed a user-friendly integrated application that utilizes the OpenCV library for detecting and tracking the jumper, overlaying video with a calibrated distance mesh, and fusion of video and audio data for landing detection. In the course of the project we recorded four competitions. Our evaluation shows that our system has reasonable hardware requirements and could be, with a moderate investment, usefully deployed in real time. The project was implemented in collaboration with University of Ljubljana, Faculty of Sports, the Ski Association of Slovenia and AZ Net Ltd.

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# Innovative Student Projects for Public Benefit

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Another successful mechanism supported by the Public Scholarship, Development, Disability and Maintenance Fund of the Republic of Slovenia and financed by the European Social Fund and the Slovenian Ministry of Education, Science and Sport is carried out by public tenders called Project work with the public and non-profit sectors in the local and regional environment – Innovative Student Projects for Public Benefit.

The purpose is the reinforcement of cooperation and connectivity between the higher education system and the environment (the public and non-profit sectors in the local/regional environment), as well as the conducting of liberal models in connection to crossing between education and the labour market, i. e. the local environment. This ensures the participants' obtainment of concrete, practical experiences during years of education, thus increasing the ease of crossing over from education to work.

In 2017 our researchers were involved in several projects, out of which, in 3 they were also principal investigators. In the rest of these projects, they collaborated as academic mentors.

## Computer vision on Smart Phone for Augmenting Tourist and Educational Content in Local Environment

Principal Investigator:  
Assist. Prof. Luka Čehovin Zajc, PhD  
luka.cehovin@fri.uni-lj.si

Modern innovative applications for mobile phones are one of the means to attract the attention of visitors to local sights and preserve the cultural and technical heritage. The aim of the project was to develop a software solution for the production and handling of multimedia content that can be presented on site based on images captured by the camera of the phone. Solving such problems requires an interdisciplinary approach with an input from computer science, multimedia, archaeology and graphic design. The project was a cooperation between the Faculty of Computer and Information Science, the Theodosius Cultural and Educational Society (DT) from Vrhoplje by Vipava, and the Technical Museum of Slovenia (TM).

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## Cryptogram – a Portal for Cryptography and Computer Security

Principal Investigator:  
Assist. Janoš Vidali, PhD  
janos.vidali@fri.uni-lj.si

The central theme of the project was to start the dissemination of knowledge and awareness about modern cryptography. As such, 10 students of computer science, multimedia and design collaborated with the Cryptographic Society of Slovenia to establish a portal for cryptography (available at <https://lkrv.fri.uni-lj.si/crypto-portal/>, in the Slovene language) which allows visitors to analyse and break simple ciphers, such as the Caesar and substitution cipher, learn about coding theory through exploring alternative ways of communication (flag signals, foreign alphabets, etc.), and raise awareness about hidden channels in communication by letting them hide messages into images.

## International Project for Science Promotion: Central European Olympiad in Informatics (CEOI)

Principal Investigator:  
Andrej Brodnik, PhD  
andrej.brodnik@fri.uni-lj.si

Faculty of Computer and Information Science, University of Ljubljana hosted from 10th to 15th of July the 24th edition of CEOI - Central European Olympiad in Informatics. CEOI is a regional Olympiad that connects nine countries - Austria, Croatia, Czech Republic, Germany, Hungary, Poland, Romania, Slovakia and Slovenia. Besides the mentioned countries, this year participated at CEOI with a special invitation also five more countries: Azerbaijan, Georgia, Israel, Italy and Switzerland. Altogether, 58 competitors from 14 different countries participated at the CEOI.

This was the first time that Slovenia had ever hosted an Olympiad in informatics. The main reason for hosting the CEOI was to raise computer science awareness among high school students. Consequently, students of five Ljubljana high schools joined the organization. Throughout the competition, participants exchanged their knowledge and experience and solved problems using computers. CEOI is a great opportunity for students since its winners frequently win on the world-wide level of the competition as well. Not just that, the winners of CEOI are among the most wanted future professionals in ICT field worldwide.

Olympiad was organized by UL FRI in cooperation with ACM Slovenia and the help of many sponsors. You can read more on CEOI at <https://ceoi2017.acm.si/> and at <https://www.facebook.com/ceoi2017/>.

