

Survey of Research Activities **2016**



University of Ljubljana
Faculty of Computer and Information Science



Remarks by the Dean

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. We pursue two main objectives: to lead the way in research conducted on this discipline; and to provide various computer experts with the best educational resources available.

Scientific research serves as the foundation for a strong academic community. It is also our firm belief that the real value of our research is realised not only when these new discoveries are shared with young students, in collaboration with industry and other business partners, but also when the professional and scientific aspects of computer and information science are developed further.

The faculty is home to a number of active research groups which attract funding from Slovenian and foreign industry partners as well as various national, EU and international programmes. The work they perform is very diverse and includes research on some of the most fascinating and rapidly developing disciplines of today, including artificial intelligence, machine learning, data mining, computer vision, bioinformatics, cognitive modelling, intelligent robotics, data acquisition and the integration of information systems, among others.

There are numerous opportunities for collaboration within the academic community, and research laboratories are always looking to tackle new challenges with their industry partners. In this spirit, the faculty has already ramped up cooperation with similar institutions abroad, which has served to consolidate our global position. In this regard, note should also be taken that our research-oriented doctoral study programme is conducted in English and is open to international students.

This booklet presents a selection of the best results from the research and activities we conducted in 2016. We hope that there is something of interest to everyone, and we kindly invite you to establish contact with the members of our faculty with whom you would like to collaborate.

–Prof. Bojan Orel, PhD
Dean



Among
the top 3 %
universities
in the world



1448

Doctoral Students

University of Ljubljana

3391

Researchers

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, which are designed according to the stipulations of the Bologna Process. 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.

5747

Employees

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

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

402

EU projects

299182

Citations Scopus (2011–2016)

2838

Publications

258619

Citations WoS (2011–2016)



Leading
research
institution
for CS
in Slovenia



27

Doctoral Students

118

Researchers

167

Employees

11262

Citations Scopus

7793

Citations WoS

Faculty of Computer and Information Science

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. 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.

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.

68

Ongoing Projects

EU: **6**
International: **11**
Industry: **22**
Slovenian Research Agency: **25**
Structural funds: **3**
Slovenian Ministry of Culture: **1**

102

Publications

SCI journals: **56**
1st quartile: **29**
exceptional (top 5%): **10**
conference: **46**

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:

- Technical University Graz (Austria)
- TU Wien (Austria)
- TU Berlin (Germany)
- ETH Zurich (Switzerland)
- University of Sarajevo (Bosna in Hercegovina)
- Czech Technical University in Prague (Czech Republic)
- University of Pavia (Italy)
- ESRF - The European Synchrotron (France)
- IMDEA Networks and Universidad Carlos III de Madrid (Spain)
- KU Leuven (Belgium)
- University College London (UK)
- Kyungpook National University (South Korea)
- University of New South Wales (Australia)
- Baylor College of Medicine (USA)
- Massachusetts Institute of Technology (USA)



United States of America 10

Total number of collaborating institutions

180



Other:

- Australia,
- Belgium,
- Bosnia and Herzegovina,
- Brasil,
- Canada,
- Croatia,
- Czech Republic,
- Denmark,
- Finland,
- Greece,
- Hungary,
- Ireland,
- Israel,
- Japan,
- Kosovo,
- Lithuania,
- Mexico,
- Montenegro,
- Romania,
- Russia,
- South Korea,
- Switzerland,
- Turkey.



Highlights



Visual object tracking is one of the most active research areas in computer vision and encapsulates a wide spectrum of applications, ranging from video surveillance systems to autonomous robots. Dozens of new trackers are published every year at major computer vision conferences and journals alone. However, the absence of a standardised evaluation methodology and standardised challenging datasets prohibits an accurate cross-paper comparison from being performed and restricts a clear overview being made of the advancements made in the field.

In order to solve this problem, we have performed the largest theoretical and empirical analysis of tracker performance measures. We have discovered a strong correlation between most of the frequently used performance measures. As result, we proposed a combination of two intuitive measures that allow a clear interpretation to be made. Based on this study we designed a rigorous comparative methodology as well as a methodology for the systematic construction of a testing dataset with high descriptive power. Our work has been published in the most prestigious computer science journals (IEEE TPAMI and IEEE TIP are the first and third computer vision journals based on JCR). In order to further popularise the methodology, we have launched the VOT Challenge initiative (<http://votchallenge.net>), which has involved us organising workshops at top computer vision conferences since 2013. In our last VOT2016 challenge we collected the results of 70 tracking algorithms, which surpasses the existing analysis a factor of three. We have also popularised the initiative in several invited lectures.

A New Short-Term Visual Tracker Evaluation Methodology

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As. Luka Čehovin Zajc, PhD

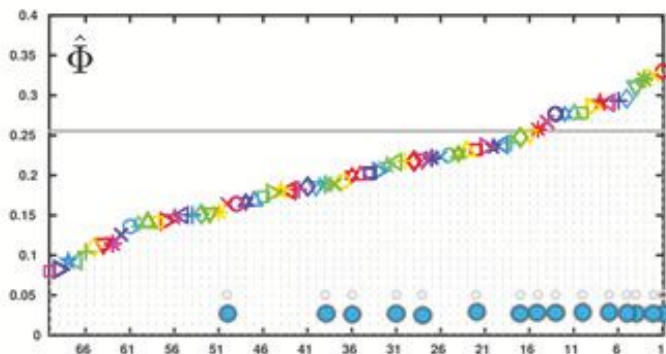
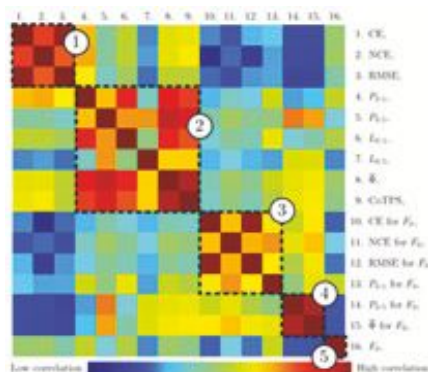
(luka.cehovin@fri.uni-lj.si)

Prof. Aleš Leonardis, PhD

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Collaborating Laboratories:

Visual Cognitive Systems Laboratory



Matej Kristan, Jiri Matas, Aleš Leonardis, Tomas Vojir, Roman Pflugfelder, Gustavo Fernandez, Georg Nebel, Fatih Porikli, Luka Čehovin (2016) A Novel Performance Evaluation Methodology for Single-Target Trackers, IEEE Transactions on Pattern Analysis and Machine Intelligence, 38 (11): 2137-2155.

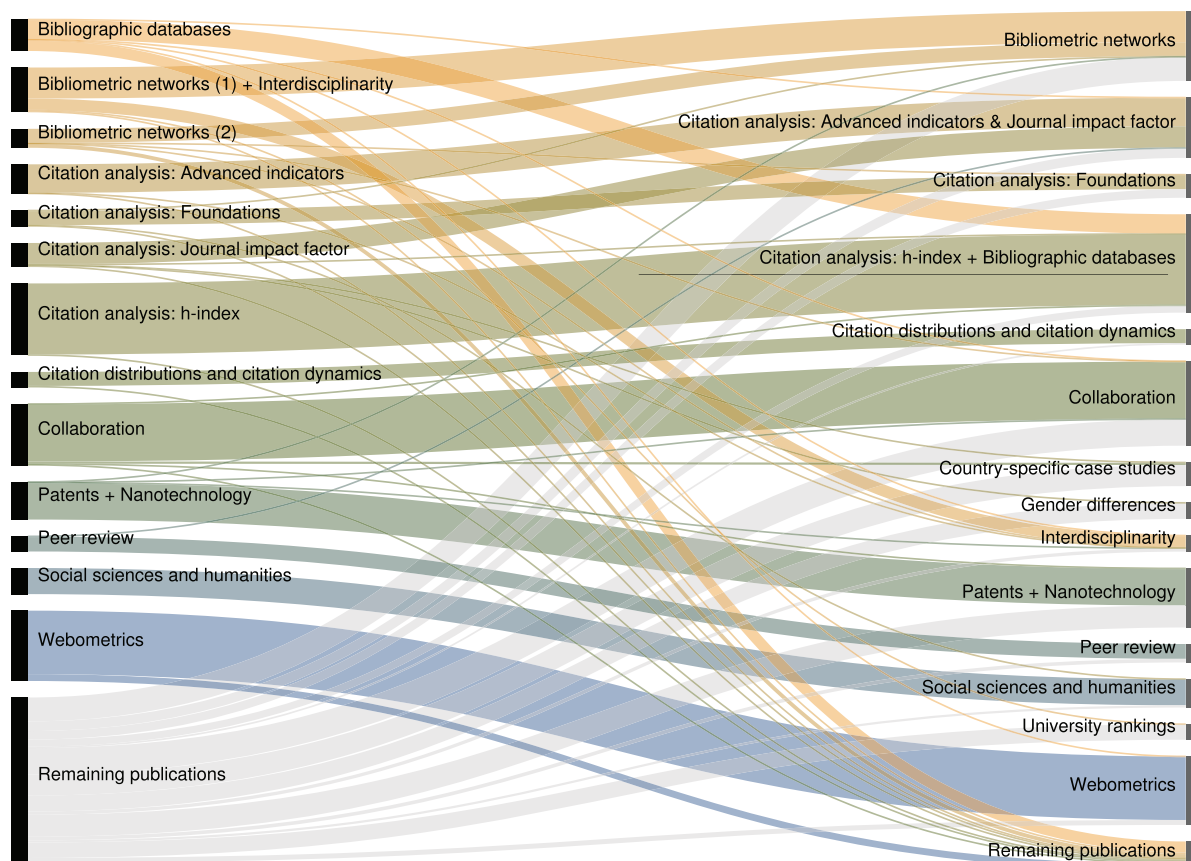
Luka Čehovin, Aleš Leonardis, Matej Kristan (2016) Visual object tracking performance measures revisited, IEEE Transactions on Image Processing, 25 (3):1261-1274.

Bibliometric studies and the evaluation of scientific literature are faced with the problem of identifying research areas or scientific fields of individual publications. Although scientific journals are classified into disciplines, there is no information about the research areas of publications themselves, while many journals are also multidisciplinary or interdisciplinary. Due to indisputable differences between different fields of science, this makes the evaluation of research performance and scientific excellence challenging. The problem is often addressed by grouping scientific publications into clusters based on direct citation relations. Citations allow large sets of publications to be clustered in an efficient way and provide a highly-detailed classification of the entire scientific literature. Methods for clustering publications are thus incorporated into many systems of scientific evaluation. However, there is no agreement on which clustering method to use, while there exist only informal notions on their performance. Together with colleagues at Leiden University, we have conducted the first systematic comparison of a large number of clustering methods for grouping scientific publications based on citations. The findings indicate that there is no “best” method. Every method considered provides a trade-off between different properties that may be considered desirable for a good clustering of publications. However, the most commonly used methods may not provide the most appropriate trade-off.

Research Areas in Scientific Literature

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Collaborating Laboratories:
Laboratory for Data Technologies



Lovro Šubelj, Nees Jan van Eck, Ludo Waltman (2016) Clustering scientific publications based on citation relations: A systematic comparison of different methods, PLoS ONE, 11(4):1-23.

Convolutional Neural Networks for Estimating Depth

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Collaborating Laboratories:
Bioinformatics Laboratory

We wish to estimate the three-dimensional structure of a scene from a pair of images. Although humans can perceive depth without difficulty, the problem of computational depth estimation remains open to this day. Our method estimates depth by searching for correspondences between objects in the left and right image; if an object that appears in the left images is found in the right image, its depth can be computed from the difference in the objects location on the two images. In the search for correspondences, we leverage a convolutional neural network, which is trained to recognize the same object from slightly different viewpoints. Our method was evaluated on three stereo datasets, on which it achieved state of the art results. The research was conducted under the supervision of Yann LeCun during my research visit at the New York University.

Jure Žbontar, Yann LeCun (2015) Computing the Stereo Matching Cost with a Convolutional Neural Network, IEEE Conference on Computer Vision and Pattern Recognition (CVPR): 1592-1599.

