JEDLIK LABORATORIES RESEARCH REPORT

2024

PÁZMÁNY
Pázmány Péter Catholic University
Faculty of Information Technology and Bionics

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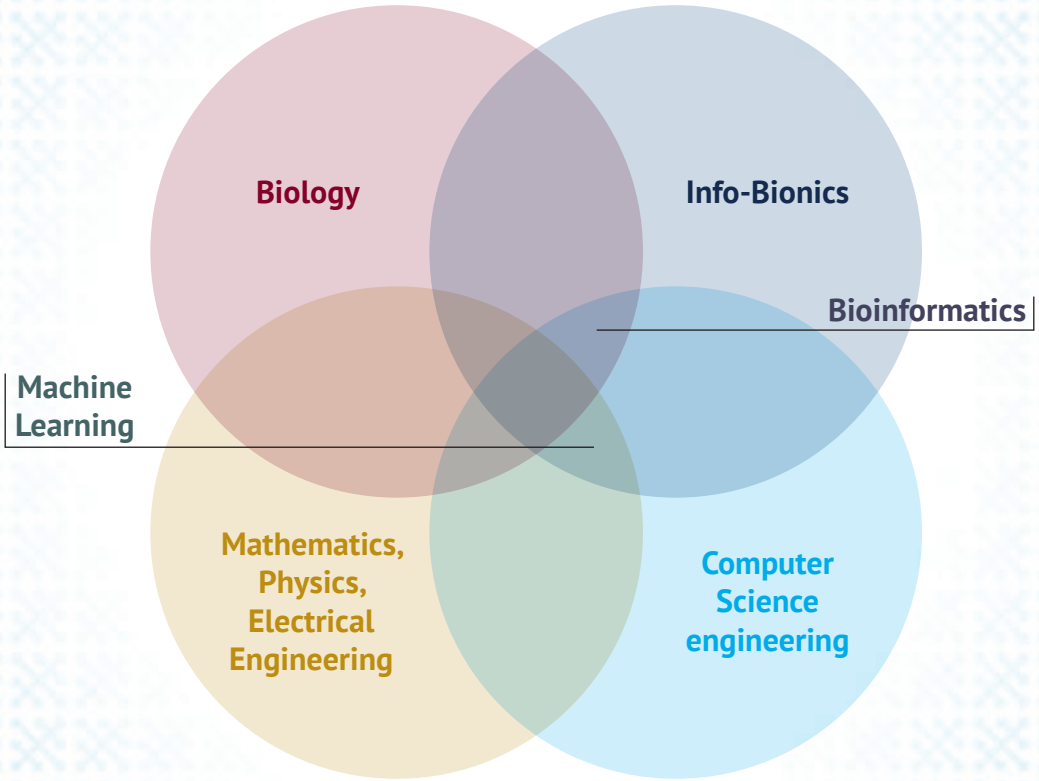

Biology
Info-Bionics
Bioinformatics
Machine
Learning
Mathematics,
Physics,
Electrical
Engineering
Computer
Science
engineering

CONTENTS

PREFACE

This booklet gives an overview on the research groups of the Jedlik Laboratories at the Faculty of Information Technology and Bionics of Pázmány Péter Catholic University.

The Jedlik Laboratories conduct research in several coupled areas: biology, computer science, mathematics, physics and info-bionics, with special focus on electrical engineering, bioinformatics and machine learning. The 32 research groups actively collaborate with each other, fostering a strong interdisciplinary approach in their investigations. By incorporating the latest developments in biology, bionics, electrical engineering and computer science, the faculty ensures the programs stay at the forefront of technological advancements. One notable aspect of the faculty's research is the active participation of both undergraduate and graduate students. Their participation in innovative projects has already led to the spin-off of seven start-up companies from the faculty. Presently, the Faculty is accredited to give doctoral degrees and habilitation in electrical engineering, information technology, and biology.

The Faculty focuses on a diverse range of research areas, including biology-inspired and neuromorphic models, bioinformatics, systems biology, nanotechnology, molecular dynamics, optics-modeling, sensing, and bio-interfaces. Additionally, they explore topics such as cellular wave computing, hardware-software technologies, microelectronic systems, sensor devices, human language technologies, telepresence, multimedia, sensory robotics, navigation, artificial intelligence, machine learning, software technology, digital computer algorithms, medical diagnostics as well as rehabilitation applications.

A special section of this booklet is dedicated to the bionics research lines we develop to compete in Cybathlon. This event is the "Olympics of Bionics", where teams from all over the world develop and use their assistive technologies for people with disabilities to compete in various challenges. On a few pages we introduce our teams and the races they participate in, also mentioning our successes in previous events.

Prof. Tamás Roska (1940-2014), founding dean of the Faculty and first director of the Jedlik Laboratories wanted to create a strongly research oriented Faculty, with a unique goal in Europe to develop synergy between information technology and neuroscience. The faculty also teamed up with a few outstanding neuroscientists from the Hungarian Academy of

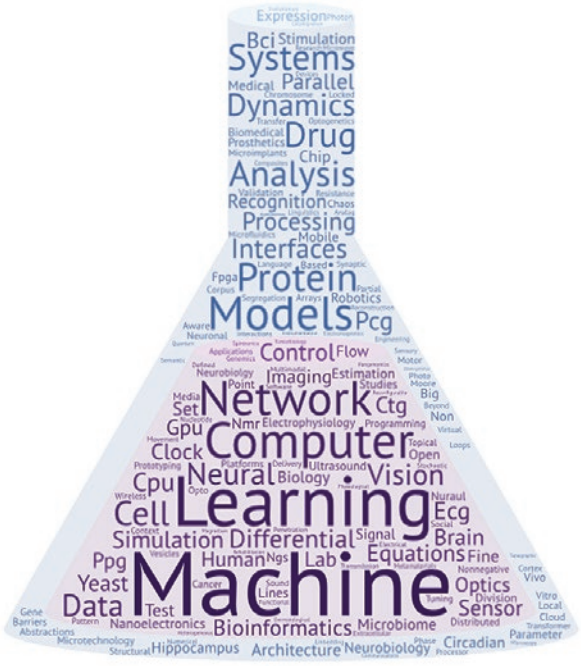
Sciences. 25 years have passed since this idea came through and the Faculty was established. Since then, research in bionics, biology, electronics and information technology has bloomed in the Jedlik Laboratories and as new multidisciplinary research lines emerged the focus has expanded with bioinformatics, nanotechnology, robotics and artificial intelligence. Now 33 research groups work in the Jedlik Laboratories and we started to reach the maximal capacity what our building can hold, showing how successfully the Faculty expanded. We are committed to preserve the human and scientific heritage of Prof. Roska and to actively develop the conditions of quality research at the Faculty.

July 30, 2024

Prof. Attila Csikász-Nagy

Director of Jedlik Laboratories

Vice Dean for Research and Innovation

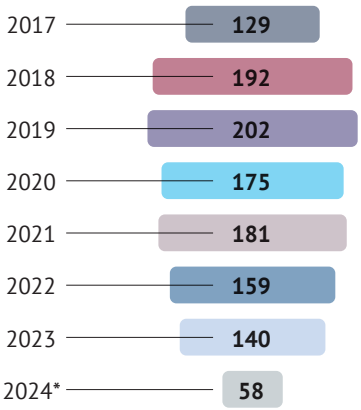


RESEARCH RESULTS IN NUMBERS

Total number of publications
3077

Total number of citations
32 378

NUMBER OF PUBLICATIONS BY YEAR



** in progress*

NUMBER OF PUBLICATIONS IN THE TOP 10% (D1) AND TOP 25% (Q1) OF BEST JOURNALS RANKED BY SCIMAGO

	Referenced journal papers	D1	Q1	D1 ratio	Q1 ratio
2021	113	29	52	26%	46%
2022	116	26	49	22%	42%
2023	89	23	41	26%	46%
2024*	42	11	21	26%	50%

** in progress*

TOP PUBLICATIONS FROM THE LAST 5 YEARS

Diblík, J., Pituk, M., Szederkényi, G.
Large time behavior of nonautonomous linear differential equations with Kirchhoff coefficients
AUTOMATICA 161 Paper: 111473 (2024)

Gaizer, T., Juhász, J., Pillér, B., Szakadáti, H., Pongor, Cs. I., & Csikász-Nagy, A.
Integrative analysis of yeast colony growth
COMMUNICATIONS BIOLOGY 7(1), 511 (2024)

Horváth, Cs., Ulbert, I., Fiáth, R.
Propagating population activity patterns during spontaneous slow waves in the thalamus of rodents
NEUROIMAGE 285 Paper: 120484 (2024)

Pavani, M., Chiroli, E., Cancrini, C., Gross, F., Bonaiuti, P., Villa, S., Giavazzi, F., Matafora, V., Bachi, A., Fava, L. L., Lischetti, T., Ciliberto, A.
Triap1 upregulation promotes escape from mitotic-slippage-induced G1 arrest
CELL REPORTS 42(3):112215 (2023)

Polcz, P., Tornai, K., Juhász, J., Cserey, Gy., Surján, Gy., Pándics, T., Róka, E., Vargha, M., Reguly, I. Z., Csikász-Nagy, A., Pongor, S., Szederkényi, G.
Wastewater-based modeling, reconstruction, and prediction for COVID-19 outbreaks in Hungary caused by highly immune evasive variants
WATER RESEARCH 241 Paper: 120098 (2023)

Zováthi, Ö., Pálffy, B., Jankó, Zs., Benedek, Cs.
ST-DepthNet: A spatio-temporal deep network for depth completion using a single non-repetitive circular scanning Lidar
IEEE ROBOTICS AND AUTOMATION LETTERS 8(6), pp. 3270-3277 (2023)

Ecker, A., Bagi, B., Vértes, E., Steinbach-Németh, O., Karlócai, M. R., Papp, O. I., Miklós, I., Hájos, N., Freund, T. F., Gulyás, A. I., Káli, Sz.
Hippocampal sharp wave-ripples and the associated sequence replay emerge from structured synaptic interactions in a network model of area CA3
ELIFE 11:e71850. (2022)

Jansson, E., Kovács, M., Lang, A.
Surface Finite Element Approximation Of Spherical Whittle-Matérn Gaussian Random Fields
SIAM JOURNAL ON SCIENTIFIC COMPUTING 44(2) pp. A825-A842 (2022)

Judák, L., Chiovini, B., Juhász, G., Pálfi, D., Mezriczky, Zs., Szadai, Z., Katona, G., Szmola, B., Ócsai, K., Martinecz, B., Mihály, A., Dénes, Á., Kerekes, B., Szepesi, Á., Szalay, G., Ulbert, I., Mucsi, Z., Roska, B., Rózsa, B.
Sharp-wave ripple doublets induce complex dendritic spikes in parvalbumin interneurons in vivo.
NATURE COMMUNICATIONS 13(1):6715. (2022)

Kocsis, D., Kichou, H., Döme, K., Varga-Medveczky, Zs., Révész, Z., Antal, I., Erdő, F.
Structural and Functional Analysis of Excised Skins and Human Reconstructed Epidermis with Confocal Raman Spectroscopy and in Microfluidic Diffusion Chambers
PHARMACEUTICS. 14(8):1689 (2022)

Reguly, I. Z., Csercsik, D., Juhász, J., Tornai, K., Bujtár, Zs., Horváth, G., ... & Csikász-Nagy, A.
Microsimulation based quantitative analysis of COVID-19 management strategies.
PLOS COMPUTATIONAL BIOLOGY, 18(1): e1009693. (2022)

Szabó, Á., Madarász, M., Lantos, Zs., Zátonyi, A., Danda, V., Spurgin, L., Manz, C., Rózsa, B., Fekete, Z.
Transparent Thiol-ene/Acrylate-Based MicroECoG Devices Used for Concurrent Recording of Fluorescent Calcium Signals and Electrophysiology in Awake Animals
ADVANCED MATERIALS INTERFACES 9(25), Paper: 2200729 (2022)

Szadai, Z., Pi, H.-J., Chevy, Q., Ócsai, K., Albeanu, D. F., Chiovini, B., Szalay, G., Katona, G., Kepecs, A., Rózsa, B.
Cortex-wide response mode of VIP-expressing inhibitory neurons by reward and punishment
ELIFE 11 Paper: 78815 (2022)

Szederkényi, G., Ács, B., Lipták, G., and Vághy, M. A.
Persistence and stability of a class of kinetic compartmental models
JOURNAL OF MATHEMATICAL CHEMISTRY 60, pp. 1001–1020 (2022)

Zováthi, Ö., Nagy, B., Benedek, Cs.
Point cloud registration and change detection in urban environment using an onboard Lidar sensor and MLS reference data
INTERNATIONAL JOURNAL OF APPLIED EARTH OBSERVATION AND GEOINFORMATION 110 Paper: 102767 (2022)

Balogh, G. D., Flynn, T. S., Laizet, S., Mudalige, G. R., & Reguly, I. Z.
Scalable Many-Core Algorithms for Tridiagonal Solvers
COMPUTING IN SCIENCE & ENGINEERING, 24(1), pp. 26-35. (2021)

Harmat, Z., Dudola, D., Gáspári, Z.
DIPEND: An Open-Source Pipeline to Generate Ensembles of Disordered Segments Using Neighbor-Dependent Backbone Preferences
BIOMOLECULES 11(10):1505 (2021)

Ignácz, A., Földi, S., Sótonyi, P., Cserey, G.
NB-SQI: A novel non-binary signal quality index for continuous blood pressure waveforms
BIOMEDICAL SIGNAL PROCESSING AND CONTROL 70 Paper: 103035 (2021)

Papp, Á., Porod, W., Csaba, Gy.
Nanoscale neural network using non-linear spin-wave interference
NATURE COMMUNICATIONS 12(1) Paper: 6422 (2021)

Varga-Medveczky, Zs., Kocsis, D., Naszlady, M. B., Fónagy, K., Erdő, F.
Skin-on-a-Chip Technology for Testing Transdermal Drug Delivery—Starting Points and Recent Developments
PHARMACEUTICS 13(11):1852 (2021)

Csaba, Gy., Porod, W.
Coupled oscillators for computing: A review and perspective
APPLIED PHYSICS REVIEWS 7(1):011302 (2020)

Horváth, Á. C., Boros, Ö. C., Komáromi, L., Borbély, S., Koppa, P., Barthó, P., Fekete, Z.
Infrared neural stimulation and inhibition using an implantable silicon photonic microdevice
MICROSYSTEMS & NANOENGINEERING 6:44 (2020)

Juhász, J., Gáspári, Z., Pongor, S.
Structure and Oxidative Folding of AAI, the Major Alfa-Amylase Inhibitor From Amaranth Seeds
FRONTIERS IN CHEMISTRY 8 (2020)

CYBATHLON – THE "BIONICS OLYMPICS"