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**“PhD students should endeavour to pursue cutting-edge research in a topic they are curious and passionate about.”**

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Marinka Žitnik,  
PhD graduate, Summa Cum Laude

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## Doctoral Study Programmes

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Computer and information science is one of the leading breakthrough areas with regard to shaping the economy, education, culture, administration and other disciplines. The marked rise of computer technology in developed countries dictates the need for highly qualified human resources which are capable of developing new computer and information technologies and implementing them in innovative environments. This study programme is designed to appeal to young people, especially those who plan on pursuing research and scientific work in computer science and informatics. The main focus of the doctoral study is on research, enabling students to receive training in both independent and team work, which encourages interdisciplinarity and also offers students the opportunity to cooperate with internationally recognised domestic and foreign experts. Special emphasis is devoted to combining scientific and professional areas, elective courses and an academic mentor programme so as to encourage students throughout the course of their studies.

At the Faculty of Computer and Information Science we offer the Doctoral study Programme in Computer and Information Science. There is a wide range of courses available which offer students the opportunity to further their research work in a specific field. The aim of the programme is to provide computer science education to independent researchers, teachers and future leaders. We also run an Interdisciplinary Study Programme Biosciences in cooperation with several faculties (the Biotechnical Faculty, the Faculty of Electrical Engineering and the Faculty of Mechanical Engineering).



# Highlights of the Doctoral Students' Research

“Those who can imagine anything, can create the impossible.”

Alan Turing



**Alan Lukežič**  
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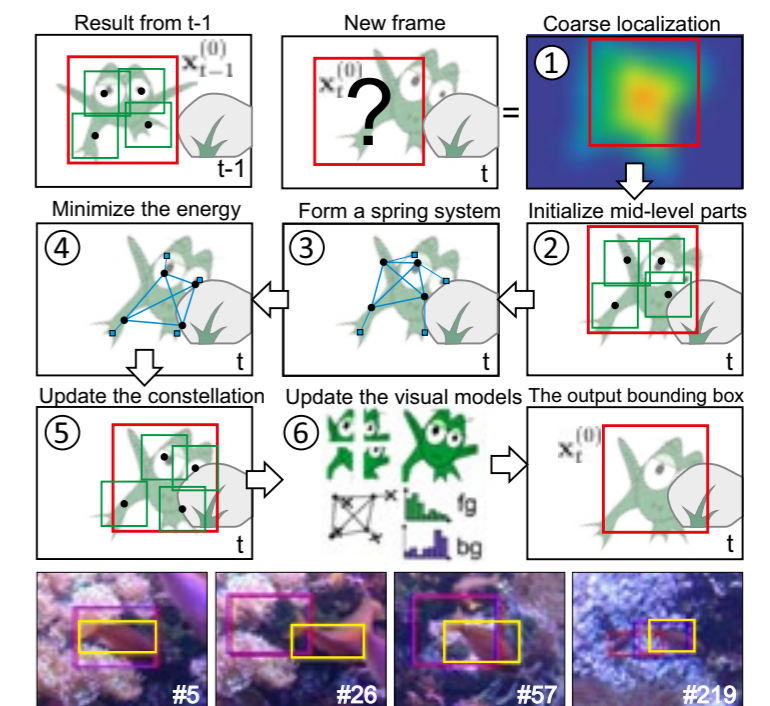
Supervisor:  
Assoc. Prof. Matej Kristan, PhD  
Visual Cognitive Systems Laboratory

“Tracking robustness is greatly improved by an explicit handling of geometric constraints among parts.”

## Deformable Parts Correlation Filters for Robust Visual Tracking

Short-term visual object tracking concerns continuously localizing a target in a video-sequence given a single example of its appearance. It has received significant attention from the computer vision community, which is reflected in the high number of papers published on the topic. The challenges come from diverse factors such as occlusion, illumination change, fast object or camera motion, appearance changes and similarity to the background. We presented a new class of layered part-based trackers that applies a geometrically constrained constellation of local correlation filters for object localization. We introduced a new formulation of the constellation model that allows efficient optimization of a fully connected constellation and adds only a negligible overhead to the tracking speed. Our tracker explicitly addresses non-rigid deformations and occlusions, resulting in increased robustness compared to the recently proposed holistic correlation filters as well as state-of-the-art part-based trackers.

Alan Lukežič, Luka Čehovin Zajc, Matej Kristan (2017) Deformable Parts Correlation Filters for Robust Visual Tracking. IEEE Transactions on Cybernetics, PP(99): 1-13.