Jure Žbontar, Yann LeCun (2016) Stereo Matching by Training a Convolutional Neural Network to Compare Image Patches, Journal of Machine Learning Research, 17(65): 1-32.

Left input image



Right input image

Output disparity map



90 m

20 m

1.7 m

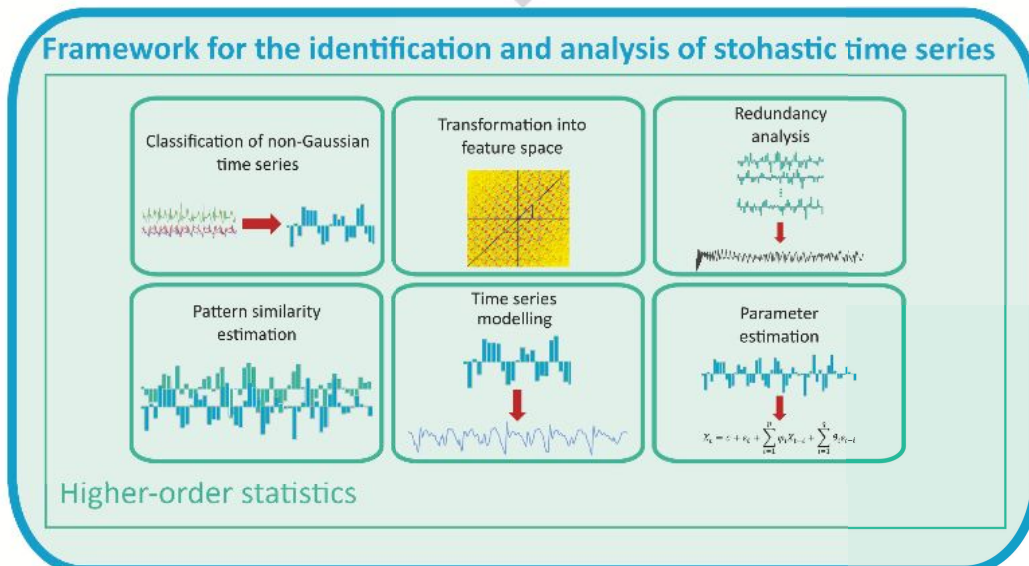
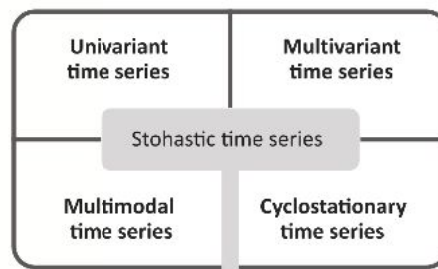
Our framework allows for the identification and analysis of stochastic time series based on statistics of higher orders. It provides insights that go beyond the interpretation of existing statistical approaches and can be used for financial analysis, business processes, analyses and trends, sensors, biometrics, etc. The proposed framework can operate over multimodal and multivariate time series, as well as over stochastic signals. The framework includes a number of components that enable the classification of time series, transforming the series into space, feature extraction, analysis, the redundancy and reduction of dimensions, the evaluation of similarities observed different patterns, the modelling of time series and the evaluation of their parameters. In practical terms, the framework is intended for the design and implementation of new approaches for identification systems, blind source separation and forecasting trends.

Framework for the Identification and Analysis of Stochastic Time Series

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Collaborating Laboratories:
 Laboratory for Integration of Information Systems

Sebastijan Šprager, Matjaž B. Jurič (2015) An efficient HOS-based gait authentication of accelerometer data, IEEE transactions on information forensics and security, 10 (7):1486-1498.



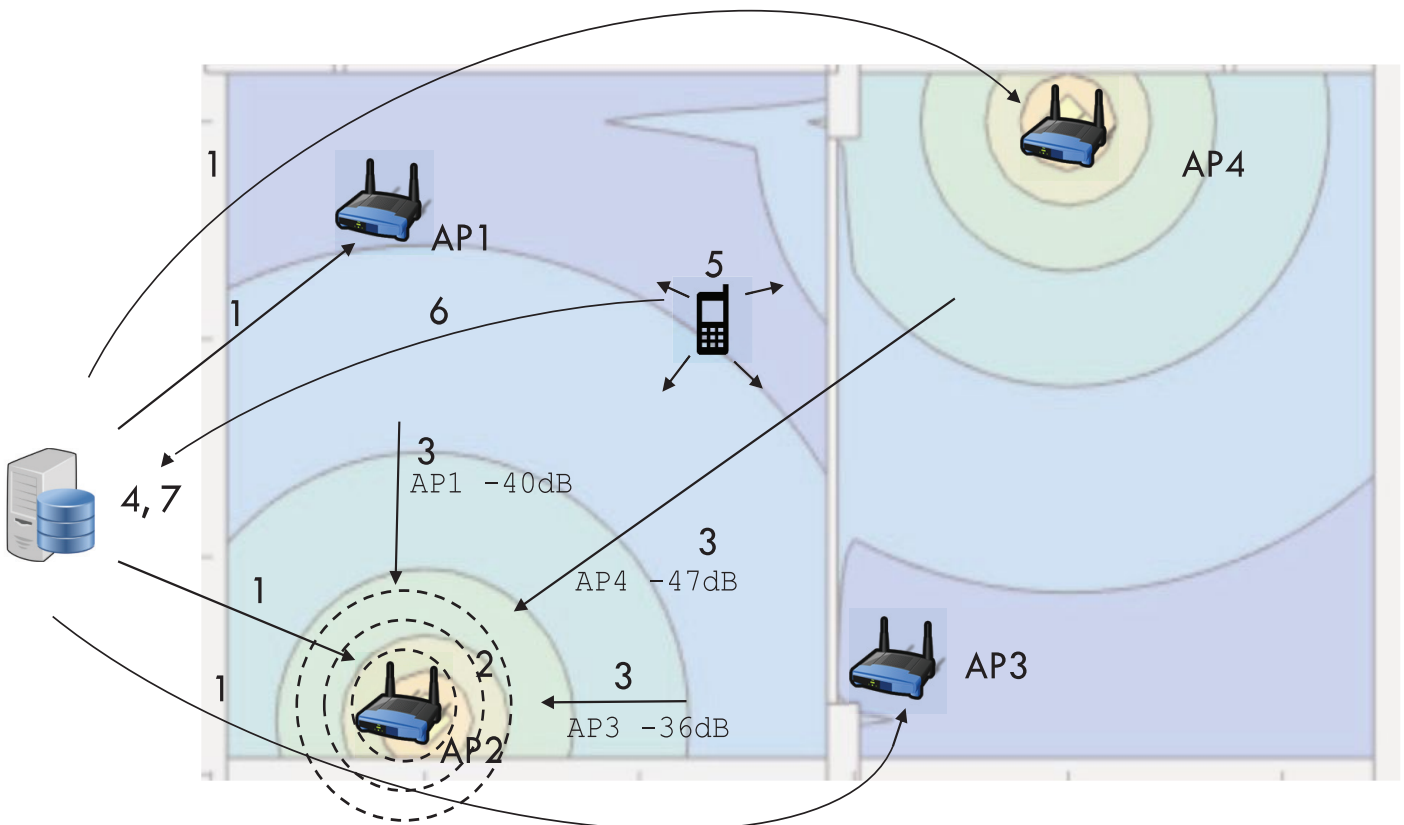
Self-Calibrating and Self-Adaptive Method for Indoor Wi-Fi Localization

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Collaborating Laboratories:
Laboratory for Integration of Information Systems

We have developed a novel method for indoor localisation which is useful for real-world deployments. Existing indoor localisation methods have several disadvantages in real-world deployments – some are static, some require costly human recalibration procedures and others require special hardware. Our method is self-calibrating and self-adaptive, is maintenance-free and is based on Wi-Fi only. The self-calibrating procedure utilises propagation models in order to infer the parameters of the space and to simulate the propagation of the signal without requiring any hardware in addition to the Wi-Fi access points. Our method is also one of the few that do not require the mobile terminal to be in access-point mode. The only input requirements are the positions of the Wi-Fi access points and the positions and properties of the walls. Testing has revealed that a usable localisation accuracy can be achieved in real-world environments solely by the proposed Wi-Fi method, which relies on simple hardware and software requirements.

Jure Tuta, Matjaž B. Jurič (2016) A Self-Adaptive Model-Based Wi-Fi Indoor Localization Method, *Sensors*, 16 (12):1-22.



Electrocardiogram ST-segment Morphology Selineation Method Using Orthogonal Transformations

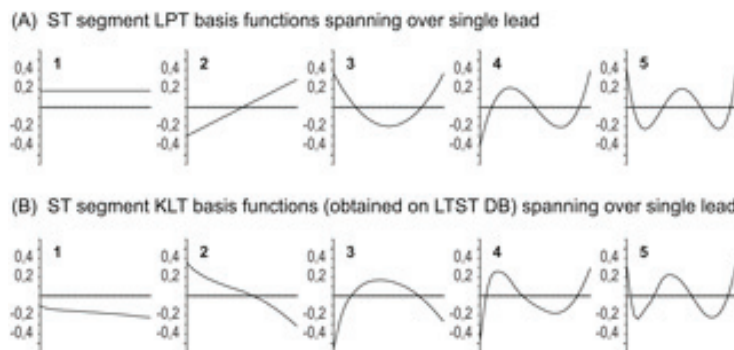
Miha Amon
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Collaborating Laboratories:
Laboratory for Biomedical Computer Systems and Imaging

Differentiation between ischaemic and non-ischaemic transient ST segment events of long-term ambulatory electrocardiograms is a persisting weakness in present ischaemia detection systems. Traditional ST segment level measuring is not a sufficiently precise technique due to the single point of measurement and high noise levels which are often present. We have developed a robust noise resistant orthogonal-transformation based delineation method which allows for the tracing of the shape of transient ST segment morphology changes from the entire ST segment in terms of diagnostic and morphologic feature-vector time series, and also allows further analysis [1]. For these purposes, we have developed a new Legendre Polynomial based Transformation (LPT) of the ST segment. Its basis functions have similar shapes to typical transient changes of ST segment morphology categories during myocardial ischaemia (level, slope and scooping), thereby providing direct insight into the types of time domain morphology changes through the LPT feature-vector space. We also generated new Karhunen-Loève Transformation (KLT) ST segment basis functions using a robust covariance matrix constructed from the ST segment pattern vectors derived from the Long-Term ST Database (LTST DB). As for the delineation of significant transient ischaemic and non-ischaemic ST segment episodes, we present a study on the representation of transient ST segment morphology categories, and an evaluation study on the classification power of the KLT- and LPT-based feature vectors to distinguish between ischaemic and non-ischaemic ST segment episodes of the LTST DB. The classification accuracy using the KLT and LPT feature vectors was 90% and 82% respectively. New sets of feature-vector time-

series for both transformations were derived for the records of the LTST DB, which is freely available on the PhysioNet website, and contributed to the LTST DB. The KLT and LPT present new possibilities for human-expert diagnostics and automated ischaemia detection.

Figure below: The derived LPT and KLT basis functions. (A) The Legendre orthogonal polynomials as the ST segment basis functions spanning over a single ECG lead. (B) The ST segment KLT basis functions obtained from the LTST DB which span over a single ECG lead. The basis functions span from Fiducial point plus 40 ms to Fiducial point plus 160 ms.



Miha Amon, Franc Jager (2016) Electrocardiogram ST-segment morphology delineation method using orthogonal transformations, PLoS one, 1(2):1-18.

Multilateration techniques have been proposed in order to verify the integrity of unprotected location claims in wireless localisation systems. A common assumption is that the adversary is equipped with only a single device, from which it transmits location spoofing signals. In this paper, we consider a more advanced model where the attacker is equipped with multiple devices and performs a geographically distributed coordinated attack on the multilateration system. The feasibility of a distributed multi-device attack is demonstrated experimentally with a self-developed attack implementation based on multiple COTS software-defined radio (SDR) devices. We launch an attack against the OpenSky Network, an air traffic surveillance system that implements a time-difference-of-arrival (TDoA) multilateration method for aircraft localisation based on ADS-B signals. Our experiments show that the timing errors for distributed spoofed signals are indistinguishable from the multilateration errors of legitimate aircraft signals, indicating that the threat of multi-device spoofing attacks is real in this system and others like it. In the second part of this work, we investigate physical-layer features that could be used to detect multi-device attacks. We show that the frequency offset and transient phase noise of the attacker's radio devices can be exploited to distinguish between a received signal that has been transmitted by a single (legitimate) transponder or by multiple (malicious) spoofing sources. On this basis, we have devised a multi-device spoofing detection system that achieves zero false positives and a false negative rate below 1%.