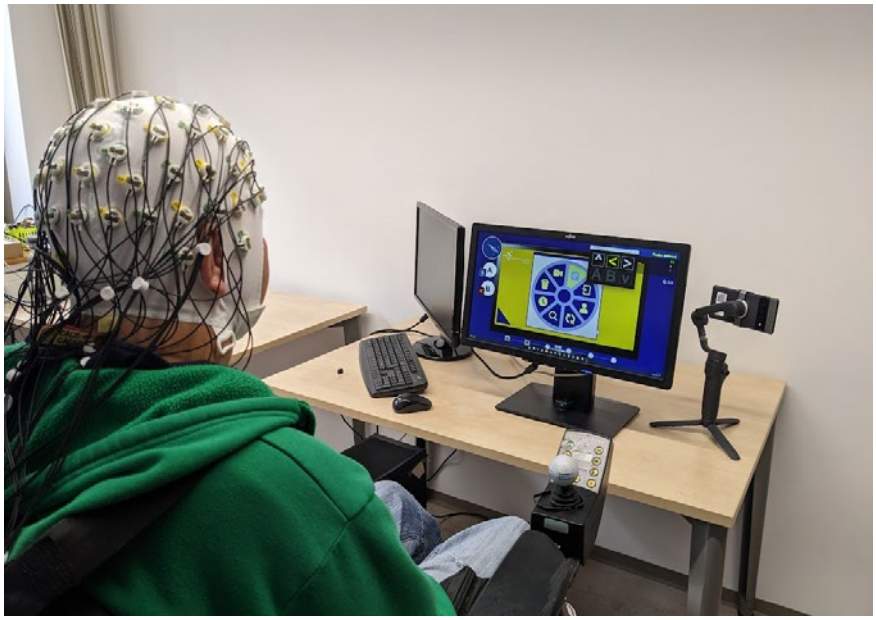
INTRODUCTION TO OUR TEAMS COMPETING AT CYBATHLON

The Cybathlon, often referred to as the "bionics olympics," is a unique competition organised by ETH Zurich. It challenges teams worldwide to develop assistive technologies that can be used by individuals with disabilities in everyday tasks. Our research and development areas align with many of the competition challenges. The event includes races in 8 disciplines such as brain-computer interfaces (BCIs), functional electrical muscle stimulation (FES), prosthetic limb control (ARM), device development for the visually impaired (VIS) and smart wheelchair development for the physically impaired (WHL). International technological competitions like Cybathlon are crucial for multiple reasons. They provide a platform for innovation, encouraging teams to develop cutting-edge assistive technologies. Participating in such competitions also raises awareness about the challenges faced by people with disabilities and showcases how technology can address these. Moreover, it motivates teams to push the boundaries of their research and development, ultimately leading to real-world applications that can significantly improve the quality of life for individuals with disabilities. It is also an important place to show the current state of the art and increase visibility to research groups that work on these solutions.

Related to the hand prosthesis race (ARM) of Cybathlon, our research group led by Benedek Tasi is working on developing advanced bionic limbs by reverse-engineering human hand anatomy and biomechanics. They specialise in creating and integrating materials that mimic tissue structures through innovative fibre and textile technologies. Their prototype is a highly sophisticated robotic hand designed for precision, strength and most of all, to feel natural. The research group is also working on control technologies ranging from electrophysiological interfaces to smart sensory gloves, spanning various applications including robotics, prosthetics, and teleoperation. The group has a strong focus on the everyday applicability of their prototypes and the marketability of their technologies as products.

In connection with the Brain-Computer Interface (BCI) race of Cybathlon, our research group led by Dr. Csaba Márton Köllőd is working on the development of algorithms to

Our anatomically correct hand prosthesis can gently grab delicate objects.



The setup of the BCI Cybathlon race can be seen with the Pilot navigating the screen with the BCI controlled mouse.

convert brain signals into control commands for a digital device. The developed BCI system allows people paralyzed from the neck down to perform everyday tasks in a virtual scenario, such as controlling an electric wheelchair, a robotic arm or the cursor of a computer using only their brain waves, the EEG signals. This innovative approach not only demonstrates the practical applications of BCI technology, but also highlights the potential for enhancing the independence and quality of life of people with severe disabilities. Our BCI research group was one of the first research groups from Hungary to participate in the Cybathlon events back in 2016.

Related to the functional electrical muscle stimulation (FES) race of Cybathlon our research group led by prof. József Laczkó is working on developing stimulation patterns, training protocols for FES cycling training of paraplegics. Our Pilot, Csaba Szamosi was involved in optimising the developed protocols. Our team uses the Berkelbike Pro tricycle, which is a hybrid tricycle that can be driven by legs only, by arms only and simultaneously by the legs and arms as well. For FES driven leg cycling it is equipped with a 6 channel programmable electrical stimulator device that allows it to control FES driven leg cycling of paraplegics. Also, the team has previously developed their own stimulation device that can be used in any overground biking or stationary training applications. Members of several institutions participate in the development of the stimulation patterns and training protocols: PPKE ITK, Wigner Research Centre for Physics, the University of Pécs and the National Institute for Medical Rehabilitation in Hungary. For the FES biking race the HunFess team combines technical sciences, natural sciences and medical sciences, and our aim is to foster FES based rehabilitation of spinal cord injured people.

Related to the vision assistance (VIS) race of Cybathlon our research group led by prof. Kristóf Karacs has all sorts of skills and expertise, covering engineering, computer science, and human-computer interaction. The research group is working on developing a mobile application that runs on a cell phone and is easy to use, called LetSee, which they have been working on for some time, and which has been made available for visually impaired users worldwide, enhancing various aspects of their daily lives. The research is focused on combining their knowledge and experience, thus they can develop a solution that can make a difference in the lives of people with visual impairments. The aim is to create a tool that is accessible, affordable, and effective, while at the same time building on the already acquired skills of visually impaired people, giving them a strong sense of independence and the ability to stay in control. Our visually impaired pilot, Peter is constantly involved in testing the application and the development of the user interface and interactions, his outstanding situational awareness and insights are key to the development of the app. The research group already has experience with mobile application development

Our pilot on the "Lyon Cyber Days" FES cycling race, as preparation for the Cybathlon FES Bike Race. The tricycle is driven by his paralyzed limbs, a controller sends electrical signals to the selected muscles via surface electrodes to generate muscle forces to drive the tricycle.

Our VIS pilot attempting the task "Empty seats" during the Cybathlon Challenge 2024. The aim is to indicate which seats are empty out of the 6 available using only the application developed.

for the visually impaired community, thus it was an obvious choice to use the technology for the Cybathlon competition as well. This will help in the marketability and accessibility of the developed solution worldwide.

Key publications:

1. *Kiss, R., Köves, Á. B., Pelyva, D. L., Tasi, B. J., Földi, S., Cserey, G., and Koller, M.* **Control design for a soft exoskeleton in simulation and identification of the role of different sensor modalities** (2023)
2. *Köllőd, Cs., Adolf, A., Iván, K., Márton, G. and Ulbert, I.* **Deep Comparisons of Neural Networks from the EEGNet Family** ELECTRONICS, 12(12):2743. (2023)
3. *Köllőd, Cs., Adolf, A., Márton, G., Wahdow, M., Fadel, W. and Ulbert, I.* **Closed loop BCI system for Cybathlon 2020** BRAINCOMPUTER INTERFACES, 10(2), pp. 114–128. (2023)
4. Radeleczki, B., Mravcsik, M., Bozheim, L., and Laczko, J. **Prediction of leg muscle activities from arm muscle activities in arm and leg cycling** THE ANATOMICAL RECORD, 306(4), pp. 710-719. (2023)
5. *Tasi, B. J., Koller, M., and Cserey, G.* **Design of the anatomically correct, biomechatronic hand** arXiv:1909.07966. (2019)
6. *Mravcsik M., Klauber A. and Laczko J.* **FES driven lower limb cycling by four and eight channel stimulations – a comparison in a case study** IN THE 12TH VIENNA INTERNATIONAL WORKSHOP ON FUNCTIONAL ELECTRICAL STIMULATION Proceedings, 89-93. ISBN: 978-3-900928-12-4 (2016)
7. *Karacs, K.* **An Integrated Assistance Tool for Visual Impairment** (2015)
8. *Karacs, K., Radványi, M., Stubendek, A., and Bezányi, B.* **Learning hierarchical spatial semantics for visual orientation devices.** IEEE BIOMEDICAL CIRCUITS AND SYSTEMS CONFERENCE (BioCAS) Proceedings. 141-144. IEEE. (2014)

RESEARCH GROUPS

BIOINFORMATICS AND DATA SCIENCE

Prof. Sándor PONGOR

Head of Research Group: Prof. Sándor PONGOR

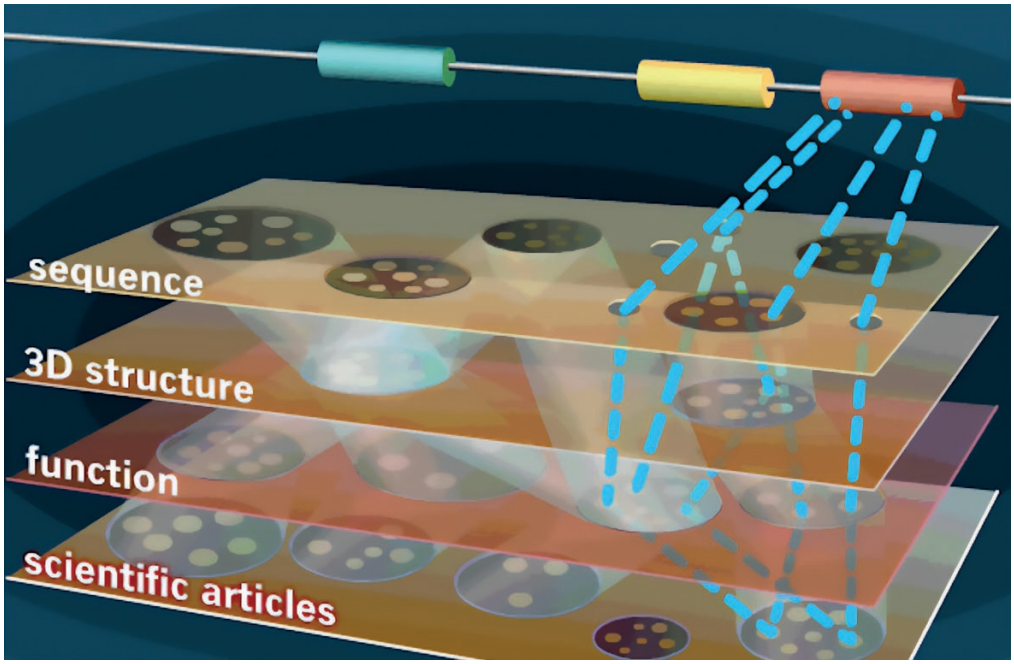
Members of the Group: Dr. Balázs LIGETI, Dr. János JUHÁSZ

Contact: pongor.sandor@itk.ppke.hu

Keywords: *bioinformatics, data science, biological sequences, genomics, data visualisation, knowledge representation, scientific communication*

Field of research: bioinformatics; info-bionics

The traditional focus of our group is the general theory of bioinformatics data. This involves describing bioinformatics data—such as sequences, 3D molecular structures, biological networks, genomes, and scientific texts—within a unified theoretical framework using systems theory and network research methods. By doing so, we aim to elucidate the fundamental principles underlying the management of biological data and databases. This is crucial for interpreting data from biological communities, such as metagenomic data. A key focus of our group is curriculum development for BSc, MSc and PhD courses, which has three main directions: fundamentals of bioinformatics, visualisation of scientific data, and data interpretation and communication, including scientific writing and presentation skills. The emergence of artificial intelligence casts new light to these areas, to which our curriculum development efforts are also adapting. Our other projects are connected to the analysis of primarily host related microbiomes. We develop methods for exploring their composition and connections.

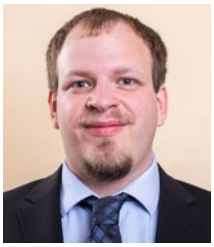


Different layers of molecular biology data (for example nucleotide sequences, 3D protein structures, biological functions) need to be connected in order to gain knowledge (published in scientific articles) about the structure and regulation of organisms. Mapping tools between different data types or layers and clustering methods within these layers are crucial for effective information transfer.

Key publications:

1. *Juhász, J., Ligeti, B., Gajdács, M., Makra, N., Ostorházi, E., Farkas, F. B., Stercz, B., Tóth, Á., Domokos, J., Sándor Pongor, S. and Szabó, D.* **Colonization Dynamics of Multidrug-Resistant Klebsiella pneumoniae Are Dictated by Microbiota-Cluster Group Behavior over Individual Antibiotic Susceptibility: A Metataxonomic Analysis** ANTIBIOTICS 10(3), 268 (2021)
2. *Marini, B., Kertész-Farkas, A., Ali, H., Lucic, B., Lisek, K., Manganaro, L., Pongor, S., Luzzati, R., Recchia, A., Mavilio, F., Giacca, M. and Marina Lusic, M.* **Nuclear architecture dictates HIV-1 integration site selection** NATURE, 14:521 (2015)
3. *Juhász, J., Kertész-Farkas, A., Szabó, D and, Pongor, S.* ***Emergence of collective territorial defense in bacterial communities: horizontal gene transfer can stabilize microbiomes*** PLOS ONE. 9(4):e95511 (2014)

NEURAL BIOINFORMATICS



Dr. Balázs LIGETI

Head of Research Group: Dr. Balázs LIGETI

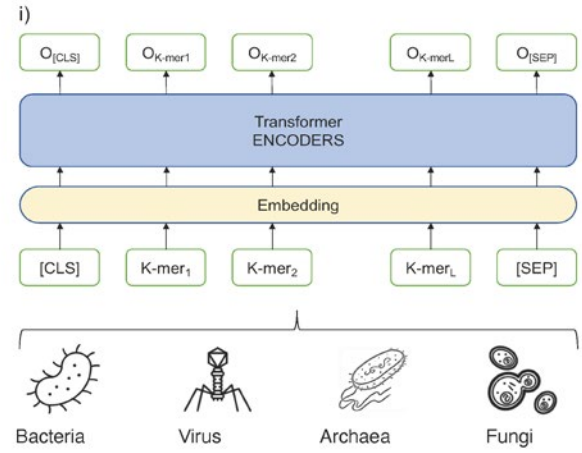
Members of the Group: Babett BODNÁR, Bendegúz FILYÓ, Dr. János JUHÁSZ, Judit JUHÁSZ, Dániel KRIZSÁN, Márton RÉTI

Contact: ligeti.balazs@itk.ppke.hu

Keywords: *ProkBERT, genomic language models, transfer learning, microbiome, phages*

Field of research: bioinformatics; machine learning

Our research group focuses on large genomic and evolutionary context-aware neural network and sequence representations. A key and fundamental question in quantitative biology is how to uncover novel patterns and structures in biological data, which is crucial for modeling, predicting, and manipulating complex organizations like a microbiome.Our most recent research focuses on understanding the complex relationships characterizing the microbiome, such as phage-bacteria interactions. Phages, which are the viruses of bacteria, can influence the structure of the microbiome, could serve as therapeutics as well as biomarkers. We designed and implemented a genomic language model, ProkBERT (ProkBERT, Ligeti et al. 2024) to solve such bioinformatics tasks. ProkBERT provides a reusable, neural network based representation, which can be applied on classification, regression or clustering tasks related to microbiome. The main advantages of the approach are that the model operates directly on nucleotide sequence, as opposed to traditional machine learning methods, which require tabular data created by a complicated bioinformatics pipeline. It is widely adaptable and shows good generalization capabilities, e.g. providing high quality prediction on unseen data. It is compact, fast and easy to use, while computationally efficient.