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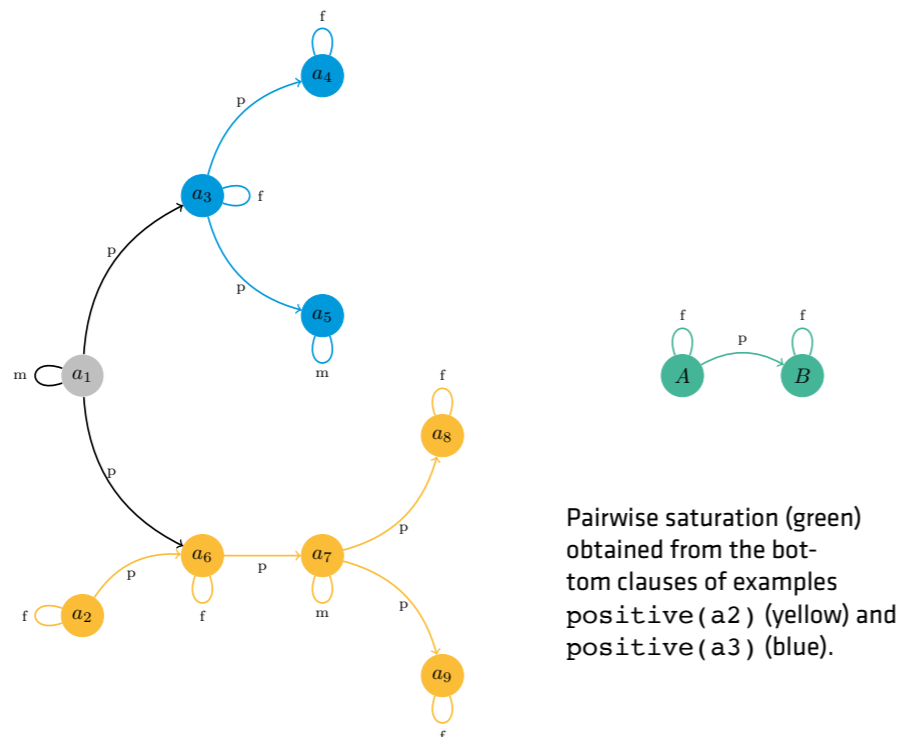
Prof. Igor Kononenko, PhD  
Laboratory for Cognitive Modeling

## Analysing Learning eExamples Before Learning Leads to Speed-Ups in ILP

Inductive logic programming (ILP) systems learn logic programs from positive and negative facts. Logic programs are represented in 1st order logic, making the representational language more powerful than the one used by the majority of machine learning algorithms. One of the main issues of using ILP are the long running times needed to induce the hypothesis. We developed a methodology which enables the speed-up of learning by bottom-up ILP systems. We explored the possibility of reducing the running times by analysing the bottom clauses of inputs into the asymmetric relative minimal generalization (ARMG) operator. Since the ARMG covers all input examples, we can identify literals that cannot appear in the ARMG and remove them prior to computing the generalization. We applied this procedure to the ProGolem system and tested its performance on several real-world data sets. The results show an average speed-up of 36% compared to ProGolem and 12% compared to ProGolem with caching, both without a decrease in accuracy. We also observe that the speed-ups vary, depending on the data set structure involved.

Miha Drole, Igor Kononenko (2017) Pairwise saturations in inductive logic programming, *Artificial intelligence review*, 47(3): 395-415.

“Deciding on what is important beforehand can speed up learning greatly.”



**Kaja Zupanc**

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Supervisor:

Assoc. Prof. Zoran Bosnić, PhD  
Laboratory for Cognitive Modeling

## Automated Essay Evaluation with Semantic Analysis

Manual grading of students' essays is a time-consuming process, but is nevertheless necessary, since essays are considered as the most useful tool to assess learning outcomes. Automated essay evaluation (AEE) represents a practical solution to this task, however, its main weakness is the predominant focus on vocabulary and text syntax, and limited consideration of text semantics. We have proposed SAGE, the Semantic Automated Grader for Essays, that incorporates additional semantic coherence and consistency aspects of grading. We evaluate the coherence by transforming sequential parts of an essay into the semantic space and measuring changes between them to estimate the flow of information from one part of an essay to another. The resulting system provides an instant semantic feedback for the writer based on the detected semantic errors in a student essay and achieves state-of-the-art grading accuracy. By publicly providing the technical details and results of our AEE system, we aim to promote the openness of this research field.