This paper is the result of ongoing research collaboration with armasuisse (a Swiss government agency) and ETH Zurich within the framework of OpenSky, a community-based receiver network which continuously collects air traffic surveillance data. OpenSky makes all the data it collects available to researchers. With over 350 billion ADS-B and Mode S messages collected so far, the OpenSky Network represents the largest air traffic surveillance dataset of its kind (<https://opensky-network.org/join-us>).



Daniel Moser, Patrick Leu, Vincent Lenders, Aanjhan Ranganathan, Fabio Ricciato, Srdjan Capkun (2016) Investigation of Multi-device Location Spoofing Attacks on Air Traffic Control and Possible Countermeasures, Proceedings of the 22nd Annual International Conference on Mobile Computing and Networking: 375-386.

Investigation of Multi-device Location Spoofing Attacks on Air Traffic Control and Possible Countermeasures

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Collaborating Laboratories:
Laboratory for Adaptive Systems
and Parallel Processing

Mobile computing devices, such as smartphones, are nowadays equipped with sophisticated sensors, including GPS, proximity sensors, cameras, accelerometers, which can be used to infer users' location, activity, social setting and more. As devices become increasingly intelligent, their capabilities evolve beyond inferring context and user behaviour to predicting them, and then reasoning and acting upon the predictions. In our work, we first analyse mobile sensing strategies, machine learning approaches towards context inference, and predictive modelling, to identify the best practices for anticipatory mobile computing [1]. We then devise solutions for the practical use of anticipation in the areas of human-computer interaction and mobile healthcare. We concentrate on using mobile sensing to predict human behaviour, and, in collaboration with healthcare specialists, provide guided therapies for a positive behavioural change [2]. Further, we are particularly interested in timely information delivery, and we are working towards an intelligent attention management system for mobile devices [3].

[1] Veljko Pejović, Mirco Musolesi (2015) Anticipatory mobile computing: A survey of the state of the art and research challenges, *ACM Computing Surveys*, 47(3):1-29.


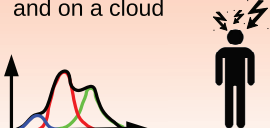


[2] Neal Lathia, Veljko Pejović, Kiran K. Rachuri, Cecilia Mascolo, Mirco Musolesi, Peter J. Rentfrow (2013) Smartphones for Large-Scale Behavior Change Interventions, *IEEE Pervasive Computing*, 12(3):66-73.

[3] Abhinav Mehrotra, Veljko Pejović, Jo Vermeulen, Robert Hendley, Mirco Musolesi (2016) My Phone and Me: Understanding User's Receptivity to Mobile Notifications, *Chi4good proceedings*: 1021-1032.

Anticipatory Mobile Computing

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Collaborating Laboratories:
Computer Structures and Systems Laboratory

Stage	Sensing	Inferring Context	Predicting Context	Intelligent Actioning
Description	Collect smartphone sensor data.	Extract features from raw data. Machine learning connects features with higher level concepts.	Build models of future events and predicted user behaviour.	Construct a decision framework based on past, current and future events.
Challenges	<ul style="list-style-type: none"> Adaptive sensing Energy efficient sampling Data storage 	<ul style="list-style-type: none"> Features and classifier selection Scalable machine learning Balance between processing on a phone and on a cloud 	<ul style="list-style-type: none"> Short- vs long-term predictions – different forecasting horizons for different purposes Incorporate data from multiple users, multiple views 	<ul style="list-style-type: none"> Learn from mistakes: reinforcement learning for improved decision making Curiosity vs accuracy: a value of a decision depends on how reliable and how proactive it is.
Example	 <p>Monitor user's voice as the day progresses. Regulate sampling rate according to resource levels and events observed.</p>	 <p>Process user's voice: create a Gaussian Mixture Model to identify user's voice and measure the stress level.</p>	 <p>Use personalised history of behaviour to predict a health hazard - a high stress level due to a busy workday.</p>	 <p>Reschedule user's meetings and their locations in order to reduce the future level of stress</p>

Extracting Qualitative Relations from Categorical Data

Collaborating Laboratories:

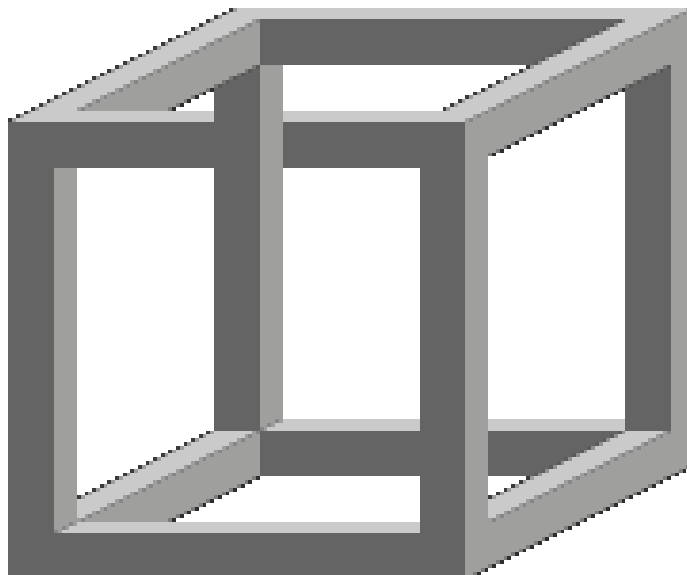
As. Jure Žabkar, PhD
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Collaborating Laboratories:

Artificial Intelligence Laboratory
Bioinformatics Laboratory

A qualitative modelling is traditionally concerned with the abstraction of numerical data. In numerical domains, partial derivatives describe the relationship between the independent and dependent variables; qualitatively, they tell us the trend for the dependent variable. In this paper, we address the problem of extracting qualitative relations in categorical domains. We generalise the notion of a partial derivative by defining the probabilistic discrete qualitative partial derivative (PDQ PD). PDQ PD is a qualitative relation between the target class and the discrete attribute; the derivative corresponds to ordering the attribute's values a_i , by $P(c|a_i)$ in a local neighbourhood for the reference point, respecting the ceteris paribus principle.

Jure Žabkar, Ivan Bratko, Janez Demšar (2016) Extracting qualitative relations from categorical data, Artificial intelligence, 239:54-69.



A well designed software engineering capstone course maximizes the benefits of students, teachers, and researchers. Apart from exposing students to state-of-the-art topics (in our case agile software development), the course enables teachers to use modern ways of teaching through practical problem solving and gives researchers opportunities to conduct empirical studies with students as subjects. In order to achieve expected benefits, extensive support tool is needed. Existing agile tools are either too simple, providing only limited functionality, or too cumbersome and difficult to use. Additionally, they are difficult to adapt to the specific needs of teaching process. In order to tackle these limitations, an in-house tool was developed.

With regard to students, the tool supports all standard activities performed by Scrum team members, such as estimating user stories, preparing Sprint plans, maintaining Sprint Backlogs, assigning tasks, conducting Daily Scrum meetings, recording the amounts of work spent and work remaining, and monitoring progress through different charts.

With regard to teachers, the tool provides functionality that is typical for the Product Owner role, as well as specific functionality required for monitoring and directing student learning. Student teams that do perform the required activities regularly or in due time are automatically reminded via e-mail. The tool also alleviates the burden of administrative work on the part of teaching staff by automating the processes of forming student teams, allocating teams to laboratory classes, and preparing team assignments.

A Computerized Support Tool for Conducting a Scrum-Based Software Engineering Capstone Course

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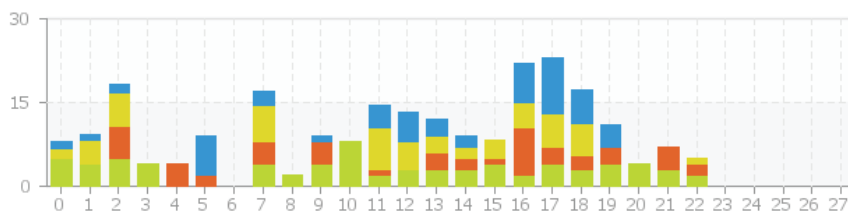
Collaborating Laboratories:
Software Engineering Laboratory

With regard to researchers, the course primarily serves a role in studying the abilities of agile estimating and planning; therefore, the tool is used for collecting data on effort estimates and the amounts of work actually spent. Different effort estimation techniques are supported that can be compared to each other.

In the figure below an example of team involvement chart is shown. The upper part represents the amount of work spent by each team member on each day of the Sprint. In the lower part, the contribution of each member is shown in tabular and graphical form.

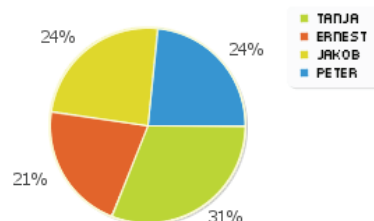
Sprint 2

Sprint duration: 15.04.2014 - 12.05.2014



Work input by Team members in Sprint 2:

Username	Planned	Work	Done
Tanja	73 h	73 h	100 %
Ernest	49.7 h	49.7 h	100 %
Jakob	56.8 h	56.8 h	100 %
Peter	55.2 h	55.2 h	100 %
SUM	234.7 h	234.7 h	100 %





Project NAPOJ – we were able to establish an active community of CS teachers in Slovenia, who prepared and are still preparing new resources and class-ready materials for Computer Science in gymnasium. In the end of 2016 there were more than 80 CS teachers already participating in the community, which is about half of all CS teachers (at gymnasium) in Slovenia. Collaborators on the project are also Matija Lokar from UL FMF and Gregor Anželj from Gimnazija Bežigrad. The project is also supported by The Ministry of Education, Science and Sport, and National Education Institute Slovenia.

NAPOJ – Building an Active Community of CS Teachers

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Collaborating Laboratories:
Laboratory for Ubiquitous Systems





An efficient representation of the motor system is vital for control of the robot and its ability to learn new skills. Despite the advances made in robot skill learning, the motor memory architecture remains limited to predefined tasks and pre-specified embodiments. We propose a new motor memory architecture that enables information sharing of different skills, on-line learning and off-line memory consolidation. We have developed an algorithm for learning and the consolidation of motor memory and have studied the space complexity of the representation in the experiments with humanoid robot Nao. We propose that the motor memory be integrated with the sensor data into a common sensorimotor memory.

Jure Žabkar, Aleš Leonardis (2016) Motor memory: representation, learning and consolidation, *Biologically inspired cognitive architectures*, 16:64-74.

Motor Memory: Representation, Learning and Consolidation

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Collaborating Laboratories:

Artificial Intelligence Laboratory
Visual Cognitive Systems Laboratory

Light Fountain: a Virtually Enhanced Stone Sculpture

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Collaborating Laboratories:
Computer Vision Laboratory



The article describes the making of an art piece combining a stone sculpture and virtual water. The motivation for this art piece was to enrich the usual static format of a stone sculpture with a dynamic dimension. The 3D surface of the stone sculpture, specially carved by one of the authors, is during an exhibition continuously captured by the Kinect sensor. The dynamic dimension is attained with virtual water droplets running over the stone surface which behave as real water droplets. Each water drop out of many thousands, which are introduced into the installation as evenly distributed rain drops falling over the sculpture, are simulated individually and run over the stone surface following the largest slope.

These simulated water drops are projected with a video projector as light points on the surface of the sculpture. Since the original intention of this art piece was to virtually enhance a stone sculpture and to observe the simulated flow of water, it was somewhat surprising that most visitors also wanted to touch the sculpture and to interact with the moving light points. By reaching into the projection cone of the installation, the public quickly realised that the rain drops instantly adapted to the changing shape of the rained-on surface. Visitors were henceforth encouraged to touch the sculpture and it seems that this merging of haptic and visual experience is an additional attraction of the art piece.