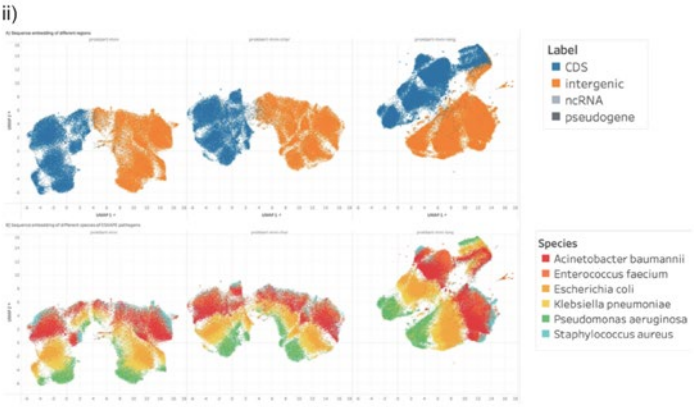


Figure i) ProkBERT operates directly on genomic data. ProkBERT was trained on large corpora of microbial sequence data (bacteria, viral, archeae and fungi). It allows transfer learning by providing reusable sequence representations. The model is ideal for solving classification, clustering and regressions problems.

Figure ii) 2D representations of different genomic features of ESKAPE pathogens. The sequences are clustered by genomic structure: coding (blue) vs. non-coding (orange) regions (figure ii/a) as well as by phylogeny (figure ii/b). Despite no annotation information were used for training model, the model captured the genomic structure.

Key publications:

1. *Ligeti, B. et al.* **ProkBERT family: genomic language models for microbiome applications.** FRONTIERS IN MICROBIOLOGY 14: 1331233 (2024)
2. *Juhász, J., Ligeti, B., Gajdács, M., Makra, N., Ostorházi, E., Farkas, F. B., Stercz, B., Tóth, Á., Domokos, J., Sándor Pongor, S. and Szabó, D.* **Colonization Dynamics of Multidrug-Resistant Klebsiella pneumoniae Are Dictated by Microbiota-Cluster Group Behavior over Individual Antibiotic Susceptibility: A Metataxonomic** Analysis ANTIBIOTICS 10(3), 268 (2021)
3. *Juhász, J., Pongor, S. and Ligeti, B.* **Toward a Systematic Genomic Survey of Bacterial Quorum Sensing Genes: Cross Cutting Regulatory and Genomic Concepts** TRENDS IN QUORUM SENSING AND QUORUM QUENCHING pp. 31-45. (2020)

STRUCTURAL BIOLOGY AND PROTEOMICS

Prof. Zoltán GÁSPÁRI

Head of Research Group: Prof. Zoltán GÁSPÁRI

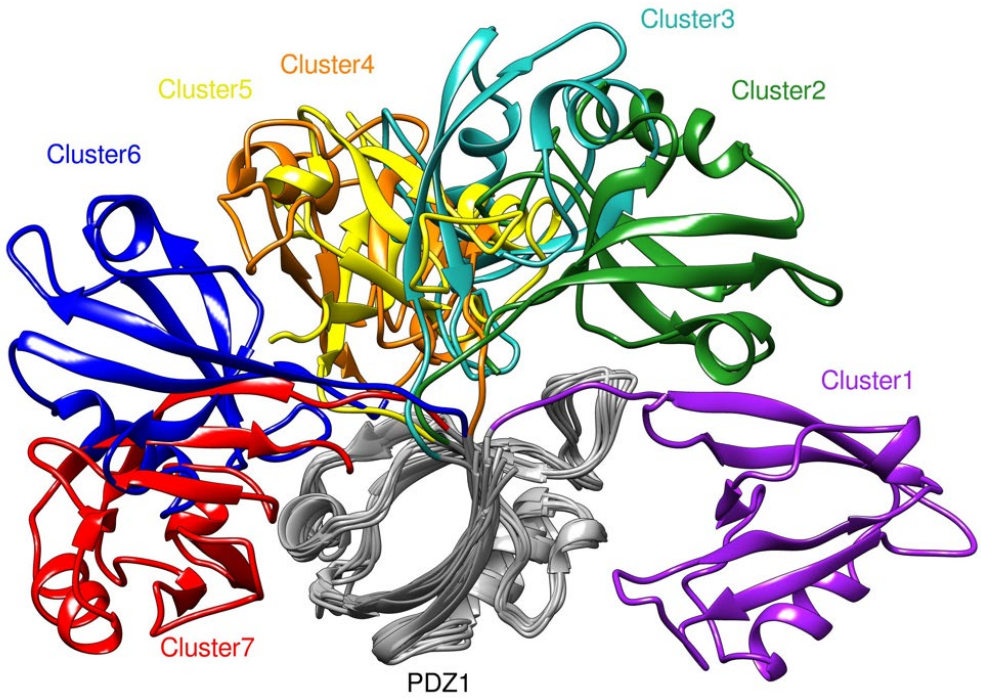
Members of the Group: Dr. Bálint PÉTERFIA, Zsófia DOBSON-KÁLMÁN, Eszter NAGY-KANTA, Anna SÁNTA, Fanni FARKAS, András László SZABÓ, Soma VARGA

Contact: gaspari.zoltan@itk.ppke.hu

Keywords: *synaptic transmission, protein expression, protein-protein interactions, protein NMR, protein structural modelling*

Field of research: bioinformatics; biology

Our research focuses on experimental and computational characterization of proteins involved in synaptic signal transduction. The postsynaptic density (PSD) is a dense and dynamic protein network contributing to the molecular processes behind learning and memory. Multivalent interactions, where two partners can bind each other at multiple sites, are especially important in forming the PSD. In our laboratory, we use biotechnology to produce protein constructs that are in turn investigated by various biophysical methods to decipher their structure, internal dynamics and partner binding properties. The obtained experimental results are integrated into different molecule- and systems-level computational models to understand the mechanistic details of the molecular function of individual domains and segments, as well as the organization of the postsynaptic protein network at a larger scale.

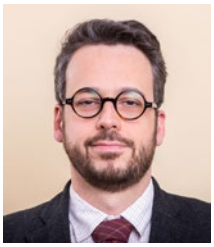


Representative structures of different clusters obtained from molecular dynamics simulations of the PDZ1-PDZ2 tandem of the PSD-95 protein. The different clusters exhibit distinct domain-domain interactions and their observed abundance during the simulations depends on the presence or absence of the PDZ ligands.

Key publications:

1. *Kalman, Z. E., Dudola, D., Meszáros, B., Gáspári, Z. and Dobson, L.* **PSINDB: The postsynaptic protein-protein interaction database** DATABASE-JOURNAL OF BIOLOGICAL DATABASES AND CURATION Paper: baac007 (2022)
2. *Sánta, A., Czajlik, A., Batta, Gy., Péterfia, B. and Gáspári, Z.* **Resonance assignment of the Shank1 PDZ domain** BIOMOLECULAR NMR ASSIGNMENTS 16(1) pp. 121-127 (2022)
3. *Kovács, B., Zajácz-Epresi, N. and Gáspári, Z.* **Ligand-dependent intra- and inter-domain motions in the PDZ12 tandem regulate binding interfaces in postsynaptic density protein-95** FEBS LETTERS 594(5) pp. 887-902. (2020)

SYSTEMS BIOLOGY OF MOLECULAR AND CELLULAR NETWORKS



Prof. Attila CSIKÁSZ-NAGY

Head of Research Group: Prof. Attila CSIKÁSZ-NAGY

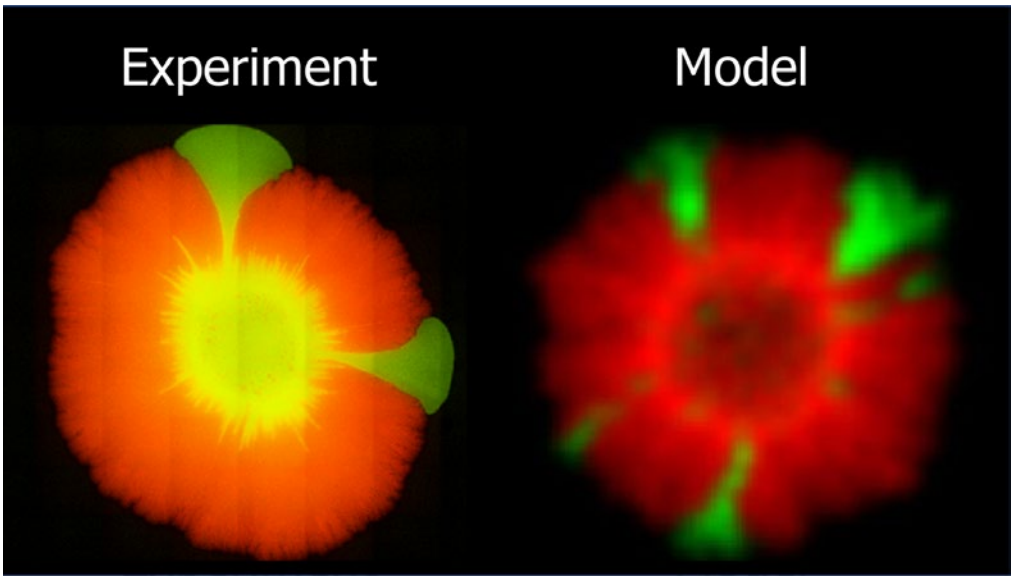
Members of the Group: Dr. Csaba István PONGOR, Dr. János JUHÁSZ, PhD students: Tünde Éva GAIZER, Bence Márk KEÖMLEY-HORVÁTH, Marcell MISKI, Bence GAIZER, Valentina MADÁR, Bíborka PILLÉR, János SZALMA, Áron WEBER

Contact: csikasz-nagy.attila@itk.ppke.hu

Keywords: *systems biology, simulation, bioinformatics, yeast, circadian clock*

Field of research: bioinformatics; info-bionics

We investigate the spatial and temporal dynamics of molecular and cellular regulatory networks (1) experimentally and (2) through mathematical modelling and model analysis techniques. The main research line on molecular networks focuses on the regulation of cell growth and proliferation, especially dealing with cell cycle regulation and its connection to ageing, to the circadian clock and to spatial control of cell growth. We also develop tools to predict changes in the complexome upon perturbations by drugs or disease. On the cellular networks track we investigate cell-cell interactions in yeast colonies and use the results of this approach in combination with theoretical ideas to design and synthetically establish multicellular colonies for specific functions. Additionally, as part of a national consortium we work on models of disease spreading in structured populations.



Microscopy image and simulation of the growth of two labelled yeast strains. On the left two strains were fluorescently labelled and grown on YPD solid media. On the right simulation result of an agent-based model is shown, where two differently coloured strains were grown together.

Key publications:

1. *Gaizer, T., Juhász, J., Pillér, B., Szakadáti, H., Pongor, Cs. I., and Csikász-Nagy, A.* **Integrative analysis of yeast colony growth** COMMUNICATIONS BIOLOGY, 7(1): 511. (2024)
2. *Reguly, I. Z., Csercsik, D., Juhász, J., Tornai, K., Bujtár, Z., Horváth, G., ... and Csikász-Nagy, A.* **Microsimulation based quantitative analysis of COVID-19 management strategies** PLOS COMPUTATIONAL BIOLOGY, 18(1): e1009693 (2022)
3. *Moreno, D. F., Jenkins, K., Morlot, S., Charvin, G., Csikasz-Nagy, A., & Aldea, M.* **Proteostasis collapse, a hallmark of aging, hinders the chaperone-Start network and arrests cells in G1** ELIFE 8: e48240 (2019)

BIOMICROFLUIDICS

Dr. András József LAKI

Dr. Kristóf IVÁN

Head of Research Group: Dr. András József LAKI, Dr. Kristóf IVÁN

Members of the Group: Mária LAKI, Márton HARTDÉGEN

Contact: laki.andras.jozsef@itk.ppke.hu, ivan.kristof@itk.ppke.hu

Keywords: *microfluidics, Lab-on-a-chip, prototyping, flow test, validation*

Field of research: biology; mathematics, physics, electrical engineering

The Biomicrofluidics Research Group at Pázmány Péter Catholic University (PPKE) specialises in the design, fluid dynamic modelling, fabrication, and testing of microfluidic devices. We conduct extensive research and development of these devices, incorporating and advancing state-of-the-art manufacturing technologies such as soft lithography, laser cutting, and layer bonding techniques. Our laboratory aims to provide innovative solutions in food safety, biomedical diagnostics, and particle separation technologies through microfluidic systems.

The development of microfluidic systems requires an interdisciplinary approach, integrating the fields of physics, chemistry, biology, and engineering. Our research group focuses on leveraging the latest advancements in these scientific disciplines to create innovative solutions that are widely applicable in practice.

Our goal is to achieve significant advancements in diagnostics and particle separation using microfluidic technologies, thereby contributing to the progress of the scientific community and industry. Additionally, we are committed to the widespread dissemination of scientific results and close collaboration with industry partners to ensure that our research is quickly realised in practical applications.

We can develop a Lab-on-a-chip device from a biological protocol to a functional prototype, which can be scaled up for mass production.

Key publications:

1. *Ponmozhi, J., Dhinakaran, S., Varga-Medveczky, Z., Fónagy, K., Bors, L. A., Iván, K. and Erdő, F.* **Development of skin-on-a-chip platforms for different utilizations: Factors to be considered** MICROMACHINES 12(3) Paper: 294 (2021)
2. *Kós, T., Iván, K., and Laki, A. J.* **Particle separation with deterministic lateral displacement** presented at Selectbio Lab-on-a-Chip and Microfluidics Europe 2021 conference, Rotterdam, The Netherlands (2021)
3. *Lengyel, M., Kállai-Szabó, N., Antal, V., Laki, A. J., and Antal, I.* **Microparticles, Microspheres, and Microcapsules for Advanced Drug Delivery** SCIENTIA PHARMACEUTICA, 87(3) (2019)

COMPUTATIONAL NEUROSCIENCE

Prof. Tamás FREUND

Dr. Szabolcs KÁLI

Head of Research Group: Prof. Tamás FREUND, Dr. Szabolcs KÁLI

Members of the Group: Máté MOHÁCSI, Luca TAR, Gábor FARKAS, Boglárka SZABÓ

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Keywords: *neurobiology, hippocampus, neuronal models, network dynamics, simulations*

Field of research: biology; info-bionics

The Computational Neuroscience research group uses various mathematical and simulation tools to study the dynamics and functions of both single neurons and networks in the hippocampus, often in combination with experiments conducted in the lab. Computational neuroscience offers a range of quantitative tools which allow us to describe the data in a succinct manner, to formulate our hypotheses about neural function clearly and precisely, and to link different scales and levels of organization through the application of mechanistic models. Models are on the one hand constrained by experimental data and, on the other hand, provide novel predictions which are testable using experimental methods. Some of the main focus areas of our group are the following: synaptic integration and nonlinear processing in neuronal dendrites; the origin and functions of population dynamics which are characteristic of the hippocampus, including theta and gamma oscillations and sharp wave-ripple events; the storage and retrieval of spatial and memorial representations in the hippocampus; fitting of neuronal parameters based on experimental data, and quantification of the expected precision of parameter inference.