Kaja Zupanc, Zoran Bosnić (2017) Automated essay evaluation with semantic analysis, *Knowledge-based systems*, 120: 118-132.

“SAGE outperforms the state-of-the-art automated essay evaluation systems by introducing novel approach to detection of semantic errors in essays.”

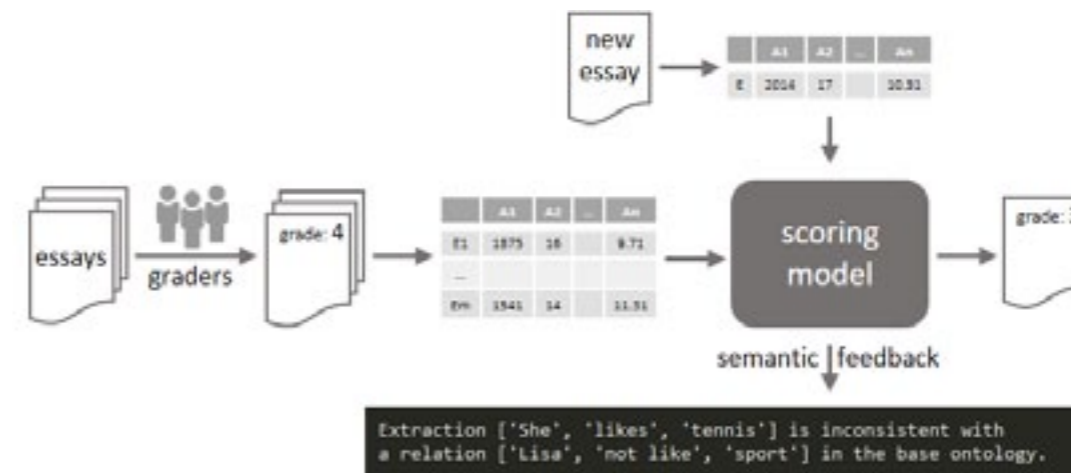


Illustration of the operation of SAGE automated essay evaluation system.



**Tomaž Hočevar**

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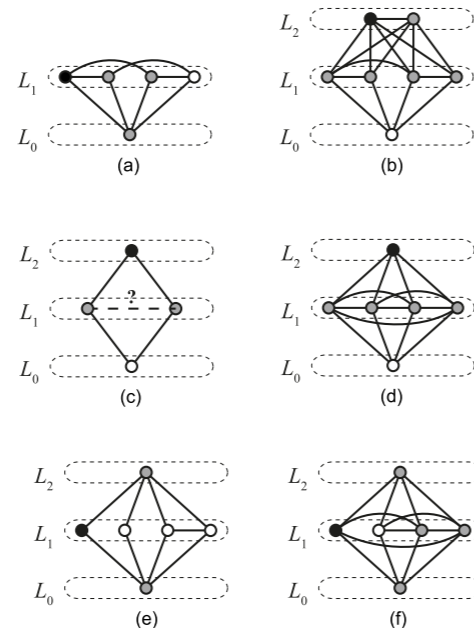
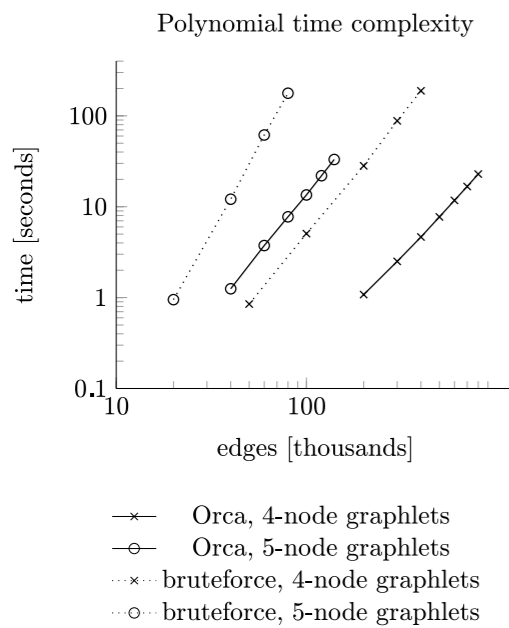
Prof. Janez Demšar, PhD  
Bioinformatics Laboratory

## Combinatorial Algorithm for Counting Small Induced Graphs and Orbits

Graphlet analysis is an approach to network analysis that is particularly popular in bioinformatics. We show how to set up a system of linear equations that relate the orbit counts and can be used in an algorithm that is significantly faster than existing approaches, based on direct enumeration of graphlets. The presented approach is a generalization of the currently fastest method for counting 5-node graphlets in bioinformatics. The algorithm requires the existence of a vertex with certain properties; we show that such a vertex exists for graphlets of arbitrary size through an analysis of several cases. The only exceptions are complete graphs and a cycle with four nodes, which are treated separately. The empirical analysis conducted of gains in time complexity agrees with the theoretical results.