Franc Solina, Blaž Meden (2016) Light fountain - a virtually enhanced stone sculpture, Digital creativity, 1-14.

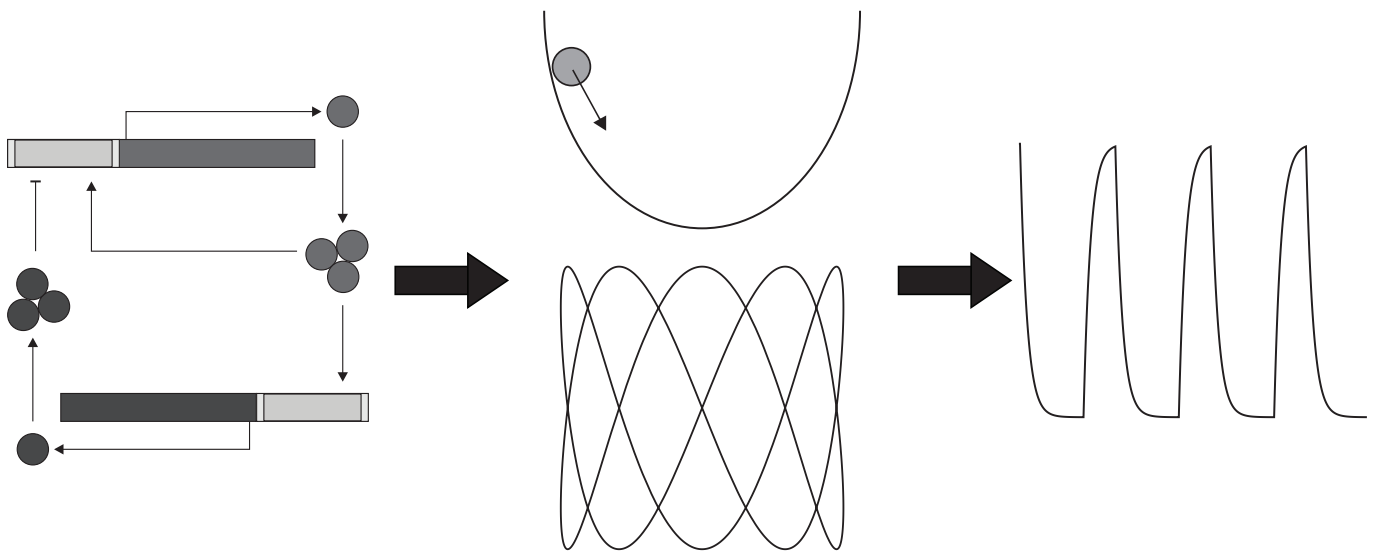
Computational analysis of biological systems is important in the context of both natural and synthetic biological systems. In-silico investigation of different synthetic designs is able to guide the implementation of biological systems with desired functionality. Analysis of natural systems is on the other hand important for understanding of underlying mechanisms that regulate several cellular responses and may lead to a better understanding of complex diseases and finding novel possibilities for their treatment. Our group is working extensively on the establishment of novel computational approaches for modelling, design and analysis of biological systems that lead to efficient use of available computational resources, higher accuracy of obtained results and increased complexity of targeted systems.

Anastasiiia Vasylychenkova, Miha Mraz, Nikolaj Zimic, Miha Moškon (2016) Classical mechanics approach applied to analysis of genetic, IEEE/ACM Trans Computational Biology and Bioinformatics: 1-8.

Computational Modelling, Design and Analysis of Biological Systems

Prof. Miha Mraz, PhD
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Collaborating Laboratories:
Computer Structures and Systems Laboratory



Orange, Data Mining Fruitful & Fun

Benevolent Dictators:

Assoc. Prof. Janez Demšar, PhD
(janez.demsar@fri.uni-lj.si)

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

Collaborating Laboratories:

Bioinformatics Laboratory

Orange is an open source data visualisation and data analysis framework for novices and experts. It features construction of data mining work flows through visual programming and a large toolbox of methods for data pre-processing, visualisation and machine learning. Developed in Biolab, it has been short-listed in virtually every top-10 open source data mining framework.

In collaboration with Soleil (Paris, France), Elettra Sincrotrone (Trieste, Italy) we are extending Orange with components for the analysis of hyper-spectral data. Among the many tools available for this purpose, Orange stands out with its intuitiveness and ease of use. In a separate project, our colleagues from Elettra Sincrotrone and European Synchrotron Radiation Facility (Grenoble, Paris) are repurposing Orange as a tool for the simulation of x-rays in synchrotron experiments. Although only two years old, the project has already gained significant traction in the community.

Figure below: Orange workflow for the prediction of cell composition with the absorbed infrared light spectra measured at different points in a cell. The dotted lines denote misclassifications.



orange

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 communal creative space for knowledge transfer and the flow of ideas between established researchers and students, who are still trying to find what they want to research.

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 modeling and reinforcement learning, and design of computer systems, ranging from high performance computing to on-chip designs. We are focused on problems where the lack of theoretical knowledge prevents exact solutions and where special software and hardware are demanded for efficient processing. 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 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.

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

Laboratory for Algorithms and Data Structures

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

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 (<http://orange.biolab.si>), a comprehensive suite that joins machine learning and visual programming, and collaborates in development of cool interactive web-based data exploration platforms like dictyExpress (<http://dictyexpress.org>).

Prof. Blaž Zupan, PhD
blaz.zupan@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 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 understanding and music information retrieval (audio understanding, organization of music archives), interactive 3D visualization (medical imaging, games, VR/AR), and e-Learning (learning for people with disabilities, gamification). We have extensive experience in developing software solutions for desktop, mobile and cloud platforms and are active in the development of visualizations, interactive learning systems, and didactic games.

Assist. Prof. Matija Marolt, PhD
matija.marolt@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
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Laboratory for Integration of Information Systems

The laboratory has established strong foundation in service computing, cloud computing, digital transformation and conducts research in the field of the integration and interoperability of applications, cloud-native architectures, microservices and APIs, 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 novel localization, authentication and gait analysis algorithms.

Prof. Matjaž Branko Jurič, PhD
matjaz.juric@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, evaluating the reliability of single models' predictions, 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, heuristic search methods in clickstream mining, multi-view learning, mining of heterogeneous networks and e-learning.

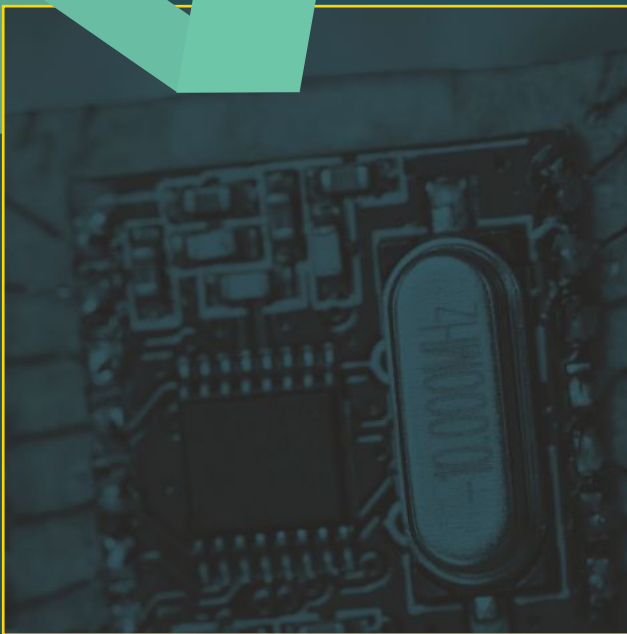
Prof. Igor Kononenko, PhD
igor.kononenko@fri.uni-lj.si

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.jurisc@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.

Prof. Gašper Fijavž, PhD
gasper.fijavz@fri.uni-lj.si

Computer Communications

Our research is focused on communication networks and protocols, cloud architectures and services, cloud and network security, virtualization, ICT sustainability, computer supported learning systems and the use of agile methodologies. We have researched the orchestration of complex virtual environments, container orchestration, examined SDN and NFV and their use in cloud environments, and developed our own virtual cloud laboratory. Our latest project focuses on carrier-grade cloud solutions for large telco providers.

Assoc. Prof. Mojca Ciglaric, PhD
mojca.ciglaric@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 Structures and Systems Laboratory

The laboratory is focused on the computational methods for modelling, simulation and analysis of fundamentally different system families. We are interested in computational approaches in systems and synthetic biology, the analysis of coordinated behaviour in biological systems, the design of quantum-dot cellular automata processing structures, and the understanding of human behaviour through the analysis of mobile sensing data. The laboratory therefore consists of four groups, the Computational Biology Group, the Collective Behaviour Group, the Quantum-dot Cellular Automata group and the Mobile Computing Group.

Prof. Nikolaj Zimic, PhD
nikolaj.zimic@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

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

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

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 three areas: unstructured text handling, data deduplication and on-line streaming data processing. The work performed also overlaps with the area of Computer Science Education.

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

Visual Cognitive Systems Laboratory

The laboratory is involved in basic and applied research of visually enabled intelligent systems. 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 the development of computer vision solutions for smart mobile devices. Our experience has been accumulated in collaboration with a variety of research partners in a number of the EU, national and industry funded projects which address these research issues.

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



**WE CAN ONLY SEE
A SHORT DISTANCE
AHEAD, BUT WE
CAN SEE PLENTY
THERE THAT NEEDS
TO BE DONE.**

– Alan Turing

Research Projects

Research work at the Faculty is carried out in 19 different laboratories. It is made through various projects funded by the European Commission, the Slovenian Research Agency, industrial partners and other funding agencies.

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 • AGROIT – Increasing Farming Efficiency Through an AgroIT Platform Based on Open Standards • SALUS – Security and Interoperability in Next Generation PPDR Communication Infrastructures • MONROE RICERCANDO – Rapid Interpretation and Cross-Experiment Root-Cause Analysis in Network Data with Orange: Ricercando

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 • Upgrade of Corpuses Gigafida, Kres, ccGigafida and ccKress

Industrial projects

Additionally to these projects the Faculty is participating on more than 20 projects funded by different institutions and industry partners, including: University College London • Autoscan GmbH • Slovenian Ministry of the Environment and Spatial Planning • DRI Investment Management Ltd. • CHS Ltd. • Slovenian Environment Agency • Armasuisse Science and Technology • Slovenian Ministry of Infrastructure • Lek d. d. • Marand Ltd • MARG Ltd. • Plinovodi Ltd. • LangTech Sàrl • Medivir Aktiebolag • NERVteht Ltd. • Garex Adria Ltd. • Slovenian Centre of Excellence for Space Sciences and Technologies • U-blox • Armasuisse, and others.

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

Metabolic and Inborn Factors of Reproductive Health, Birth • Artificial Intelligence and Intelligent Systems • Computer Vision • Synergy of the Technological Systems and Processes • Pervasive Computing • Parallel and Distributed Systems • Conquering the Curse of Dimensionality by Using Background Knowledge • Posttranscriptional Regulatory Networks in Neurodegenerative Diseases • Model for Domain-Specific Trend Prediction Based on Semantic Enrichment of Unstructured Patterns Epidemiology and Biodiversity Studies of Plant Pathogens • Maintenance of Large Databases Based on Visual Information Using Incremental Learning • Designed Cellular Logic Circuits • Trust Management and Reputation Systems • Data Fusion in Systems Biology of a Social Amoeba Dictyostelium • Epidemiology and Biodiversity Studies of Plant Pathogens • Advancement of Computationally Intensive Methods for Efficient Modern General-Purpose Statistical Analysis and Inference • Signal and Information Processing Systems in Sensor Networks • Centre for Language Resources and Technologies of University of Ljubljana • Automatic Detection and Localization of Ischemia by the use of Data Mining Algorithms • Intelligent Computer Techniques for Improving Medical Detection, Analysis and Explanation of Human Cognition and Behaviour Disorders • Open Information Extraction for Slovene and Serbian Languages • Intelligent Agile Method Framework (iAMF) • Representations of Quantum Groups via Computational Linear Algebra • Algebra, Discrete Mathematics, Probability and Game Theory • Graph Optimisation and Big Data

BioPharm.SI: Next Generation of Biologics

Project Type:

Structural Funds Project

Project Coordinator:

Centre of Excellence for Biosensors,
Instrumentation and Process Control

Principal Investigator at FRI:

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

Collaborating Laboratories:

Bioinformatics Laboratory

Biologics are one of 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 Slovenian company Lek and by 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, 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.