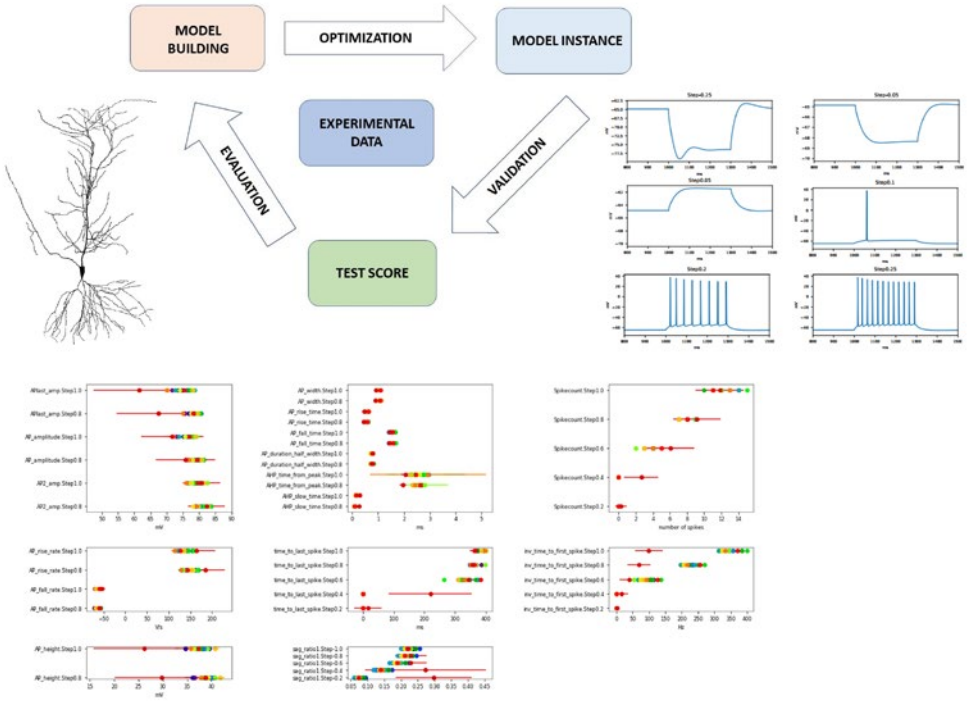


Illustration of a data-driven modeling workflow for building detailed models of neurons. Morphological and biophysical data are used to construct models whose unknown parameters are tuned via automated methods to match electrophysiological recordings. Models are then validated in an automated manner, quantitatively comparing their behavior with experimental data from various paradigms.

Key publications:

1. *Ecker, A., Bagi, B., Vértes, E., Steinbach-Németh, O., Karlócai, M. R., Papp, O. I., Miklós, I., Hájos, N., Freund, T. F., Gulyás, A. I. and Káli, S.* **Hippocampal sharp wave-ripples and the associated sequence replay emerge from structured synaptic interactions in a network model of area CA3** ELIFE 11: e71850 (2022)
2. *Sáray, S., Rössert, C. A., Appukuttan, S., Migliore, R., Vitale, P., Lupascu, C. A., Bologna, L. L., Van Geit, W., Romani, A., Davison, A. P., Muller, E., Freund, T. F. and Káli, S.* **HippoUnit: A software tool for the automated testing and systematic comparison of detailed models of hippocampal neurons based on electrophysiological data** PLOS COMPUT BIOL. 17(1): e1008114. (2021)
3. *Káli, S. and Dayan, P.* **Off-line replay maintains declarative memories in a model of hippocampal-neocortical interactions** NAT NEUROSCI. 7(3): 286-94. (2004)

INTEGRATIVE NEUROSCIENCE

Prof. István ULBERT

Dr. Domonkos HORVÁTH

Head of Research Group: Prof. István ULBERT, Dr. Domonkos HORVÁTH

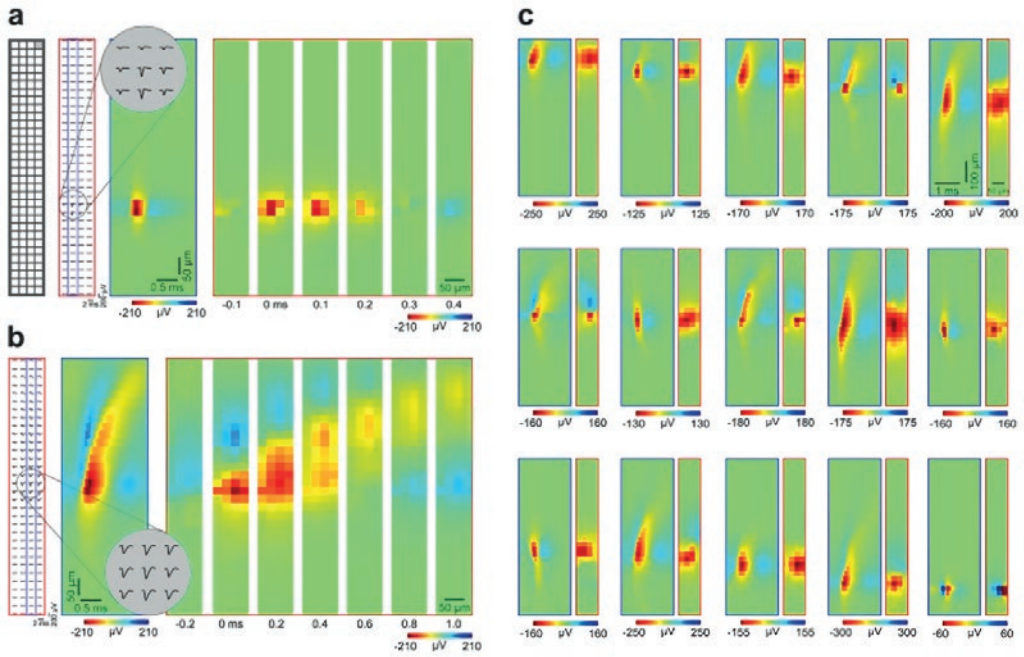
Members of the Group: Dr. Lucia WITTNER, Dr. Richárd FIÁTH, Dr. Gergely MÁRTON, Dr. Dániel HILLIER, Beáta Tünde SZABÓ, Ágnes KANDRÁCS, Dr. Csaba Márton KÖLLŐD, Ward FADEL, András ADOLF, Melinda RÁCZ

Contact: ulbert.istvan@ttk.hu, horvath.domonkos.aron@itk.ppke.hu

Keywords: *electrophysiology, optogenetics, BCI, human studies*

Field of research: biology; info-bionics

The laboratory covers a broad range of disciplines, including electrophysiology, materials science, microchip and microelectromechanical systems (MEMS), computing, neuroscience, and optical imaging. The aim of the research is to investigate the physiological and pathological function of the central nervous system. The laboratory staff is involved in several collaborative projects in the field of in vivo and in vitro electrophysiology and optical imaging. In 2014, the laboratory joined the Hungarian National Brain Research Program, in which it participates in the design and testing of thin-film electrodes. Main research areas: design and validation of new nervous system instruments; investigation of evoked potentials, spontaneous and epileptic cortical activities; mapping of thalamocortical neural networks responsible for sensory information processing; development of brain-computer interfaces. The group is also responsible for teaching a BSc and an MSc course, where the students can learn about electrophysiological recording methods and their applications.



Spatiotemporal profiles of high-resolution spike waveforms of sorted single units. (a) Left: schematic of the recording site layout. Middle left: Mean spike waveforms of a cortical neuron with a narrow spike (putative interneuron) on all channels. Middle right: Color map showing the spatiotemporal profile of the spike waveform on channels (n = 32) framed by the blue rectangle in the middle left (column of sites which contain the peak waveform channel). The inset at the top demonstrates magnified mean spike waveforms on nine adjacent channels which recorded the spikes with the largest amplitudes. Right: Color maps illustrating the twodimensional spatial profiles of the spike waveform on all channels (red rectangle in the middle left) at multiple time points (time step, 0.1 ms). Time zero corresponds to the trough (negative peak) of the spike waveform. (b) The spatiotemporal profile of the spike waveform of a neuron with a wide spike (putative principal cell). Note the longer duration and the dorsal propagation of the spike in the color maps (time step on the right, 0.2 ms). (c) Additional examples (n = 15) of extracellular spike waveforms of various single units.

Key publications:

1. *Horváth, C., Ulbert, I., and Fiáth, R.* **Propagating population activity patterns during spontaneous slow waves in the thalamus of rodents** NEUROIMAGE, 285, 120484 (2024)
2. *Hofer, K. T., Kandrács, Á., Tóth, K., Hajnal, B., Bokodi, V., Tóth, E. Z., Erőss, L., Entz, L., Bagó, S. G., Fabó, D., Ulbert, I. and Wittner, L.* **Bursting of excitatory cells is linked to interictal epileptic discharge generation in humans** SCIENTIFIC REPORTS, 12, 6280 (2022)
3. *Horváth, Cs., Tóth, L. F., Ulbert, I. and Fiáth, R.* **Dataset of cortical activity recorded with high spatial resolution from anesthetized rats** SCIENTIFIC DATA, 8, 180, (2021)

MICRODIALYSIS AND PHARMACOLOGICAL TECHNIQUES

Prof. Franciska VIDÁNÉ ERDŐ

Head of Research Group: Prof. Franciska VIDÁNÉ ERDŐ

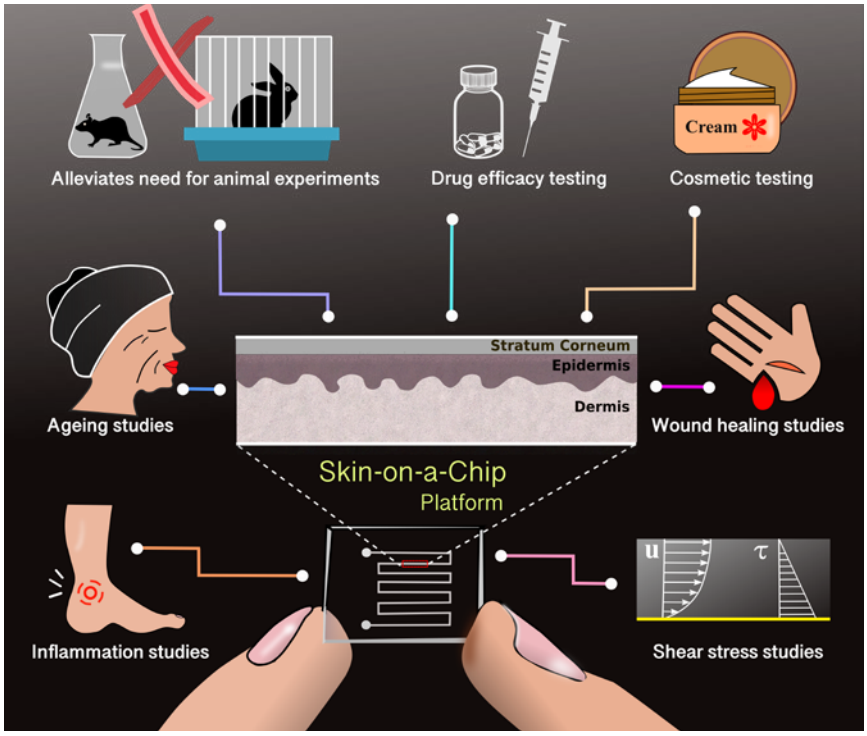
Members of the Group: Dorottya KOCSIS, Fanni SZEPETNEKI, Luca ZSIBORÁS, Berta BÖRCSÖK, Anita BÁTHORY-FÜLÖP, Beatrix VIDA

Contact: erdo.franciska@itk.ppke.hu

Keywords: *transdermal drug penetration, skin-on-a-chip, skin substitutes, artificial skins, simulation of skin penetration*

Field of research: biology

In the laboratory, we deal with the border areas of biology, pharmaceutical research, pharmaceutical technology and tissue engineering. In addition, we participate in numerous collaborations, partly within our University, and partly with domestic and foreign universities and research institutes. We examine the properties, barrier function, chemical composition, histological structure of healthy and diseased skin, as well as the absorption of topically applied drugs and cosmetics. We make modeling of drug penetration with mathematical simulation, and we participate in the development and testing of different microfluidic diffusion chambers. As a new direction, we also take a role in testing the absorption of ophthalmic products, and we also collaborate with researchers from Semmelweis University and the University of Extremadura (Spain) in the development and optimization of the 3D skin bioprinting method.



The skin-on-a-chip microfluidic platforms can be used for skin aging studies, for analysing skin disorders and to develop therapeutic strategies and testing cosmetic products. This in vitro systems are physiologically relevant models which can replace the animal experiments and able to mimic the dynamism of the living organs.

Key publications:

1. *Szederkényi, G., Kocsis, D., Vághy, M. A., Czárán, D., Sasvári, P., Lengyel, M., Naszlady, M. B., Kreis, F., Antal, I., Csépányi-Kömi, R. and Erdő, F.* **Mathematical modeling of transdermal delivery of topical drug formulations in a dynamic microfluidic diffusion chamber in health and disease** PLOS ONE 19(4):e0299501 (2024)
2. *Ponmozhi, J., Dhinakaran, S., Kocsis, D., Iván, K. and Erdő, F.* **Models for barrier understanding in health and disease in lab-on-a-chips** TISSUE BARRIERS 12(2):2221632 (2024)
3. *Kocsis, D., Kichou, H., Döme, K., Varga-Medveczky, Z., Révész, Z., Antal, I. and Erdő, F.* **Structural and Functional Analysis of Excised Skins and Human Reconstructed Epidermis with Confocal Raman Spectroscopy and in Microfluidic Diffusion Chambers** PHARMACEUTICS 14(8):1689 (2022)

NEURAL CIRCUITS AND COMPUTATION

Dr. Balázs RÓZSA

Head of Research Group: Dr. Balázs RÓZSA

Members of the Group: Dr. Linda JUDÁK, Dr. Gábor JUHÁSZ, Dr. Dénes PÁLFI, Réka LÁNYI, Viktória KISS, Zsolt MEZRICZKY, Miklós MADARÁSZ

Contact: rozsabal@koki.hu

Keywords: *in vitro and in vivo 2-photon microscopy, 2D and 3D imaging, photo-stimulation, electrophysiology, cortex, hippocampus*

Field of research: biology; info-bionics

To understand the functional operation of the brain, it is necessary to use novel imaging techniques such as 3D two-photon microscopy, which allows real-time measurement and activation of neuronal somas and extensions, enabling the inspection of network mechanisms. Our proprietary 3D AO scanning technology has significantly increased measurement speed and signal-to-noise ratio efficiency. Additionally, we have developed an online, real-time motion correction method for eliminating movement that occurs during in vivo experiments. As a result, it is now possible to rapidly measure pyramidal cell and interneuron activity in 3D in moving, behaving animals using both calcium sensors and the recently introduced voltage sensors. Through our measurements, we are discovering previously unknown signaling systems in the brain related to reward and punishment that influence learning processes across the entire neocortex and hippocampus. In this laboratory, we focus mainly on developing and improving photostimulation methods. In our laboratories at BrainVisionCenter, our primary research facility established in collaboration with Botond Roska, we are making progress with ongoing human retinal measurements. We currently have more than 40 international patents.