Hočevar T, Demšar J (2017) Combinatorial algorithm for counting small induced graphs and orbits. PLoS ONE, 12(2): e0171428.

“Orca, which is currently the fastest 5-node graphlet counting algorithm, can be generalized to graphlets of larger size.”



**Matevž Pesek**

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Supervisor:

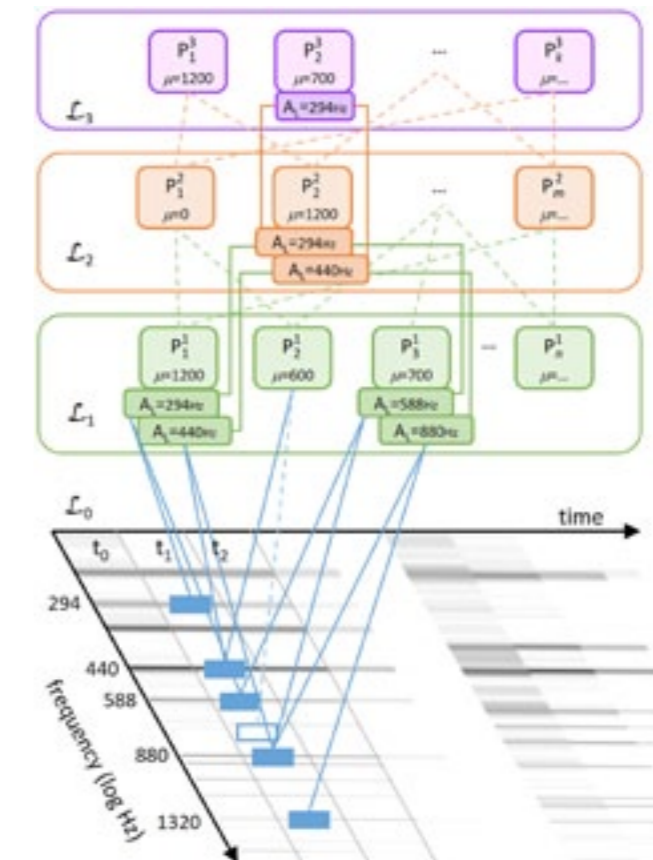
Assoc. Prof. Matija Marolt, PhD  
Laboratory of Computer Graphics  
and Multimedia

## Robust Real-Time Music Transcription with a Compositional Hierarchical Model

The systems for automatic extraction and annotation of audio materials are mostly developed and evaluated on professional studio recordings created in ideal recording conditions. We reach for the larger, hidden sets of musical recordings that are created in everyday life by non-professional performers. We have developed a new compositional hierarchical model—a transparent alternative to existing deep neural-network-based models, which fail to provide an insight into the learned concepts. The model has been tested on a collection of Slovene folk song recordings, which are of non-studio quality, recorded in the field, using portable devices. The songs are folk songs performed by amateur singers. A comparison with the best approaches from the field has demonstrated that the compositional hierarchical model on the collection of Slovenian folk songs transcribes the most precise and robustly transmitted singing. Owing to the small computational complexity involved, the transcription can be performed in real time, allowing for the model to be used in embedded and mobile devices with low computational power.

Matevž Pesek, Aleš Leonardis, Matija Marolt (2017) Robust Real-Time Music Transcription with a Compositional Hierarchical Model, PLoS ONE, 12(1): e0169411.

“Exploring cultural heritage with new deep architecture approaches.”