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 heterogenous 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

EkoSMART: A Smartcity Ecosystem

Project Type:

Structural Funds Project

Project Coordinator:

Marand Ltd

Principal Investigator at FRI:

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

Collaborating Laboratories:

Laboratory for Data Technologies
Laboratory for Ubiquitous Systems
Artificial Intelligence Laboratory
Computer Communications Laboratory
Laboratory for Computer Graphics and Multimedia
Laboratory for Integration of Information Systems

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.



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)

Collaborating Laboratories:

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, and some companies have already started introducing this concept into their production facilities. 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. Taking into account the Smart Specialisation Strategy of Slovenia prepared by SVRK and the priorities of the Factories of the Future roadmap under Horizon 2020 prepared by EFFRA, four areas were identified in which decisive breakthroughs could be achieved in Slovenia in the near future: control technologies, tooling, robotics, and photonics. This means that in GOSTOP we combined the majority of the horizontal fields pinpointed by the Smart Specialisation Strategy of Slovenia documents for the Factories of the Future area. In all these fields, the most promising research topics of interest to Slovene industry were determined and, where the knowledge required in the Slovene research organisations existed, synergies were identified between them. Several value chains in the programme were combined, within the scope of which new products will be developed in the near future. In this way, the competitiveness of Slovenian industry will be improved significantly. On the one hand, GOSTOP includes the development of new products and breakthrough technologies by agile SMEs. On the other hand, however, the overall Factories of the Future concept will be developed, thereby leading to integrated systems to be used by large Slovenian companies in order to optimise their production and develop new products with high added value. An example of the kind of product included in GOSTOP would be the vision of a turnkey factory. The success of GOSTOP will contribute to raising the added value and export volume of the participating companies and Slovenian industry as a whole.

The popularity of mobile devices like smartphones and tablets, combined with the always everywhere Internet connectivity provided by mobile broadband (MBB) networks, has radically changed the way most people live and work. Due to the increasing importance of MBB network infrastructures in society and economy, there is nowadays a compelling need to gather objective information about their performances. Such information is very valuable for many parties including operators, regulators and policy makers, consumers and society at large, businesses whose services depend on MBB networks, researchers and innovators. Within this motivating framework, 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>). The MONROE platform supports several independent experiments and smaller projects, including RICERCANDO (Rapid Interpretation and Cross-Experiment Root-Cause Analysis in Network Data with Orange), an independent project run at the Faculty of Computer and Information Science of the University of Ljubljana. The goal of the RICERCANDO project is to develop an advanced toolbox for mining MONROE data to support integrative exploration, visualization and interpretation of data and meta-data across multiple experiments. The integration of these data with advanced data mining and interactive data exploration features will support the human experts in the process of detecting and understanding the root-cause of the network problems and performance degradations. A distinguishing feature

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

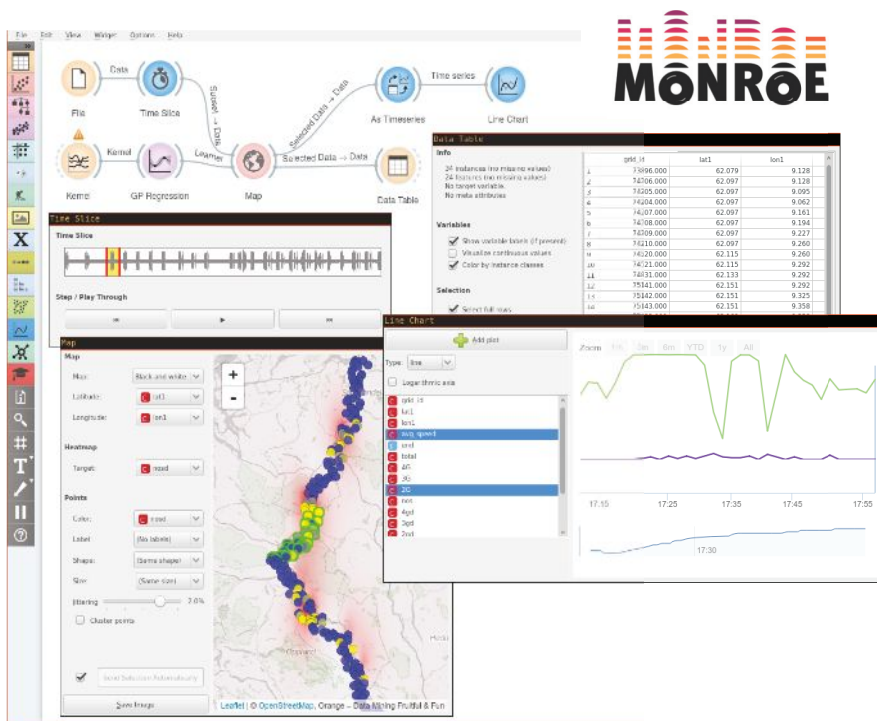
Project Type:
EU project

Project Coordinator:
Simula Research Laboratory, Norway

Principal Investigator at FRI:
Assoc. Prof. Fabio Ricciato, PhD
(fabio.ricciato@fri.uni-lj.si)

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

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).





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

Project Type:
EU project

Project Coordinator:
Universiteit van Amsterdam, Netherlands

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

Collaborating Laboratories:
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 virtualised, 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.

SALUS, Security and Interoperability in Next Generation PPDR Communication Infrastructures

Project Type:
EU project

Project Coordinator:
Instituto de Telecomunicacoes, Portugal

Principal Investigator at FRI:
Prof. Denis Trček, PhD
(denis.trcek@fri.uni-lj.si)
as. David Jelenc, PhD
(david.jelenc@fri.uni-lj.si)

Collaborating Laboratories:
Laboratory of e-media



Public Protection and Disaster Relief (PPDR) agencies in EC member states are relying on digital Private Mobile Radio (PMR) networks for mission-critical voice and data communication. These networks are highly resilient and properly dimensioned to cope with crisis and emergency handling, and are well protected against monitoring and intrusion by means of encryption, authentication and integrity. The two main standards for digital PMR networks in Europe are TETRA (TErrestrial Trunked RAdio) and TETRAPOL. The majority of these networks are based on mature technology, requiring old-fashion synchronous links (backbone), and using proprietary hardware solutions that eventually become obsolete. These networks also provide limited inter-technology coverage providing very ineffective management of emergency events, both at the national level and in cross-border regions. The main goal of SALUS is to design, implement and evaluate a next generation com-

munication network for Public Protection and Disaster Relief (PPDR) agencies, supported by network operators and industry, which will provide security, privacy, seamless mobility, QoS and reliability support for mission-critical PMR voice and broadband data services. The project covers the full techno-economic scope regarding development and deployment of the next generation PPDR networks by focusing on the integration with / migration to 4G wireless communications developments targeting three critical scenarios 1) city security, 2) disaster recovery, and 3) temporary protection. Salus will address key research challenges such as enterprise architectures, economic and business analysis, and a number of technical aspects concerning QoS, resilience, inter-systems handover (secure, seamless and fast), enhanced security, privacy mechanisms in heterogeneous network infrastructure, and multicast broadband PPDR services.



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

Project Type:

EU project

Project Coordinator:

Enel Distribuzione s.p.a.

Principal Investigator at FRI:

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

Collaborating Laboratories:

Laboratory for Integration of Information Systems

The four year project, launched in early 2015, is part-funded by the European Commission's Horizon 2020 research programme, with the aim of addressing 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, in the process boosting jobs and growth in Europe. Besides UL, 17 partners from 10 EU countries participates in the project, including four of the continent's leading Distribution System Operators: Italian's Enel, French company ERDEF, Swedish company Vattenfall and Spain's Endesa Distribucion.

CREA - Network of Summer Academies for the Improvement of Entrepreneurship in Innovative Sectors

Project Type:
EU project

Project Coordinator:
Politecnico di Milano (POLIMI), Italy

Principal Investigator at FRI:
Andrej Brodnik, PhD
(andrej.brodnik@fri.uni-lj.si)
Assist. Prof. Matija Marolt
(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 able to produce specific structural changes and arrangements in the European entrepreneurial base, to influence the future paths of social change and innovation to a large extent. CREA project wants to validate a new European Model of Summer Academy for students who want to develop business ideas focus on creativity and ICT and able to explore innovation in advanced fields: new products for new markets, social innovation, meaning drive innovation in old sectors, service innovation, technology driven innovation etc. CREA will test 2 edition of Summer Academy simultaneously organized in 6 European Cities (Milan, Stuttgart, Ljubljana, Newcastle, Tallin, Utrecht), which will end with an international event (CREA ICT Business Idea Contest) for the presentation of results to international investors and the awarding of a prize. The project includes training courses, mentoring activities and the incubation program for start up companies that will be able to use the opportunities of ICT and Creativity to propose new business model with a European vision.

The general objectives of CREA project are: (a) To create European wide system of Summer Academies for university and last year high school students entirely focused on ICT entrepreneurship; (b) To create a model of Summer Academy action oriented with a strong focus on ICT and entrepreneurial skills development and a rich offer of mentoring, support for business planning, matchmaking opportunities and generation of ICT related business idea; (c) To stimulate the development of new start up business ideas boosting on ICT and creativity; (d) To complement and extend similar existing Summer Academy program while strongly focusing on ICT and creativity entrepreneurship; (e) To organize and promote ICT Business Idea Contests.

Visual Assistant

Project Type:

Industrial Project

Principal Investigator at FRI:

Assist. Prof. Tomaž Dobravec, PhD
(tomaz.dobravec@fri.uni-lj.si)

Collaborating Laboratories:

Laboratory for Algorithms and Data Structures

The aim of the project is to explore the limitations and to develop new techniques for the Visual assistant core methods. The Visual Assistant manipulates the perceptual components of visual information on smart devices tailored to the eye condition of the visually impaired person to improve functional vision even for people with severely impaired sight. Better understanding of the fundamental perception components ultimately leads to a visually impaired user's ability to decipher the shapes of objects enabling easier comprehension of dispersed and non-continuous visual information. Our method analyses and dissects images into perception layers and by enhancing shape related clues in each of them separately and finally blends them together to recreate a primal impression of the scene to influence both the presentation and perception of visual information. Modified visual information on a smartphone, tablet or TV becomes more accessible for the visually impaired and doing so without any changes to the underlying presentation device or installed programs. This latter feature makes the mobile visual assistant an ideal add on for any smart or presentation device currently on the market.

visual assistant

sistem za prilagajanje vidnih informacij za slabovidne



The goal of the project is to research novel positioning algorithms by leveraging radio signals from the mobile cellular network, with a special focus on 4G/LTE signals. The research will involve a mixture of theoretical and experimental activities, with extensive use of real measurement data and field testing. This project is sponsored by the R&D branch of u-blox, a market leader in the production of wireless and positioning integrated circuits and modules (www.u-blox.com).