Key publications:

1. *Judák, L., Chiovini, B., Juhász, G., Pálfi, D., Mezriczky, Z., Szadai, Z., Katona, G., Szmola, B., Ócsai, K., Martinecz, B., Mihály, A., Dénes, Á., Kerekes, B., Szepesi, Á., Szalay, G., Ulbert, I., Mucsi, Z., Roska, B. and Rózsa, B.* **Sharp-wave ripple doublets induce complex dendritic spikes in parvalbumin interneurons in vivo.** NAT COMMUN 13(1): 6715 (2022)
2. *Szadai, Z., Pi, H-J., Chevy, Q., Ócsai, K., Albeanu, D. F., Chiovini, B., Szalay, G., Katona, G., Kepecs, A. and Rózsa, B.* **Cortex-wide response mode of VIP-expressing inhibitory neurons by reward and punishment** ELIFE 11: e78815 (2022)
3. *Geiller, T., Sadeh, S., Rolotti, S. V., Blockus, H., Vancura, B., Negrean, A., Murray, A. J., Rózsa, B., Polleux, F., Clopath, C. and Losonczy, A.* **Local circuit amplification of spatial selectivity in the hippocampus** NATURE 601(7891): 105-109 (2022)

NEUROENDOCRINE

Prof. Zsolt LIPOSITS

Dr. Imre KALLÓ

Dr. Imre FARKAS

Head of Research Group: Prof. Zsolt LIPOSITS, Dr. Imre KALLÓ, Dr. Imre FARKAS

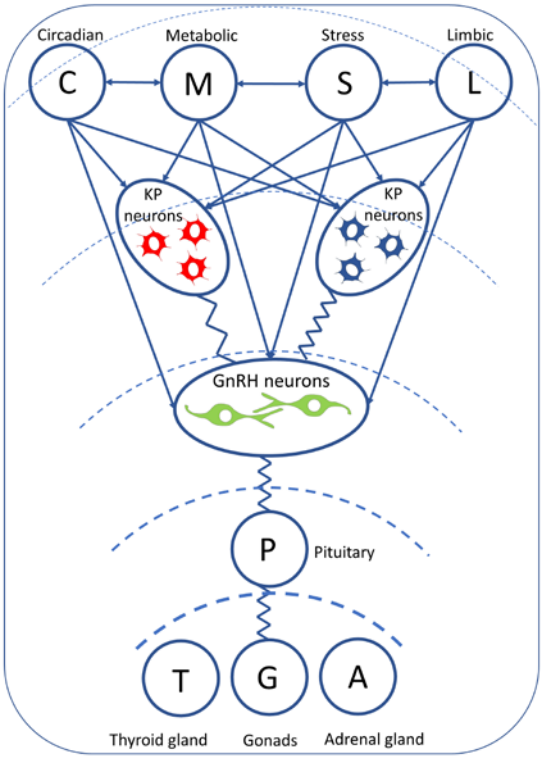
Members of the Group: Barbara GÖBLYÖS, Emil KOPLÁNYI

Contact: liposits.zsolt@koki.hun-ren.hu, kallo.imre@koki.hun-ren.hu

Keywords: *neurobiology, hypothalamus, opto- and chemogenetics, gene expression*

Field of research: biology; bioinformatics

The Neuroendocrine Research Group investigates primarily the neural- and hormonal regulation of the endocrine- and autonomic functions of rodents by using a combination of functional neuroanatomical, molecular biological and neurophysiological techniques in wild-type and genetically modified experimental animals. The functions, activity and the signal transmission of the gonadotropin-releasing hormone (GnRH) producing neurons, which provide the primary output of the neuronal network, show significant changes during the cyclic operation of the ovaries, as well as, after the cessation of the cycles, during menopause. The sex- and estrous cycle phase-dependent gene expression profile is mapped with single cell high throughput assays and validated in the key cellular elements regulating reproduction, including the GnRH neurons. The highly relevant regulatory genes and signaling pathways are identified by using bioinformatical and analytical approaches. The molecular biological, neuroanatomical and functional data produced establish a base for modelling the consequences of the pathological and potential therapeutic changes in endogenous levels of gonadal hormones. The major research topics are the following: Examination of the mutual regulatory inputs between the GnRH neurons and their afferent neuronal systems during the different phases of the ovarian cycle and in pathophysiological conditions. Investigation of the age-dependent reduction of estrogen-signaling, studying its consequences in the central nervous system, and providing data for prevention and establishing new therapeutic approaches.



The scheme shows a multilevel control of the hypothalamo-hypophyseal-endocrine axes studied by our research group, which operates through feed-forward neuronal and humoral signaling and feedback mechanisms. The kisspeptin neurons, which play a key role in the mediation of the estrogen feedback, and the GnRH neurons, which provide the major output, are in the center of the neuronal network regulating reproduction.

Key publications:

1. *Vastagh, C., Farkas, I., Csillag, V., Watanabe, M., Kalló, I. and Liposits, Z.* **Cholinergic Control of GnRH Neuron Physiology and Luteinizing Hormone Secretion in Male Mice: Involvement of ACh/GABA Cotransmission** J NEUROSCI 44(12): e1780232024 (2024)
2. *Vastagh, C., Csillag, V., Solymosi, N., Farkas, I. and Liposits, Z.* **Gonadal Cycle-Dependent Expression of Genes Encoding Peptide-, Growth Factor-, and Orphan G-Protein-Coupled Receptors in Gonadotropin- Releasing Hormone Neurons of Mice** FRONT MOL NEUROSCI 13: 594119 (2021)
3. *Bálint, F., Csillag, V., Vastagh, C., Liposits, Z. and Farkas, I.* **Insulin-Like Growth Factor 1 Increases GABAergic Neurotransmission to GnRH Neurons via Suppressing the Retrograde Tonic Endocannabinoid Signaling Pathway in Mice** NEUROENDOCRINOLOGY 111(12): 1219-1230 (2020)

NEUROMODULATION

Dr. Loránd ERŐSS

Head of Research Group: Dr. Loránd ERŐSS

Member of the Group: Dr. István ULBERT, Dániel FABÓ, Zsófia JORDÁN, László HALÁSZ

Contact: eross.lorand@itk.ppke.hu

Keywords: *neuromodulation, movement disorders, epilepsy, pain*

Field of research: biology

In the biotechnological sense, neuromodulation is the frontier between natural science, medicine and engineering, which aims to improve the quality of life of people with neurological diseases, including many implantable and extracorporeal, electrical and chemical technologies . With the foundation of the group, we created an interdisciplinary workshop where the above disciplines meet . Our goal was to create an integrative center where research in the field, everyday clinical medicine, university graduate and postgraduate medical and bionics training, and the neuromodulation industry can develop in close cooperation . In such an environment, research conducted at the center can directly shape medical practice and information technology, as well as medical undergraduate and postgraduate education, and on the other hand, clinical needs and experiences also directly influence research and industrial development.

The state-of-the-art and most modern operating theater complex in the country and Europe has been built at the National Institute of Mental, Neurological and Neurosurgery.

Key publications:

1. *Jordán, Zs., Szabó, J. P., Sákovics, A., Kelemen, A., Halász, L., Erőss, L. and Fabó, D.* **Epileptiform discharges in the anterior thalamus of epilepsy patients** ISCIENCE 27(5) Paper: 109582 (2024)
2. *Várkuti, B., Halász, L., Hagh Gooie, S., Miklós, G., Smits Serena, R., van Elswijk, G., McIntyre, Cameron C., Lempka, Scott F., Lozano, Andres M. and Erőss, L.* **Conversion of a medical implant into a versatile computer-brain interface** BRAIN STIMULATION 17(1) pp. 39-48. (2024)
3. *Ujma, Péter P., Dresler, M., Simor, P., Fabó, D., Ulbert, I., Erőss, L. and Bódizs, R.* **The sleep EEG envelope is a novel, neuronal firing-based human biomarker** SCIENTIFIC REPORTS 12(1) Paper: 18836 (2022)

QUANTITATIVE BIOLOGY OF CELL DIVISION

Prof. Andrea CILIBERTO

Head of Research Group: Prof. Andrea CILIBERTO

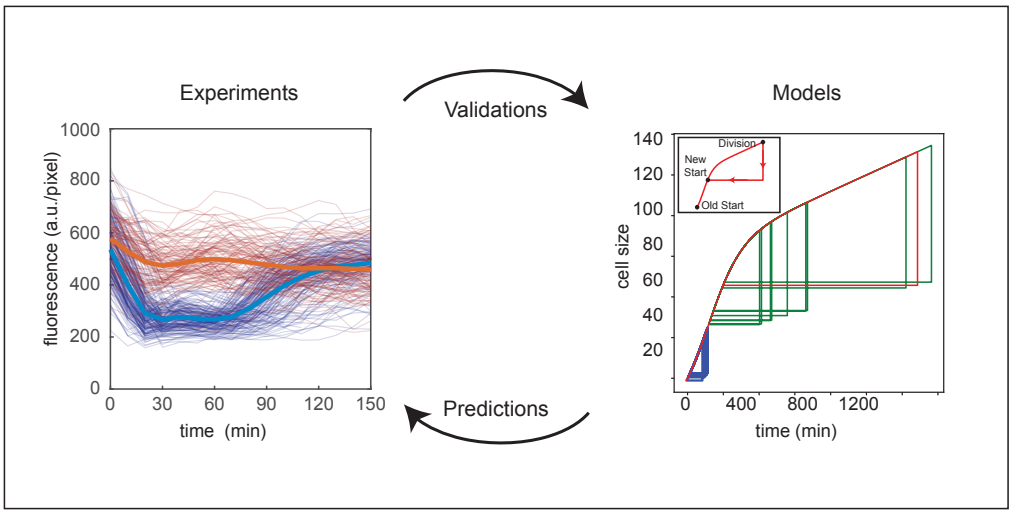
Member of the Group: Alma Beatrix STIER

Contact: andrea.ciliberto@ifom.eu

Keywords: *cell division, chromosome segregation, mathematical models*

Field of research: biology; mathematics, physics, electrical engineering

Cells are machines made to divide. Any insult that stops them from dividing creates a situation of stress that can be solved in different ways: either cell die, or senesce, or manage to divide regardless of the insult. In our lab, we study how cells cope with such prolonged arrest. Our interest is driven by sheer curiosity, but also by the fact that many drugs used to cure cancer act by arresting the cell cycle. It is then important to understand how to channel cells' fate toward arrest and death rather than proliferation. We address this problem with a combination of experiments and mathematical models, done both in yeast (a model system) and mammalian cells. Recently, we identified pathways cells use to become resistant to drugs impairing microtubules. Our activities are integrated with a twin lab in IFOM (Milan), the Institute of molecular oncology of the italian association for cancer research (AIRC). Currently, the lab based in Budapest is specialized in performing mathematical models and analysing data.



Key publications:

1. *Pavani, M., Chiroli, E., Cancrini, C., Gross, F., Bonaiuti, P., Villa, S., Giavazzi, F., Matafora, V., Bachi, A., Fava, L. L., Lischetti, T. and Ciliberto, A.* **Triap1 upregulation promotes escape from mitotic-slippage-induced G1 arrest** CELL REP. 42(3): 112215 (2023)
2. *Pavani, M., Bonaiuti, P., Chiroli, E., Gross, F., Natali, F., Macaluso, F., Póti, Á., Pasqualato, S., Farkas, Z., Pompei, S., Cosentino Lagomarsino, M., Rancati, G., Szüts, D. and Ciliberto A.* **Epistasis, aneuploidy, and functional mutations underlie evolution of resistance to induced microtubule depolymerization.** EMBO J. 40(22): e108225 (2021)
3. *Bonaiuti, P., Chiroli, E., Gross, F., Corno, A., Vernieri, C., Štefl, M., Cosentino Lagomarsino, M., Knop, M. and Ciliberto, A.* **Cells Escape an Operational Mitotic Checkpoint through a Stochastic Process** CURR BIOL. 28(1): 28-37.e7 (2017)

TRANSLATIONAL ONCOLOGY

Dr. Tamás GARAY

Head of Research Group: Dr. Tamás GARAY

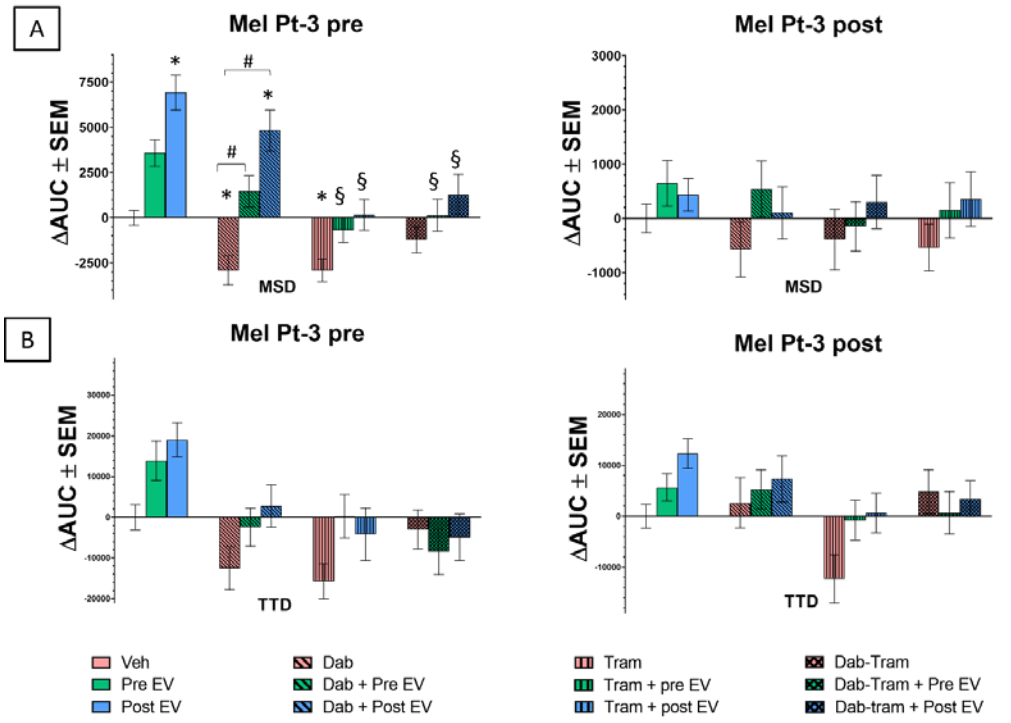
Members of the Group: Gréta BÁNYAI, Nikolett DOBOS, Júlia KVASZNICZA, Afrodité NÉMETH, Marcell SZÁSZ, Adrienn VERMESSY

Contact: garay.tamas@itk.ppke.hu

Keywords: *cancer cell-lines, extracellular vesicles, tumorbiology, cell migration*

Field of research: biology; cell biology

The Laboratory of Translational Oncology was co-founded by the Department of Internal Medicine and Oncology of Semmelweis University and the Faculty of Information Technology and Bionics of Pázmány Péter Catholic University. Accordingly, this Laboratory has the unique opportunity to address questions arising in the daily clinical routine with the competences of both medical-biological and engineering approaches (bench-to-bed). Similarly, scientific results can be easily transferred into the clinics to serve as outgoing point for new scientific questions and as new therapeutic approaches (bed-to-bench). In the course of investigations in the Laboratory of Translational Oncology we have a comprehensive cell culture laboratory with cutting edge techniques; our aim is to identify new therapeutic targets, prognostic and predictive markers (nucleic acids and proteins, extracellular vesicles) in histological tumor samples or liquid biopsies, that could be crucial in understanding of tumorous processes. Effects of activation and inhibition of potential target molecules (e.g. on proliferation/cell cycle or the activation/inhibition of downstream signaling pathways) are tested in tumor cell models. A distinguished attention is paid to the change of migratory activity of tumor cells, as cell migration is an inevitable process during the formation of metastases.