**Žiga Emeršič**

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Supervisor:

Assoc. Prof. Peter Peer, PhD  
Computer Vision Laboratory

## Ear Biometrics

A convolutional neural network as a special case of deep learning approach is widely used in the computer vision domain and biometry. We recently were successful in 1) presenting a network for ear detection in the wild, where, unlike competing techniques from the literature, our approach does not simply return a bounding box around the detected ear, but instead provides accurate and detailed, pixel-wise information about the location of the ears in the image [1]; 2) presenting a trained network with limited training data for ear recognition in the wild, where we explored different strategies towards model training with limited amounts of training data and showed that by selecting an appropriate model architecture, using aggressive data augmentation, and selective learning on existing (pre-trained) models, we are able to train an effective model [2].

[1] Žiga Emeršič, Luka L. Gabriel, Vitomir Štruc, Peter Peer (2017) Convolutional encoder-decoder networks for pixel-wise ear detection and segmentation, IET Biometrics (revision under review).

[2] Žiga Emeršič, Dejan Štepec, Vitomir Štruc, Peter Peer (2017) Training convolutional neural networks with limited training data for ear recognition in the wild, IEEE International Conference on Automatic Face and Gesture Recognition (FG 2017), 987-994.

“Detecting and recognizing ears in the wild with deep learning.”



In these images faces were pixelated in order to guarantee anonymity.