Cellular Wireless Positioning - uBlox

Project Type:

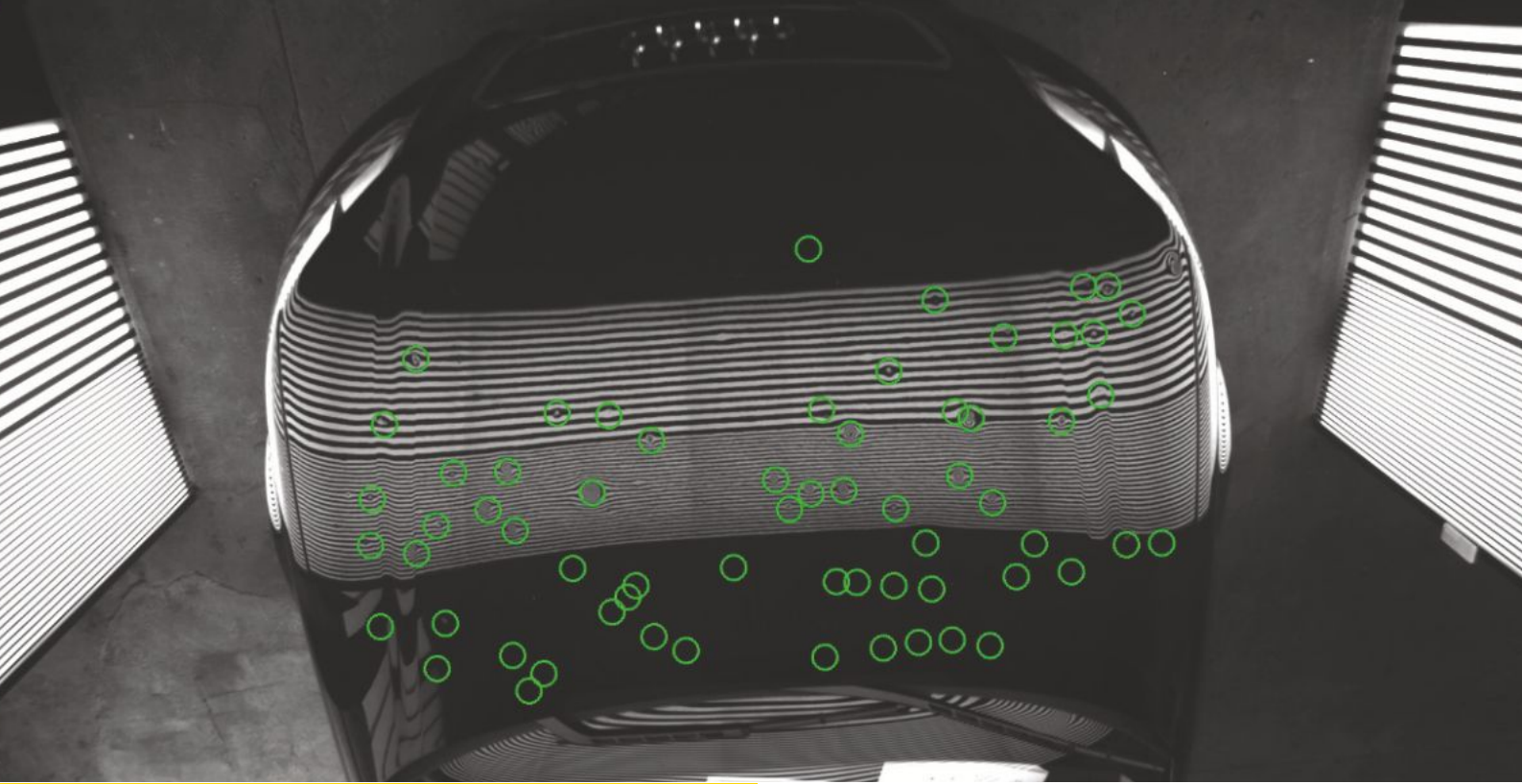
Industrial Project

Principal Investigator at FRI:

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Collaborating Laboratories:

Laboratory for Adaptive Systems and
Parallel Processing



Autoscan

Project Type:

Industrial Project

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Collaborating Laboratories:

Visual Cognitive Systems Laboratory

The purpose of the project is to build an automated system for inspecting damage on cars. For this purpose, a rich sensory system of proximity sensors and cameras is to be designed and advanced computer vision solutions are to be developed in order to detect the various parts of the cars, including the glass, all the defects and to position them in the car model. 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.

Project “Model for Domain-Specific Trend Prediction based on Semantic Enrichment of Unstructured Patterns” deals with the possibility of forecasting trends based on the semantic enrichment of unstructured patterns. With the expansion of the Internet new sources of mostly unstructured data constantly arise. The results of trend forecasting based on simple searches in search engines are surprising and show that the potential is huge. Additionally, a significant progress in the field of analysis of large amounts of unstructured data has also contributed to the successful extraction of formal knowledge from this data. However, due to abundance of unstructured data and the absence of adequate methodological support, pattern recognition and trend forecasting is still too demanding of both time and financial terms. Currently, time advances in cloud computing, processing large amounts of data and large number of transactions allows the development of such solutions without building costly data centers. Thus we believe that it is possible to develop an automated model that will not only recognize patterns, but will also be able to use them to forecast trends within a particular domain by leveraging methods of data acquisition, analysis and data sampling from heterogeneous data sources. Our approach exploits the existing models for obtaining formal knowledge, introduces an innovative consensus-based decision model for pattern recognition using methods of artificial intelligence and an innovative mathematical model for trend forecasting. The proposed common solution can be adapted to particular domains, which can provide greater relevancy and accuracy of forecasts in shorter time with fewer resources.

Model for Domain-Specific Trend Prediction Based on Semantic Enrichment of Unstructured Patterns

Project Type:

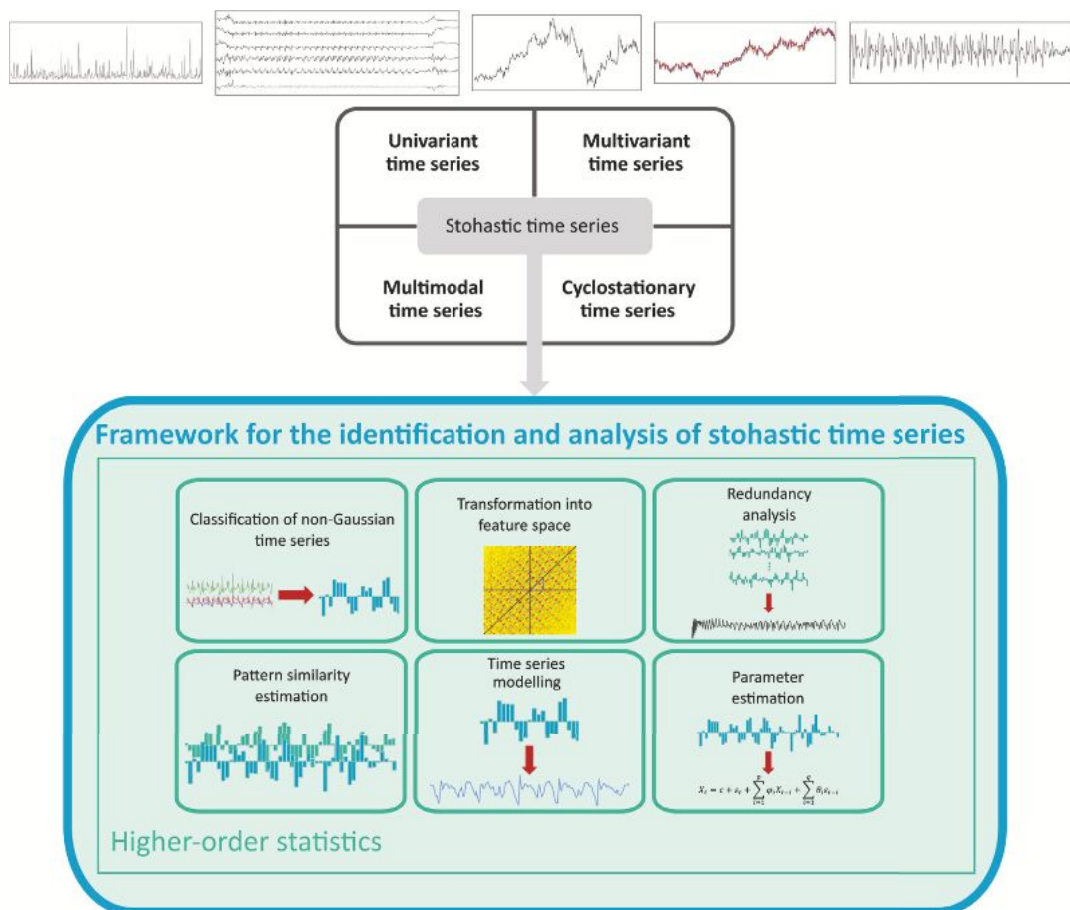
Basic Research Project funded by the Slovenian Research Agency

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Collaborating Laboratories:

Laboratory for Integration of Information Systems



Advancement of Computationally Intensive Methods for Efficient Modern General-Purpose Statistical Analysis and Inference

Project Type:

Applied Research Project funded by the Slovenian Research Agency and industry partner

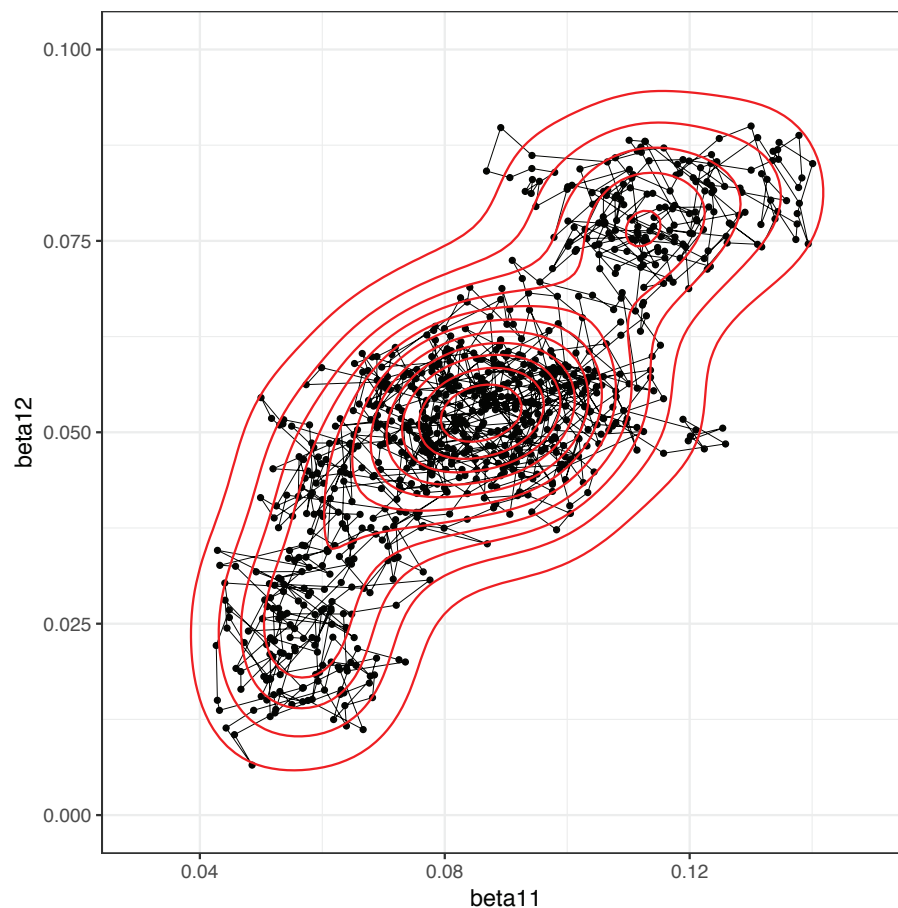
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Collaborating Laboratories:

Laboratory for Cognitive Modelling

Efficient statistical computation has been highlighted as one of the top open practical problems in statistics. The main objective of this applied project is to research efficient general-purpose parallel computation and implement it as part of existing tools or a standalone tool for Bayesian inference. In the early phases, we are working on parallelizing specific models. We have demonstrated a 100x speedup for regularized linear and multinomial logistic Bayesian regression at a low hardware cost. These more efficient methods are already being applied to two problems at a scale that was not accessible before: pollution source attribution and landscape classification. We plan to achieve our main objective by automatically parallelizing the most expensive parts of general-purpose Markov Chain Monte Carlo computation algorithms using graphical processing units. In collaboration with our project partners, we will apply our methods to relevant research problems in Geography, Neuroscience, Sports, and Industry.