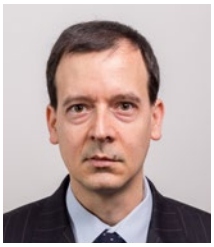


*Effect of EV, Dabrafenib (Dab), Trametinib (Tram) and combined treatment on single-cell migration. Cell migration was recorded for 24 hours, semiautomatic tracking of single cells performed using CellTracker and MSD and TTD calculated. Results of three independent measurements are shown as mean ± SEM, and p-value less than 0.05 considered as statistically significant (to vehicle: *, to Dab: #, to EV-only: §). The picture is published in "Key publications 1."*

Key publications:

1. *Németh, A., Bányai, G. L., Dobos, N. K., Kós, T., Gaál, A., Varga, Z., Buzás, EI., Khamari, D., Dank, M., Takács, I., Szász, A. M. and Garay, T.* **Extracellular vesicles promote migration despite BRAF inhibitor treatment in malignant melanoma cells** CELL COMMUN SIGNAL. 22(1):282 (2024)
2. *Petenyi, F.G., Garay, T., Muhl, D., Izso, B., Karaszi, A., Borbenyi, E., Herold, M., Herold, Z., Szasz, A.M. and Dank, M.* **Modulated Electro-Hyperthermic (mEHT) Treatment in the Therapy of Inoperable Pancreatic Cancer Patients—A Single-Center Case-Control Study** DISEASES 9(4): 81 (2021)

ANALYSIS AND CONTROL OF DYNAMICAL SYSTEMS



Prof. Gábor SZEDERKÉNYI

Head of Research Group: Prof. Gábor SZEDERKÉNYI

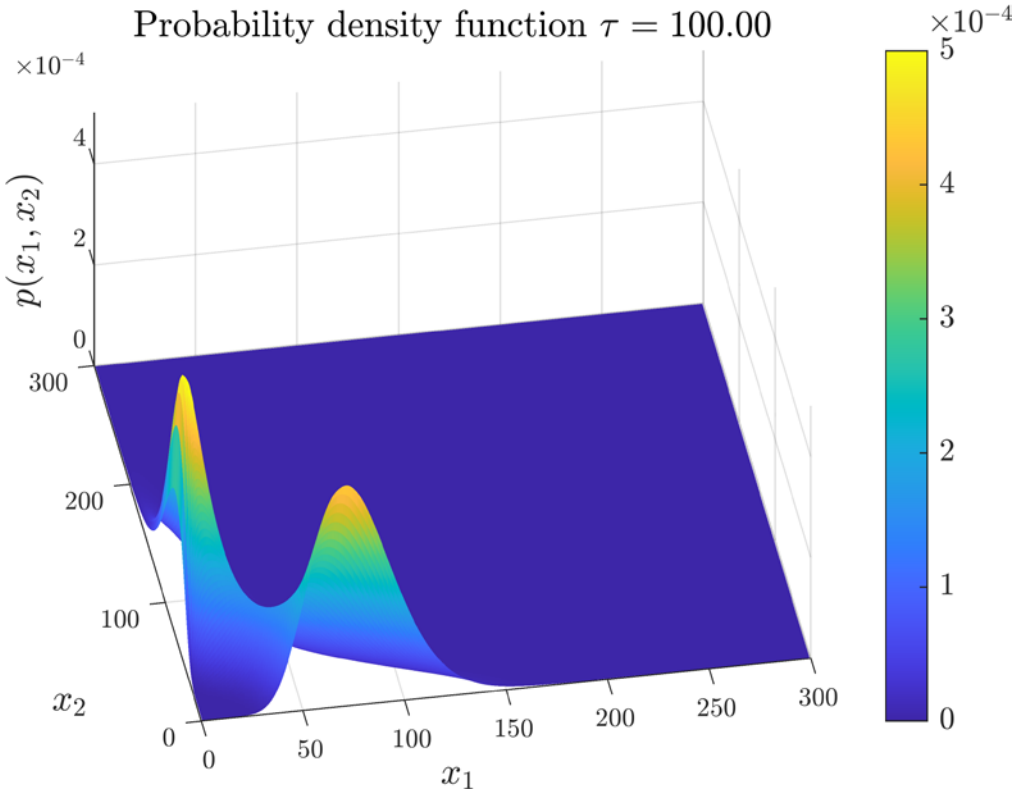
Members of the Group: Dr. Péter POLCZ, Balázs CSUTAK, Mihály András VÁGHY, Gergely HORVÁTH, Dávid SOMOGYI, Dorka KECSKÉS

Contact: szederkenyi@itk.ppke.hu

Keywords: *dynamical systems, control, parameter estimation, network models, nonnegative models*

Field of research: computer science engineering; info-bionics

The application of mathematical models describing a certain aspect of reality is indispensable for the understanding and efficient operation of technological or natural systems. When we are interested in the evolution of certain quantities usually in time and/or space, we use dynamic models. The deep understanding and the targeted manipulation of such models' behaviour are studied by systems and control theory which provides a common framework for handling dynamical models from different application fields and thus supports to form an interdisciplinary viewpoint. The primary target of our research is the analysis, control and identification of biologically motivated systems matching the main focus of the Faculty. During the years 2020 and 2021, we put a special emphasis on the system theoretic study of the COVID-19 pandemic besides the ongoing basic research topics. Our latest research problems are related to generalized ribosome flow models and gene regulation networks.



Stationary probability density function of the protein concentrations of a 2-dimensional genetic toggle switch computed via compartmental discretization.

Key publications:

1. *Pereira, M., Kulcsár, B., Lipták, G., Kovács, M. and Szederkényi, G.* **The Traffic Reaction Model: A kinetic compartmental approach to road traffic modeling** TRANSPORTATION RESEARCH PART C: EMERGING TECHNOLOGIES 158: 104435 (2024)
2. *Vághy, M. A., Otero-Muras, I., Pájaro, M. and Szederkényi, G.* **A Kinetic Finite Volume Discretization of the Multidimensional PIDE Model for Gene Regulatory Networks** BULLETIN OF MATHEMATICAL BIOLOGY 86(2) pp. 1-26. (2024)
3. *Vághy, M. A. and Szederkényi, G.* **Persistence and stability of generalized ribosome flow models with time-varying transition rates** PLOS ONE 18(7): e0288148 (2023)

APPLICATIONS OF KILOPROCESSOR ARRAYS

Prof. Péter SZOLGAY

Dr. Zoltán NAGY

Head of Research Group: Prof. Péter SZOLGAY, Dr. Zoltán NAGY

Members of the Group: Dr. András KISS, Vamsi Kiran ADHIKARLA, Levente SÁNTHA, Mary GUINDY

Contact: szolgay.peter@itk.ppke.hu, nagy.zoltan@itk.ppke.hu

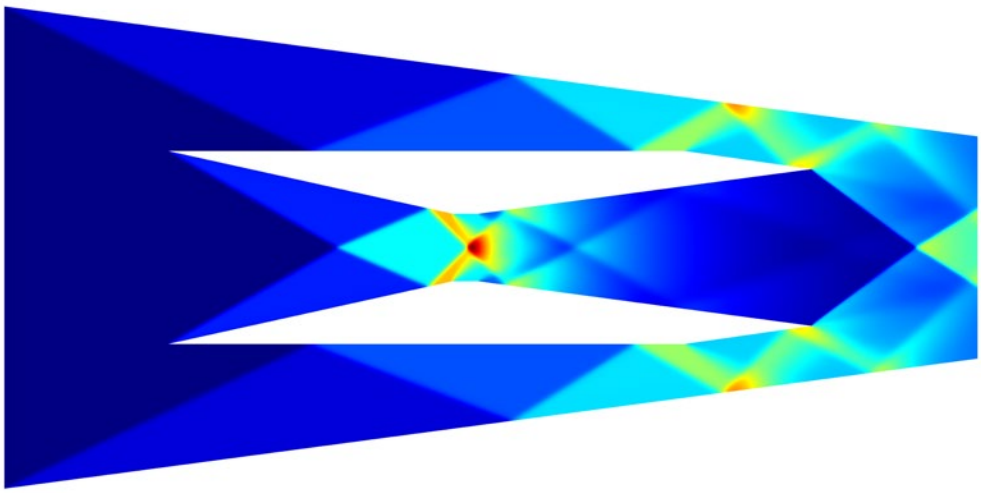
Keywords: *parallel computing, processor arrays, heterogeneous architectures, FPGA, reconfigurable computing*

Field of research: computer science engineering

In the research laboratory, we deal with the design and measurement of analog and digital circuits. In previous years, several circuits designed in the laboratory were also manufactured. Currently, the main focus is the design and implementation of digital circuits on programmable logic devices. The applications cover a wide range from the simulation of complex physical systems through image processing to the acceleration of search in bioinformatics databases.

We have developed a small-sized and low-power image processing architecture with the UAV Vision Lab. We accelerated a charged alpha-helix detection algorithm on FPGA with the Structural Biology and Proteomics Lab. We accelerated the simulation of micromagnetic arrays on FPGA in cooperation with the Optics, Magnonics and New Generation Hardware Laboratory.

During the design of circuits, in addition to traditional hardware description languages (VHDL, Verilog), high-level synthesis plays an increasingly important role, which enables the description of the architecture in C/C++. The latest integrated circuit design software (Cadence, Mentor) and development environments for FPGA design are available in the lab.



Accelerating Computational Fluid Dynamics (CFD) simulation on FPGA: Shock waves in a 2D intersection of a scramjet engine.

Key publications:

1. *Fejér, A., Nagy, Z., Benois-Pineau, J., Szolgay, P., de Rugy, A. and Domenger, J-P.* **Hybrid FPGA–CPU-Based Architecture for Object Recognition in Visual Servoing of Arm Prosthesis** JOURNAL OF IMAGING 8:2 p. 44 (2022)
2. *Zarandy, A., Horvath, A. and Szolgay, P.* **CNN Technology-Tools and Applications** IEEE CIRCUITS AND SYSTEMS MAGAZINE 18:2 pp. 77-89. (2018)
3. *Nagy, Z., Nemes, Cs., Hiba, A., Csík, Á., Kiss, A., Ruszinkó, M. and Szolgay, P.* **Accelerating unstructured finite volume computations on field-programmable gate arrays** CONCURRENCY AND COMPUTATION: PRACTICE AND EXPERIENCE 26(3) pp. 615-643. (2014)

DATA. MEDIA. COMMUNITY

Dr. Gergely LUKÁCS

Head of Research Group: Dr. Gergely LUKÁCS

Members of the Group: Hunor BÁLINT, Dániel DOBÁK, Balázs KOVÁCS, Dániel PÁSZTOR, Lili Anna STAJER, András SZENTENDREY, Klaudia SZILI, Melinda SZIKSZ

Contact: lukacs@itk.ppke.hu

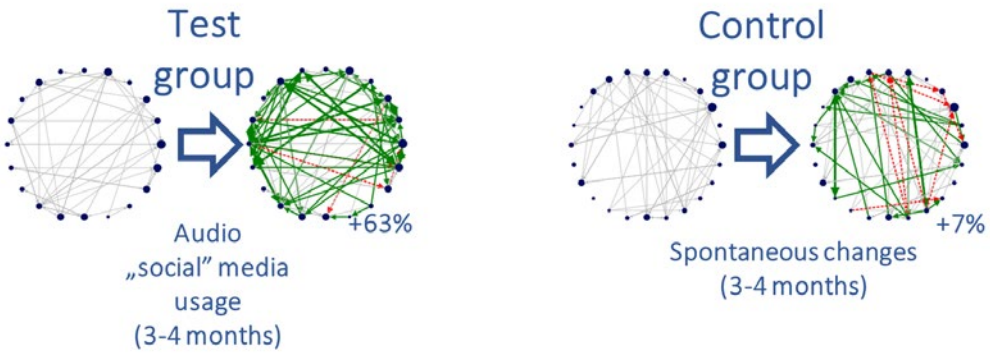
Keywords: *big data, machine learning, social media, generative AI*

Field of research: computer science engineering; machine learning

Data management and machine learning have been key areas for years. In recent times, data-driven generative artificial intelligence has become a central player, causing further landslide technological and societal changes. In the lab, we work on the technological side of the topic on the one hand, and on the other hand -- in interdisciplinary collaborations -- on applications that promise societal benefits. In the latter, we also place particular emphasis on issues affecting human relationships and communities, which are largely, and unfortunately often negatively, influenced by technology.

On the technology side, building on our previous work, we have recently explored the potential applications of generative AI for big data and machine learning. We also use big data tools to analyse the parameters of large language models (a small model can have 7 billion parameters), the "engine" of generative AI.

On the application side, we analyse social media data, in a collaborative context, on the interaction between pair bonds and social media use. Generative AI also offers new possibilities for the creation of voice-based social media, speech-music playlists. Finally, new possibilities for the analysis of medical literature are offered by technological tools and solutions.

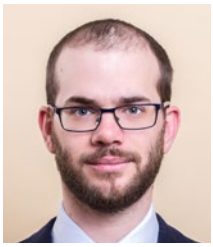


Strengthening community ties with audio-based „social" media: Each node represents a student, each edge a positive answer to the question „Who can you ask for help in your studies": Solid green line: new tie; dotted red line: lost tie; grey line: no change. The test group used our audio social media prototype for 3-4 months, the control group did not use it.