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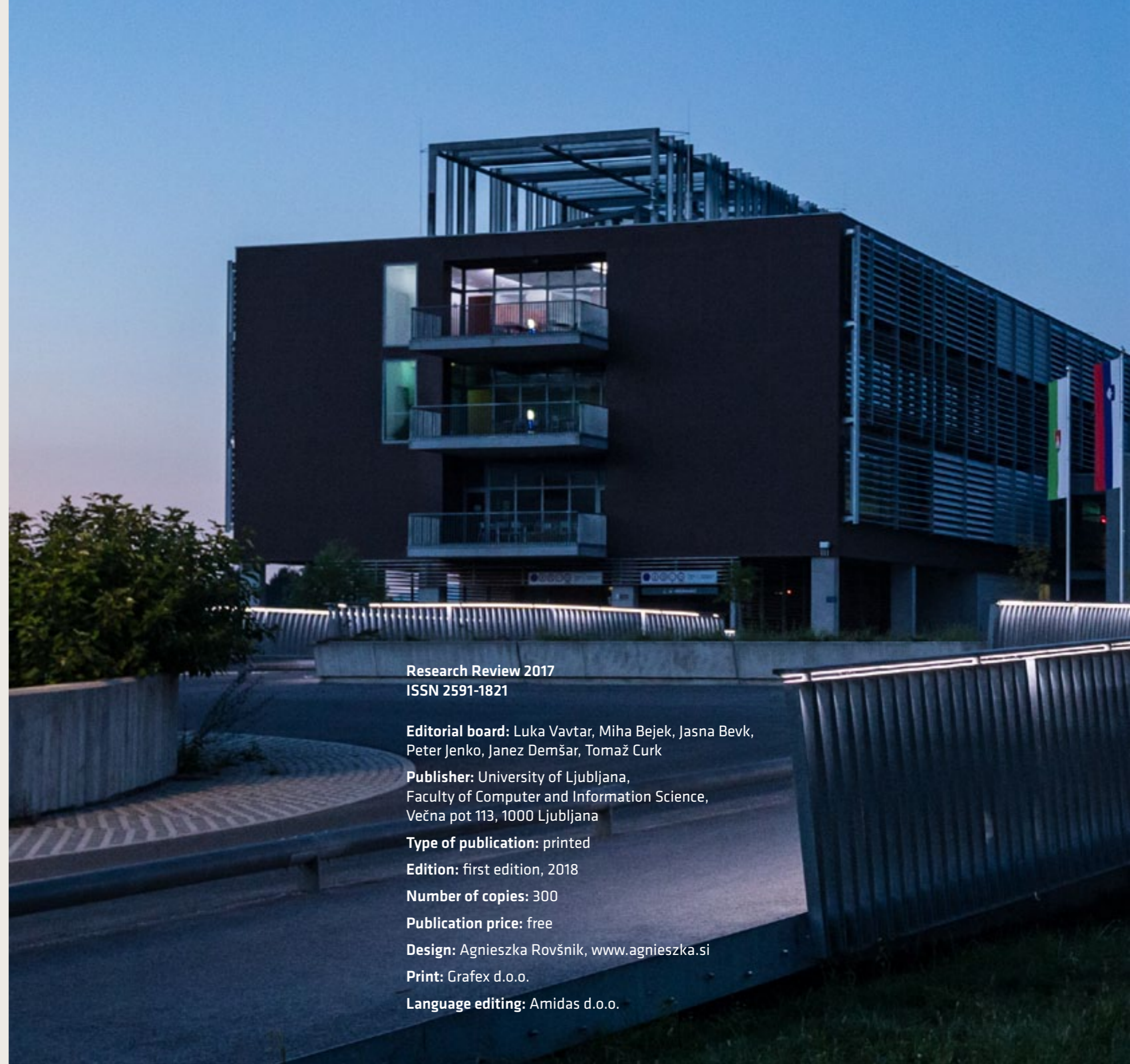
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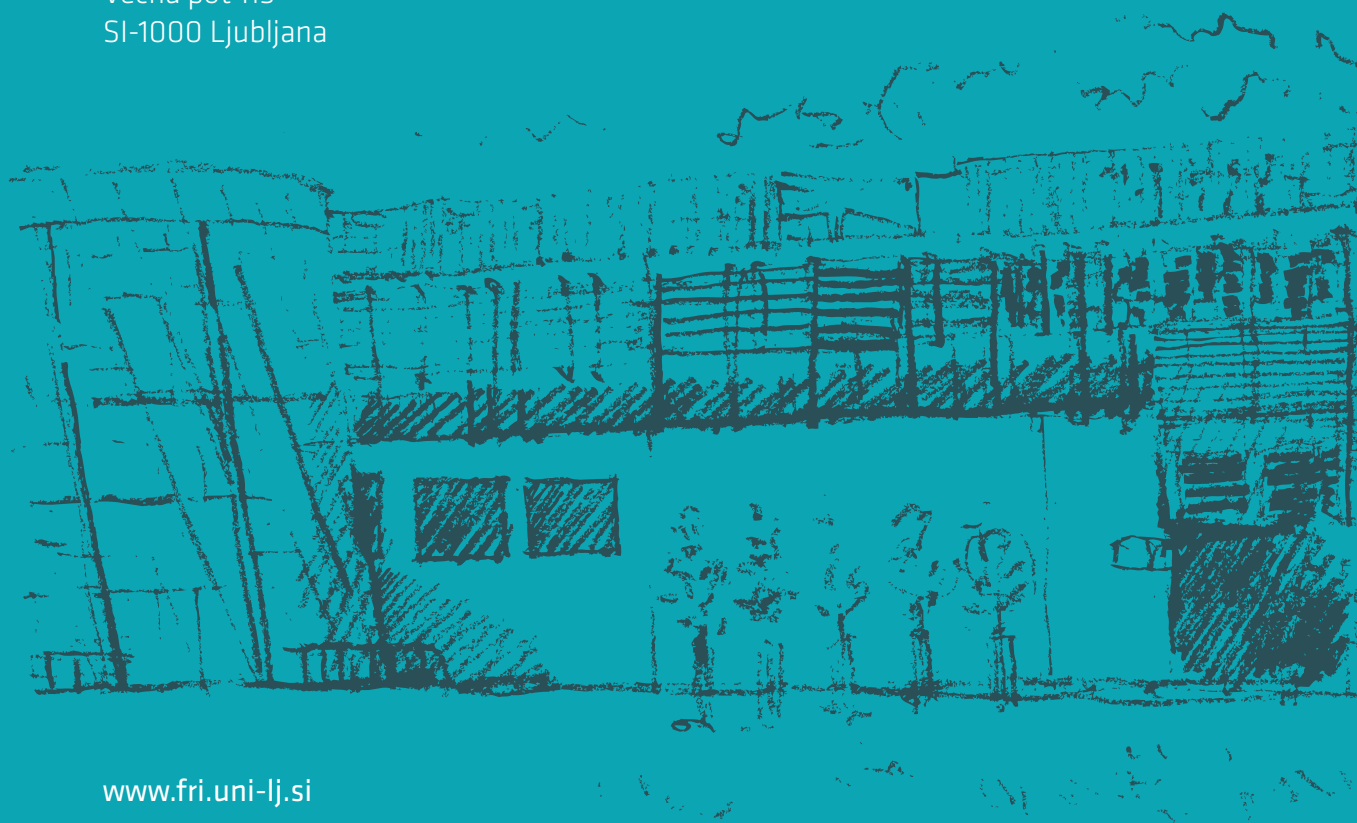
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