Gigafida is a reference corpus of Slovene language containing Slovene texts from daily newspapers, magazines, all sorts of books, web pages, parliamentary speeches transcripts etc., all together around 1.2 billion words in 40,000 documents. It is a basis for balanced corpus Kres, and freely available corpora ccGigaFida and ccKres. Currently these corpora contain documents created until 2012. More information about the corpora is available at <http://www.slovenscina.eu/korpusi/>

The project to upgrade these corpora has three goals: collecting new materials, machine processing of new and existing documents, and public availability of upgraded corpora, their distribution and public dissemination. The collection of new materials is going to focus on currently underrepresented texts (like textbooks and other primary and secondary school materials), news portals and daily newspapers. The aim is to increase the Gigafida corpus to 1.5 billion words. Machine processing shall automatically tag all the documents in a uniform way and store them in a standardised format. The documents will be deduplicated. The updated corpuses will be publicly available through concordancers in CLARIN infrastructure and presented to general public and professional community.

Upgrade of Corpuses Gigafida, Kres, ccGigafida and ccKress

Project Type:

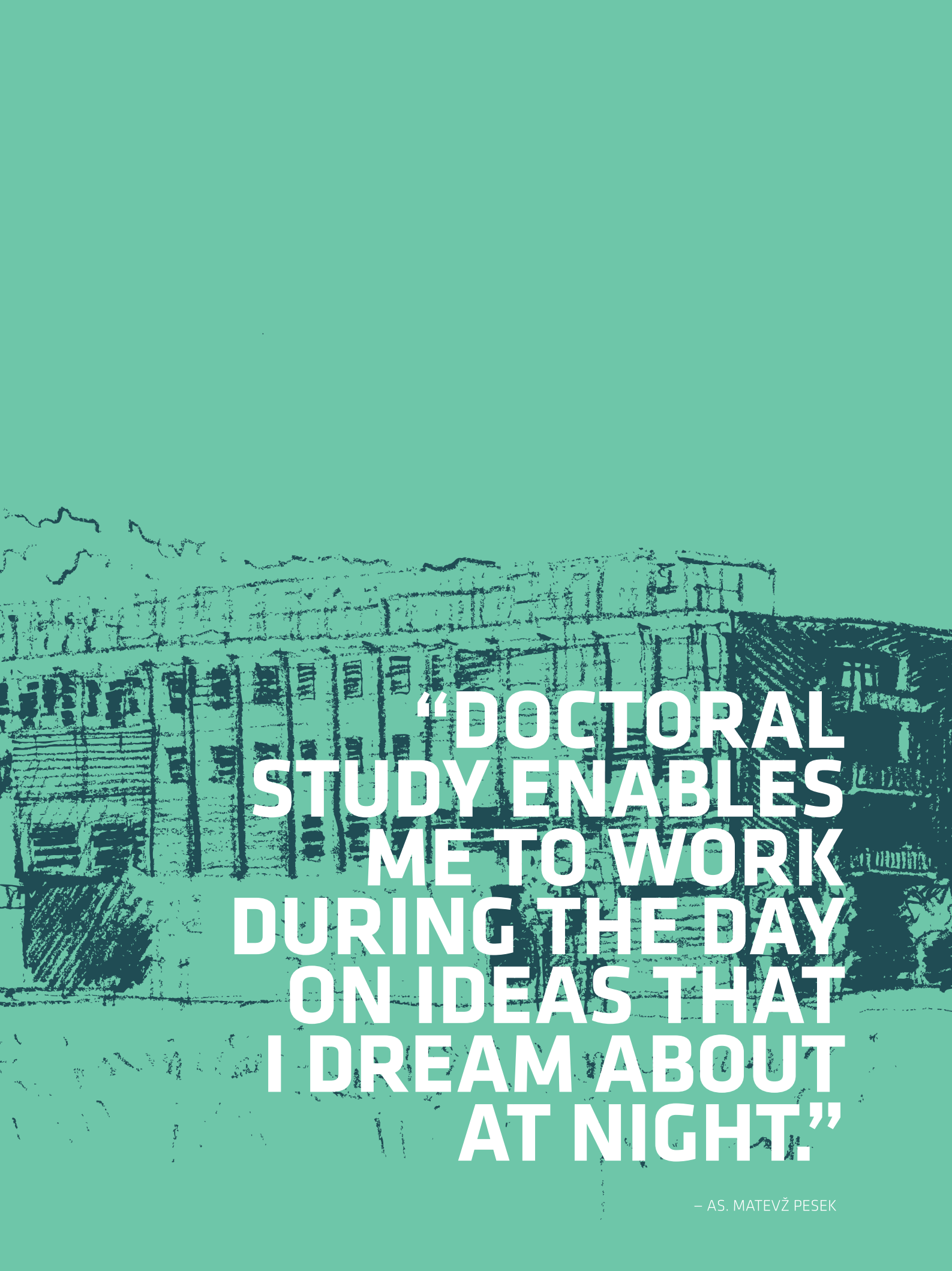
Other national project

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Collaborating Laboratories:

Laboratory for Cognitive Modelling



**“DOCTORAL
STUDY ENABLES
ME TO WORK
DURING THE DAY
ON IDEAS THAT
I DREAM ABOUT
AT NIGHT.”**

– AS. MATEVŽ PESEK

Doctoral Study Programmes

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 de-

voted 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

Graphlet Counting

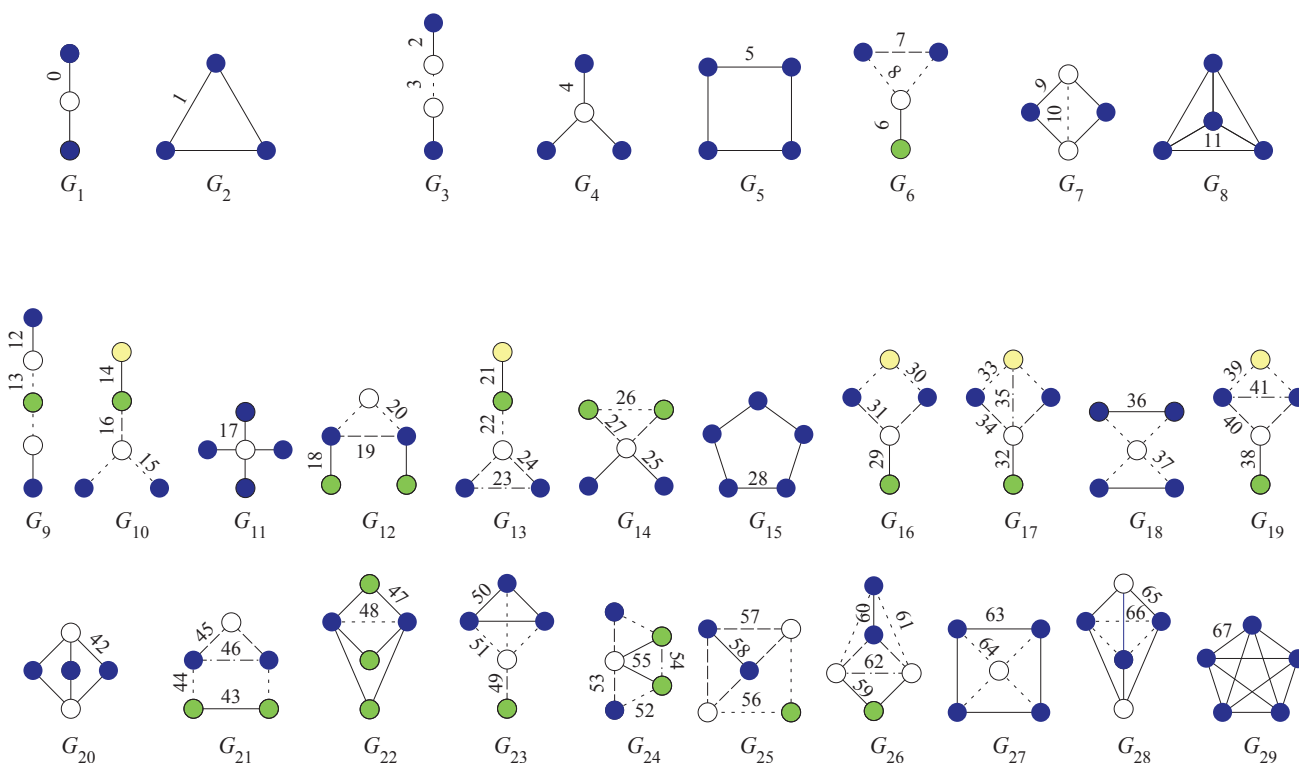
Network analysis plays a significant role in many aspects of science and business, ranging from genetic and protein networks in bioinformatics to social networks in the mining of user data. Describing the roles of individual nodes and edges, clustering them and predicting their future development requires their locally defined properties to be observed. One of the methods used (particularly in bioinformatics) is based on the counting of graphlets and graphlet orbits.

A node or an edge can be described by a vector containing the counts of the various kinds of graphlets (small connected induced subgraphs) in which it appears, or the “roles” (orbits) it takes within these graphlets. An R package (*orca*) was implemented with functions for the rapid computation of such counts on sparse graphs. Instead of enumerating all the induced graphlets, however, the algorithm devised has its basis on the relations derived between the counts, which reduces the time complexity by an order of magnitude that is less than in previous approaches.



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Tomaž Hočevar, Janez Demšar (2016) Computation of Graphlet Orbits for Nodes and Edges in Sparse Graphs, *Journal of Statistical Software*, 71(10), 1-24.



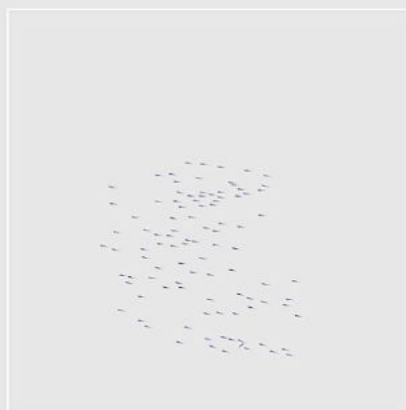
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Evolution of Fuzzy Animats in a Competitive Environment

The phenomenon known as collective behaviour is one of the most beautiful spectacles that can be observed in nature. Despite having been researched and analysed by scientists from a variety of disciplines and perspectives, it remains something of an enigma. In order to assist studies carried out on the phenomenon, an artificial life-like open-ended evolutionary model was developed in which the behaviour of predators and prey is governed by fuzzy logic.

In this model, focus was devoted on the evolution of prey behaviour when prey face different predation pressures. We demonstrated that, unlike previous evolutionary models, this newly developed model is capable of producing a number of different forms of collective behaviour that resemble, both visually and quantitatively, the collective motion commonly observed in nature (e.g. swarming, milling, polarized motion and dynamic motion). The analysis conducted on the resulting behaviours suggest that antagonism in pressures might be necessary in order for prey to evolve polarized movement.



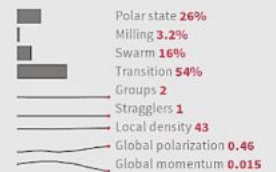
12 polarized

Frame 1109/5400



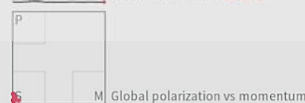
10 dynamic

Frame 1109/5400



4 swarming

Frame 1109/5400



6 milling

Frame 1109/5400



Jure Demšar, Iztok Lebar Bajec (2017) Evolution of collective behaviour in an artificial world using linguistic fuzzy rule-based systems, PLoS ONE, 12(1): e0168876. Jure Demšar, Erik Štrumbelj, Iztok Lebar Bajec (2016) A balanced mixture of antagonistic pressures promotes the evolution of parallel movement, Scientific Reports, 6, 39428.