Key publications:

1. *Tésenyi, T., Lukács, Á., Járay, M. and Lukács, G.* **Identification of social network patterns among Hungarian clinical pastoral care professionals** XXXVIII SUNBELT CONFERENCE, Utrecht, Hollandia (2018)
2. *Lukács, G. and Jani, M.* **Analyzing speech and music blocks in radio channels: Lessons learned for playlist generation** ELEVENTH INTERNATIONAL CONFERENCE ON DIGITAL INFORMATION MANAGEMENT (ICDIM) p. 6. pp. 179-184. (2016)
3. *Jani, M., Lukács, G. and Takács, G.* **Experimental investigation of transitions for mixed speech and music playlist generation** PROCEEDINGS OF THE 4TH ACM INTERNATIONAL CONFERENCE ON MULTIMEDIA RETRIEVAL, ICMR 2014 ASSOCIATION FOR COMPUTING MACHINERY (ACM) p. 7. pp. 392-398. (2014)

HIGH PERFORMANCE COMPUTING



Dr. István Zoltán REGULY

Head of Research Group: Dr. István Zoltán REGULY

Members of the Group: Gábor Dániel BALOGH, Bálint SIKLÓSI, Balázs DRÁVAI

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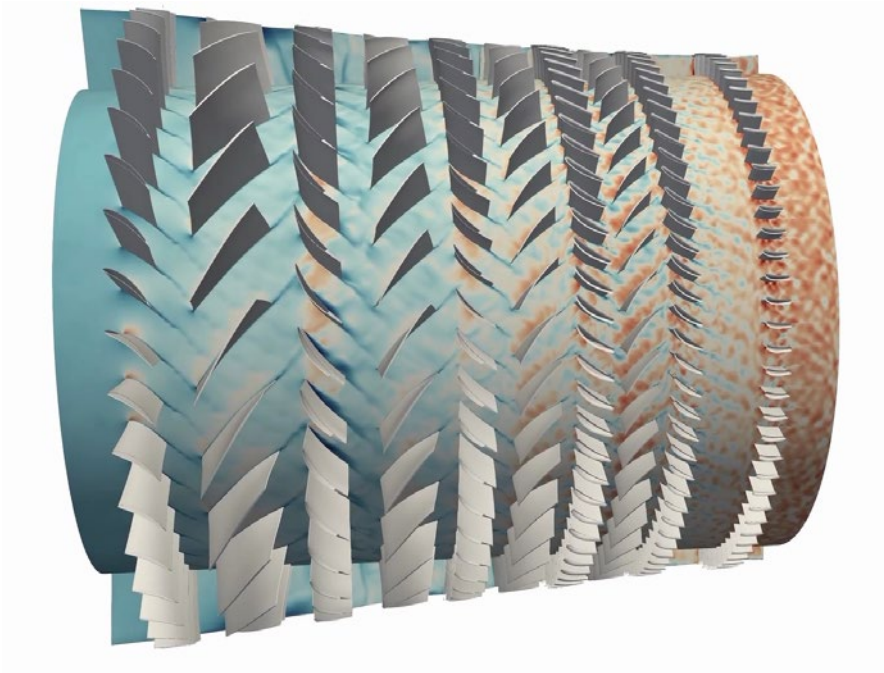
Keywords: *programming abstractions, CPU, GPU, distributed computing, parallel computing*

Field of research: computer science engineering; machine learning

The research lab deals with maintaining and optimizing the utilization of parallel hardware solutions (high computational capacity servers) established within the Faculty, and also explores the high-level description of the optimal software-hardware interface. Our group conducts research using domain-specific programming languages OP2 and OPS to enable engineers and physicists to describe their problems efficiently and concisely without needing to concern themselves with the details of parallel hardware operations. Thus, from the high-level description of algorithms interpreted on structured and unstructured meshes, the OP2 and OPS languages generate high-performance code optimized for various parallel hardware. In our research, we collaborate with academic and industrial research groups, providing them access to modern architectures and high-performance computing environments.



The high-fidelity simulation of aircraft engines enables the design and development of effective airplanes. The simulation process is computationally intensive - thanks to our research it can be run on the largest supercomputers in the world, built with the latest massively parallel CPUs and GPUs.

Key publications:

1. *Mudalige, G. R., Reguly, I. Z., Prabhakar, A., Amirante, D., Lapworth, L. and Jarvis, S. A.* **Towards Virtual Certification of Gas Turbine Engines With Performance-Portable Simulations** 2022 IEEE INTERNATIONAL CONFERENCE ON CLUSTER COMPUTING (CLUSTER) pp. 206-217. (2022)
2. *Balogh, G. D., Flynn, T. S., Laizet, S., Mudalige, G. R. and Reguly, I. Z.* **Scalable Many-Core Algorithms for Tridiagonal Solvers** COMPUTING IN SCIENCE & ENGINEERING 24(1) pp. 26-35. (2021)
3. *Sulyok, A. A., Balogh, G. D., Reguly, I. Z. and Mudalige, G. R.* **Locality optimized unstructured mesh algorithms on GPUs** JOURNAL OF PARALLEL AND DISTRIBUTED COMPUTING 134 pp. 50-64. (2019)

MACHINE PERCEPTION AND GEO-INFORMATION COMPUTING

Prof. Csaba BENEDEK

Head of Research Group: Prof. Csaba BENEDEK

Members of the Group: Dr. Yahya IBRAHIM, Lóránt KOVÁCS, Marcell KÉGL, Vilmos MADARAS, Balázs PÁLFFY, József KÖVENDI, Balázs BÓDIS

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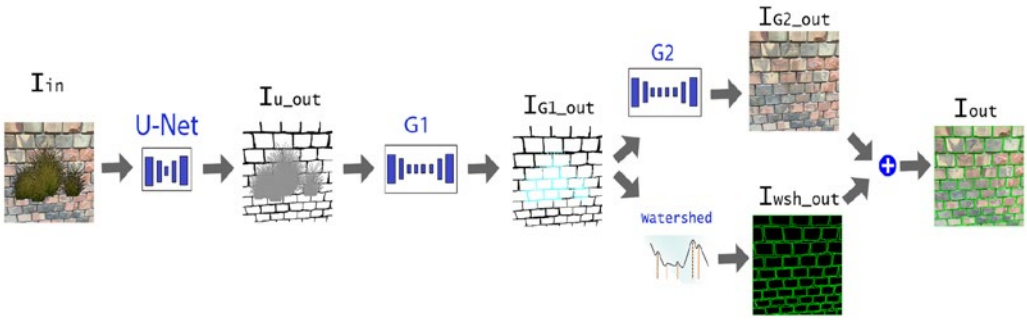
Keywords: *machine vision, pattern recognition, point cloud analysis, 3D reconstruction*

Field of research: computer science engineering; machine learning

Up to date 3D sensors revolutionized the acquisition of environmental information. 3D vision systems of self-driving vehicles can be used not only for safe navigation, but also for real time mapping of the environment, detecting and analyzing static, and dynamic objects and scene elements. The new generation geo-information systems (GIS) store extremely detailed 3D maps about the cities, consisting of dense 3D point clouds, registered camera images and semantic metadata. Automatic filtering and processing of medical 3D data (MR, CT or ultrasound) with rapidly evolving quality and resolution is becoming increasingly important nowadays. The use of digital tools is also playing an increasing role in cultural heritage preservation, automated scene analysis and model reconstruction from images and laser scanning data is a key task for archaeological research.

The main goal of the research and development work in the Machine Perception and Geo-information Computing Laboratory is to obtain a holistic interpretation of our environment by automatically processing and fusing the measurements of sensors that record spatial information for different applications. Our research is carried out in cooperation with PPKE ITK and the HUN-REN SZTAKI Machine Perception Research Laboratory.

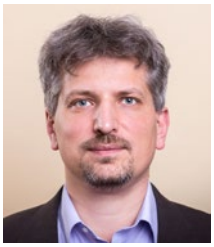


Support of cultural heritage protection: demonstration of a process that separates individual bricks/building elements in photographs of different masonry walls and automatically fills in missing/occluded wall image regions in a realistic way for human observers

Key publications:

1. *Zováthi, Ö., Nagy, B. and Benedek, Cs.* **Point Cloud Registration and Change Detection in Urban Environment Using an Onboard Lidar Sensor and MLS Reference Data** INTERNATIONAL JOURNAL OF APPLIED EARTH OBSERVATION AND GEOINFORMATION, ELSEVIER 110: 102767 (2022)
2. *Benedek, Cs.* **Multi-level Bayesian Models for Environment Perception** SPRINGER INTERNATIONAL PUBLISHING ISBN 978-3-030-83654-2 (2022)
3. *Nagy, B., Kovács, L. and Benedek, Cs.* **ChangeGAN: A deep network for change detection in coarsely registered point clouds** IEEE ROBOTICS AND AUTOMATION LETTERS 6(4) pp. 8277 - 8284. (2021)

MOBILE SENSOR PLATFORMS AND MULTIMODAL SENSING NETWORKS



Dr. András OLÁH

Dr. Kálmán TORNAI

Head of Research Group: Dr. András OLÁH, Dr. Kálmán TORNAI

Members of the Group: András HALÁSZ, Lóránt DAUBNER, Dániel NÉMETH, Levente BOLYKI; Attila TIHANYI, Máté LŐRINCZ

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Keywords: *mobile platforms, sensor data processing, open-set recognition, sensor networks*

Field of research: computer science engineering; machine learning

The primary focus of our research is the industrial application of WSN, where the sensor network is augmented with an actuator network. The design of the distributed-control must consider the constraints on the tolerance of delays that is typical to a specific industrial field. In 2011 we established the MAD (Mobile Application Development) laboratory lead by Kálmán Tornai. In MAD Lab, the most important smartphone platforms (currently Android and iOS, formerly Windows) are available to develop applications that process and analyze the data acquired by internal or external sensors of the smartphones. The research objective is to find methods that can verify the user identity of the device and to prevent unauthorized access. The aim is to solve the problem at high accuracy on the basis of the analysis of sensor measurements with a soft-biometric approach. The importance of the method is given by the weaknesses of traditional, widespread methods that can be easily spoofed. The applied AI and ML algorithms can be used on other data analysis and recognition problems where suspicious user behaviors must be detected.

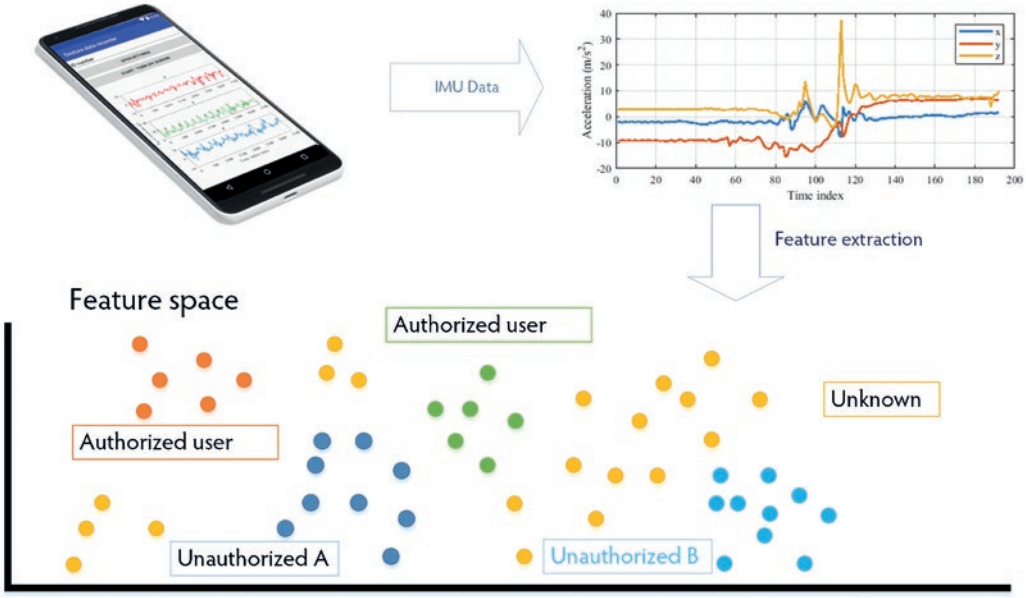
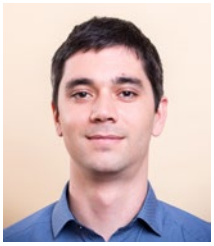


Illustration of the workflow, how open-set recognition is applied to IMU sensor readings of a smart mobile phone. The proposed method can distinguish known users and separate them from unknown (unknown to the system during the training phase) patterns.

Key publications:

1. *Halász, A. P., Al Hemeary, N., Daubner, L. S., Zsedrovits, T. and Tornai, K.* **Improving the Performance of Open-Set Recognition with Generated Fake Data** ELECTRONICS 12(6): 1311 (2023)
2. *Németh, D. I. and Tornai, K.* **Electrical Load Classification with Open-Set Recognition** ENERGIES 16(2): 800 (2023)
3. *Tornai, K. and Scheirer, W. J.* **Gesture-based User Identity Verification as an Open Set Problem for Smartphones** PROCEEDINGS OF THE 12TH IAPR INTERNATIONAL CONFERENCE ON BIOMETRICS (2019)

UAV VISION



Dr. Tamás ZSEDROVITS

Head of Research Group: Dr. Tamás ZSEDROVITS

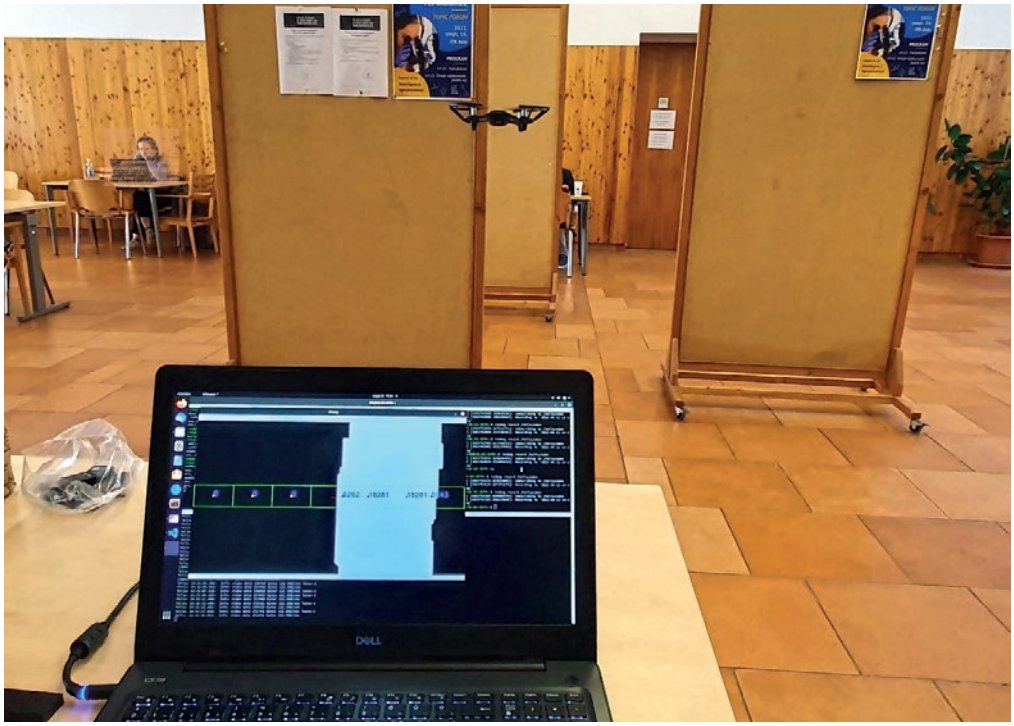
Members of the Group: Nawar AL-HEMEARY, Lóránt DAUBNER, Csongor TARNAI, Balázs Ádám LENGYEL, Gergő MÉSZÁROS

Contact: zsedrovits.tamas@itk.ppke.hu

Keywords: *UAV, computer vision, sense-and-avoid, embedded systems, bio-motivated algorithms*

Field of research: computer science engineering; machine learning

The UAV Vision Lab aims to explore the intersection of unmanned aerial vehicles (UAVs) and computer vision. A key research focus is optimizing computational tasks for UAVs to achieve minimal power consumption using compact, cost-effective tools. One primary research area is camera-based collision avoidance, which involves detecting and tracking distant aircraft through one or more camera feeds. The goal is to create an efficient collision avoidance system with low power consumption and small size, essential for real-time onboard processing. Another research focus is on ergonomic control methods for UAVs, aiming to develop more natural, quicker-to-learn, and more precise piloting techniques compared to current standards. A third significant research area involves indoor applications of UAVs, utilizing machine vision to perform tasks without relying on external reference systems, using only onboard sensors such as cameras, IMUs, and LiDAR. For example, in 3D cave mapping, the lab aims to use these sensors to create highly accurate 3D maps of cave passages, enhancing the discovery of new paths and assisting cavers. Additionally, students at the lab work on various projects, including developing simulators for collision avoidance, creating 3D building models with photogrammetric tools, face recognition and tracking with drone swarms, neuromorphic collision avoidance, visual indoor navigation, and building a video annotation database.