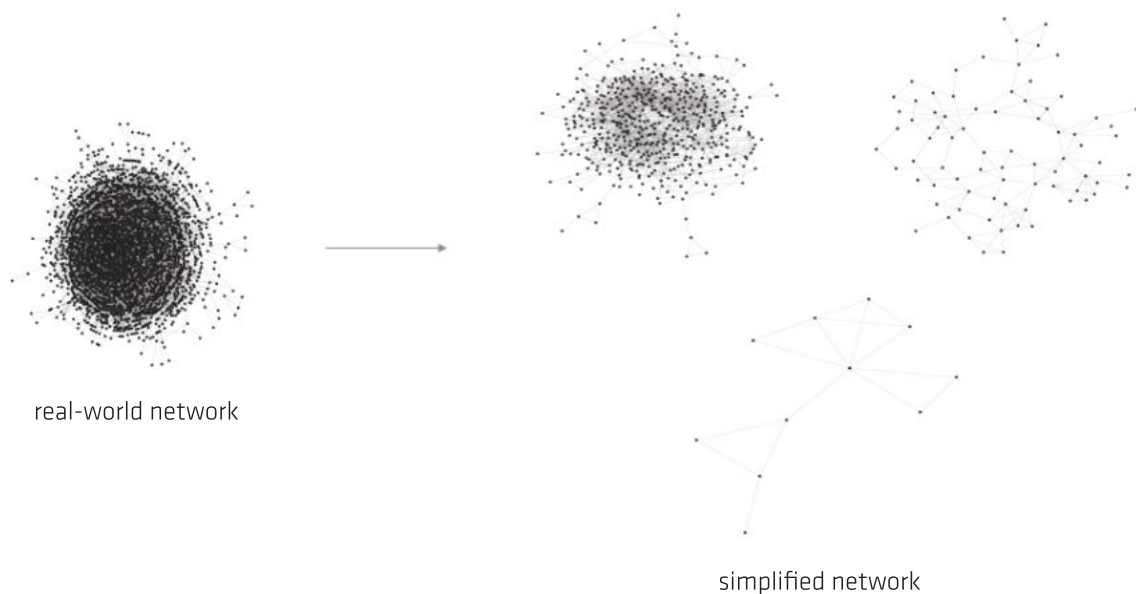
Network Simplification

Since many real-world networks are large and complex, they can be difficult to understand, analyse or visualize. Network data is not always complete and may change quickly over time. Therefore, a number of studies propose a variety of simplification techniques and explore the changes in network properties introduced by this simplification. In this thesis, the changes to real-world networks introduced by simplification are analysed and the differences between these simplification techniques are examined. An approach for assessing the effectiveness of simplification is also proposed. Using the similarity between original and simplified networks as a basis, the simplification techniques are compared. A number of real-world networks of various types and sizes are simplified, and the possible ways to preserve the network properties on simplified networks of different sizes are explored. On the basis of the analytical findings, a scheme is then introduced in order to select the optimum simplification technique for a specific network.



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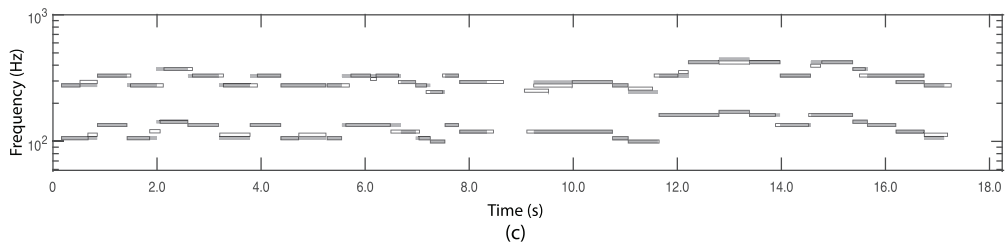
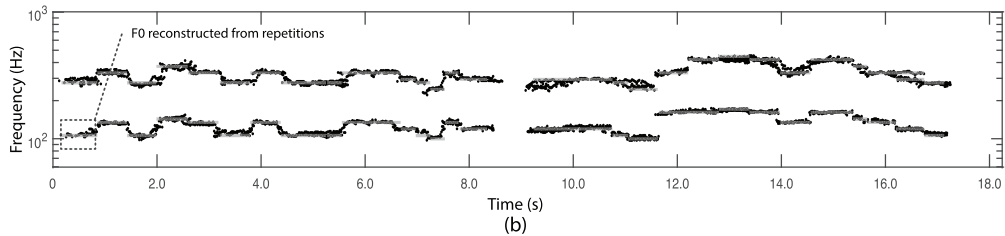
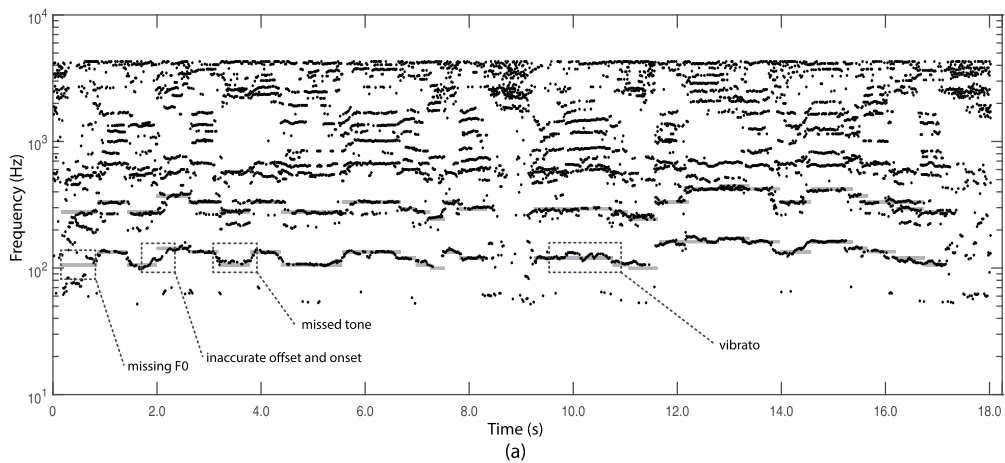
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Music Information Retrieval

The primary objective of musical segmentation is to develop algorithms that find similar audio signal patterns for the specific aspect desired (e.g. melody, rhythm and timbre) and to define the boundaries between the repetitions. The goal of musical transcription is to develop algorithms that extract pitches from the audio signal for each time frame – for either monophonic or polyphonic music. Music segmentation and transcription represent two crucial aspects of the research undertaken in the field of music information retrieval. The challenges faced in folk music audio recordings are even more pressing owing to poor recording conditions and amateur performers (which cause the high levels of noise in recordings), out-of-time singing, pitch drifting, etc. The methods developed are currently failing to yield acceptable results.

In this thesis, two methods have been developed and evaluated: a music segmentation method [1] and a music transcription method [2], both of which are specialised for folk music recordings and outperform the current state-of-the-art methods being used.



Ciril Bohak, Matija Marolt (2016) Probabilistic Segmentation of Folk Music Recordings, *Mathematical Problems in Engineering*, vol. 2016. Ciril Bohak, Matija Marolt (2016) Transcription of Polyphonic Vocal Music with a Repetitive Melodic Structure, *Journal of the Audio Engineering Society*, 64(9): 664-672.

Integrative Computational RNA Biology

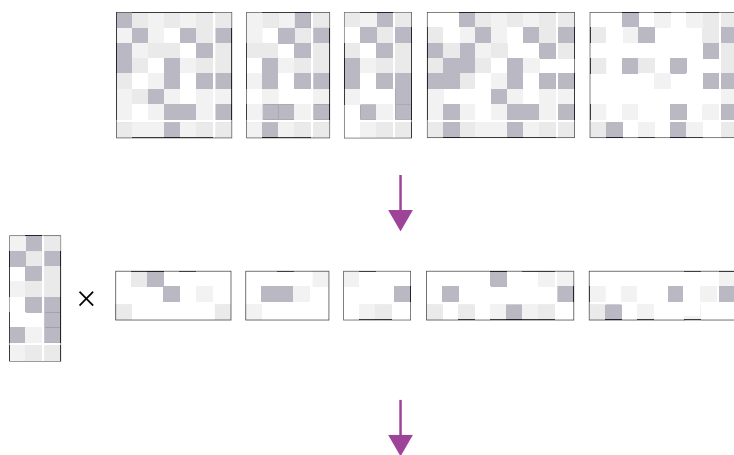
Identifying the patterns of RNA-protein interaction is key in understanding the role RNA binding proteins play in the post-transcriptional regulation of gene expression, including splicing, transport, modifications and RNA stability. We have developed an integrative orthogonality-regularised nonnegative matrix factorisation (iONMF) method to integrate multiple data sources and discover non-overlapping and class-specific patterns of varying abundances. To model protein-RNA binding, it is necessary to integrate the rapidly growing experimental data with the latest genome annotation, gene function, RNA sequence and structure.

Our integration of the largest compendium to date, which included 31 experimental data sets on 19 RNA binding proteins, revealed that the integration of multiple data sources improves the ability to predict interaction sites. We also identified the key predictive factors of protein-RNA interaction: RNA structure, sequence motifs and co-binding of other RNA binding proteins.



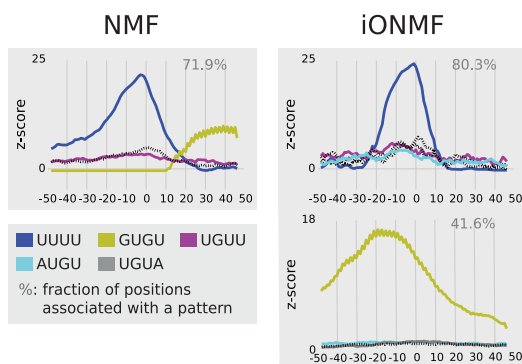
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Supervisor:
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Multiple data sources in matrix form

iONMF model finds non-overlapping patterns



Model inspection reveals interesting things, such as RNA motifs recognized by a protein



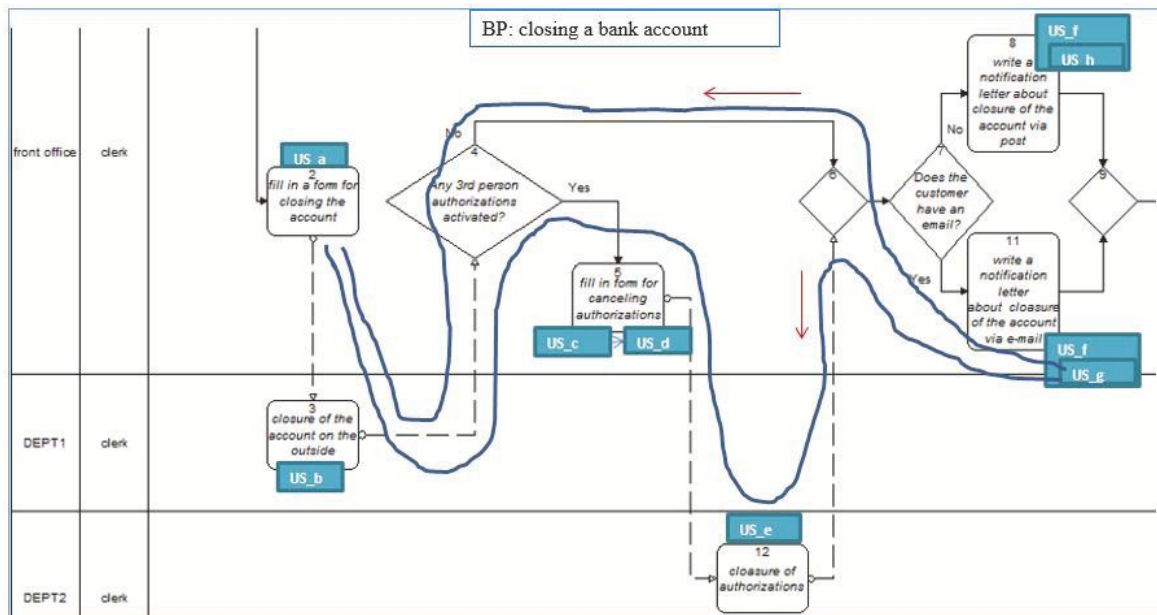
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Understanding User Story Context

In order to gain a proper understanding of a user story, an understanding of its dependencies is required. Any lack thereof could lead to missing information regarding the user story's context. In this paper, a method is proposed that facilitates a better understanding of the execution order and integration dependencies of user stories through the application of business process models. Our method associates a user story with an activity element in a BPMN model. In this way, the business process model can be used to infer information about the execution order and integration dependencies of the user story. In our experiment, we applied comprehension, problem-solving and recall tests. The statistical results provide support for all of the hypotheses made. There also appears to be a much better understanding of the execution order and integration dependencies of user stories when associated business process models are available. Our method contributes to the discipline of conceptual modelling in agile development.





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