Experiment with a bio-motivated vision system for autonomous obstacle avoidance on drones. The image shows the drone flying through the free path between the display panels in a complex environment. The system consists of pre-processing based on a mammal retina model and a U-net for the vision task. The video is recorded and streamed by a DJI Tello drone to a laptop running ROS on Ubuntu for drone control and communication and the neural network with a PyTorch-based implementation on the laptop's dedicated GPU.

Key publications:

1. *Pethő, M. and Zsedrovits, T.* **UAV obstacle detection with bio-motivated computer vision** 17TH INTERNATIONAL WORKSHOP ON CELLULAR NANOSCALE NETWORKS AND THEIR APPLICATIONS (CNNA) pp. 1-4. (2021)
2. *Hiba, A., Sántha, L. M., Zsedrovits, T., Hajder, L. and Zarandy, A.* **Onboard Visual Horizon Detection for Unmanned Aerial Systems with Programmable Logic** ELECTRONICS (SWITZ) 9(4): 614 (2020)
3. *Zsedrovits, T., Bauer, P., Jani Mátyásné Pencz, B., Hiba, A., Gőzse, I., Kisantal, M., Németh, M., Nagy, Z., Vanek, B., Zarándy, A. and Bokor, J.* **Onboard visual sense and avoid system for small aircraft** IEEE AEROSPACE AND ELECTRONIC SYSTEMS MAGAZINE 31(9) pp. 18-27. (2016)

ACOUSTIC IMAGING AND MEDICAL SIGNALS (AIMS-LAB)

Dr. Márton Áron GODA

Head of Research Group: Dr. Márton Áron GODA

Members of the Group: Dr. Miklós GYÖNGY, Dr. Janka HATVANI, Dr. Miklós KOLLER, Kristóf MÜLLER

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Keywords: *PCG, ECG, PPG, CTG, ultrasound imaging and biomedical signal processing*

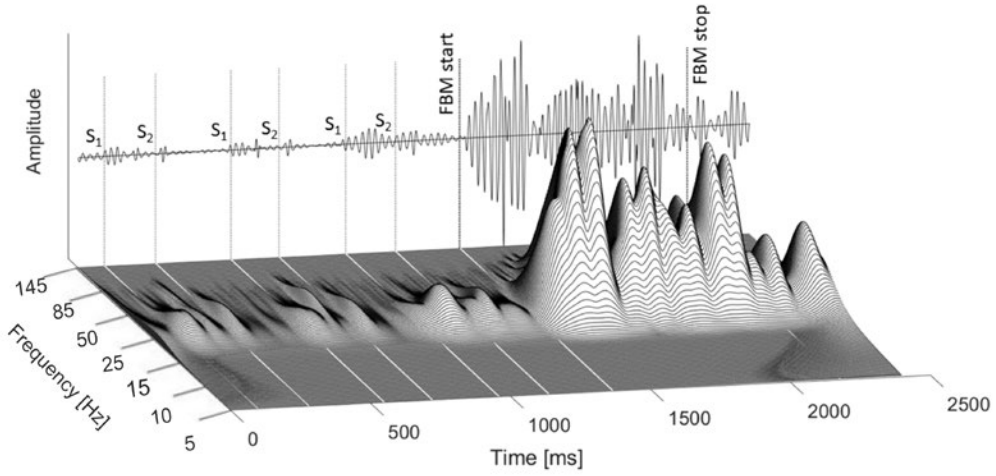
Field of research: info-bionics; computer science engineering

Our laboratory hosts two research groups. The Acoustic Imaging group aims to understand various wave processes and phenomena to map the properties of various objects, including biological tissue, prenatal sonography, and other side projects like water echography in rivers. Primarily ultrasound is used, however other modalities such as optics and CT are also of interest. We develop models that allow us to go beyond the classical resolution limits imposed by the diffraction limit.

The Medical Signals group focuses on fetal activity monitoring in the third trimester, using PCG, ECG, PPG, CTG, and other related biomedical imaging tools. During the phonographic measurement, non-invasive acoustic sensors are placed on the maternal abdomen wall. The main goal of this research group is to aid the current clinical standards, especially in the field of fetal PCG and Ephnography.

The research groups are highly motivated to provide Ultrasound Imaging and Biomedical Signal Processing courses by appropriate experimental measurement and demonstration tools. We have strong networks with hospitals, clinics, and biomedical companies, too.

Collaborative Partnerships: Obstetrics and Gynaecology Department, St. Margaret Hospital (Budapest, Hungary), Department of Dermatology, Venereology and Dermatooncology, Semmelweis University (Budapest, Hungary), Dermus (Hungary), 77 Elektronika (Hungary)



Time and frequency analysis of Fetal Breathing Movement episodes in fetal phonocardiography signal. The FBM and heart sounds exhibit distinct frequency characteristics, with the FBM signal appearing at lower frequencies and the peak values of heart sounds being located at higher frequencies. The separation between the starting frequency of the FBM and the heart sounds is well-defined. Specifically, the FBM can be readily detected within the 20-30 Hz frequency band, whereas the heart sounds manifest themselves at higher frequency ranges.

Key publications:

1. *Goda, M. Á., Charlton, P. H. and Behar, J. A.* **pyPPG: A Python toolbox for comprehensive photoplethysmography signal analysis** PHYSIOLOGICAL MEASUREMENT 45(4), 045001 (2024)
2. *Goda, M. Á., Telek, T. and Kovács F.* **Novel phonographybased measurement for fetal breathing movement in the third trimester** SENSORS 2021(1), p. 211. (2021)
3. *Hatvani, J., Horváth, A., Michetti, J., Basarab, A., Kouamé, D. and M. Gyöngy, M.* **Deep Learning-Based Super-Resolution Applied to Dental Computed Tomography** IEEE TRANSACTIONS ON RADIATION AND PLASMA MEDICAL SCIENCES (in print, 2018)

IMPLANTABLE MICROSYSTEMS

Prof. Zoltán FEKETE

Head of Research Group: Prof. Zoltán FEKETE

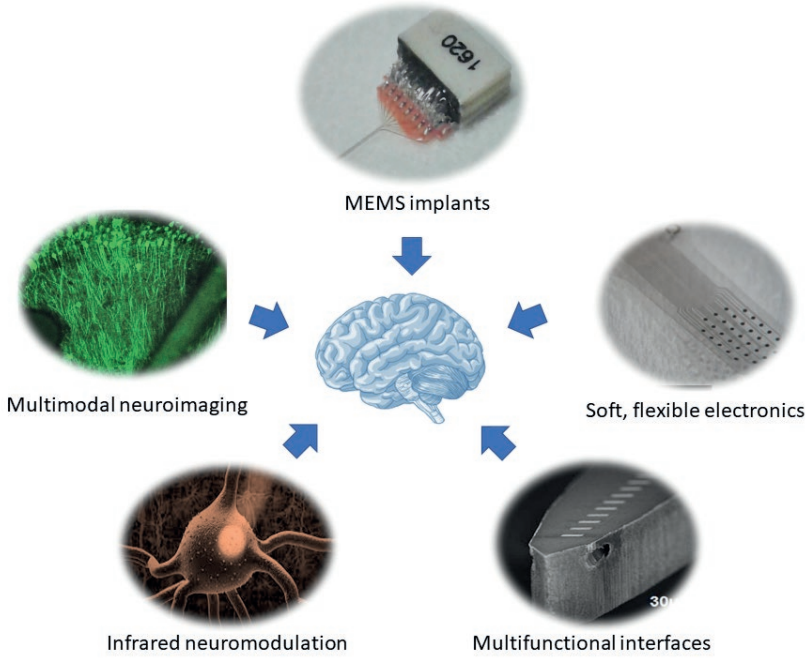
Members of the Group: Dr. Ágoston Csaba HORVÁTH, Dr. Ágnes SZABÓ, Zsófia BALOGH-LANTOS, Levente VÍG, Ákos MÓROCZ, Dr. Richárd FIÁTH, Dr. Péter BARTHÓ

Contact: fekete.zoltan@itk.ppke.hu

Keywords: *microtechnology, neurobiolgy, brain-machine interfaces, microimplants*

Field of research: info-bionics

Our group utilizes the recent advancement in microengineering to create novel brain-machine interfaces in the microscale. Manufacturing technology and characterization of such miniaturized sensors and actuators, and their applications in vivo require truly interdisciplinary approaches including material science, electronics technology, neurobiology and informatics. One of the most challenging task is the development of microdevices implanted in the neural tissue. Our research group is engaged in the design, implementation, and testing of microimplants that are able to record cellular communication with high spatial and temporal resolution and are also able to control cellular processes by means of optical and pharmacological stimulation. In the field of optical stimulation, our lab validates novel microdevices engineered to perform focal infrared stimulation in the deep tissue. This technology is also leveraged to characterize the response of individual cells to infrared neuromodulation in the living experimental animals.



Our group combines expertise from neuroscience and engineering sciences to create microscale device to interrogate or stimulate brain cells. These interfaces are created using MEMS (micro-electromechanical systems) technology, and enables to combine electrophysiology with neuroimaging, optoelectronics or microfluidics.

Key publications:

1. *Fedor, F. Z., Madarász, M., Zátonyi, A., Szabó, Á., Lőrincz, T., Danda, V., Spurgin, L., Manz, C., Rózsa, B. and Fekete Z.* **Soft, thiol-ene/acrylate based electrode array for long-term recording of intracranial EEG signals with improved biocompatibility in mice** ADVANCED MATERIALS TECHNOLOGIES 7: 2100942 (2022)
2. *Ebrahimi, N., Bi, C., Cappelleri, D. J., Ciuti, G., Conn, A. T., Faivre, D., Habibi, N., Hošovský, A., Iacovacci, V., Khalil, I. S. M., Magdanz, V., Misra, S., Pawashe, C., Rashidifar, R., Rodriguez, P., Sitti, M., Fekete, Z. and Jafari, A.* **Magnetic Actuation Methods in Bio/Soft Robotics** ADVANCED FUNCTIONAL MATERIALS 31: 2005137 (2021)
3. *Horváth, Á. C., Boros, Ö. C., Komáromi, L., Borbély, S., Koppa, P., Barthó, P. and Fekete, Z.* **Infrared neural stimulation and inhibition using an implantable silicon photonic microdevice** MICROSYSTEMS & NANOENGINEERING 6: 44 (2020)

MOVEMENT ANALYSIS AND MOTOR CONTROL

Dr. József LACZKÓ

Head of Research Group: Dr. József LACZKÓ

Members of the Group: Dr. Lilla BOTZHEIM, Dr. Mariann MRAVCSIK, Márton Bese NASZLADY, Balázs RADELECZKI, Amelita FODOR

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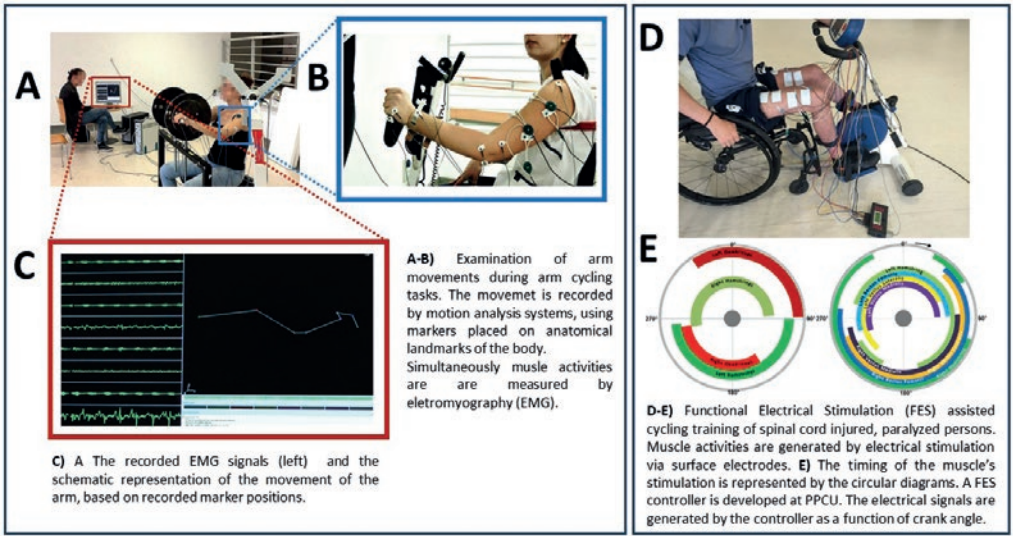
Keywords: *motor control, movement rehabilitation, functional electrical stimulation*

Field of research: info-bionics; mathematics, physics, electrical engineering

The laboratory investigates how the central nervous system controls human limb movements for well coordinated execution of motor tasks. Such tasks are for instance, reaching a target with the arm, transporting an object held in the hand or cycling movements by the lower limbs or upper limbs.

We apply a movement analyzing systems for recording kinematic and electromyographic data during human limb movements. Markers are placed on anatomical landmarks of the body and the positions of the markers are recorded. Simultaneously, applying surface electromyography (EMG) muscle activities are measured. Special interest of the laboratory is functional electrical muscle-stimulation and its application in rehabilitation of paralyzed, spinal cord injured persons. We continue our research in cooperation with colleagues from the Wigner Research Centre for Physics and apply it in the National Institute for Medical Rehabilitation.



The figure illustrates different aspects of our research work from data recording and exploratory research (Panel A-B-C) to the practical applications (Panel D-E). Our goal is to improve the rehabilitation and living conditions of motor-impaired people with the common application of informatics, and natural sciences.

Key publications:

1. *Radeleczki, B., Mravcsik, M., Bozheim L. and Laczko, J.* **Prediction of leg muscle activities from arm muscle activities in arm and leg cycling** THE ANATOMICAL RECORD 306(4) pp. 710-719. (2023)
2. *Botzheim, L., Laczko, J., Torricelli, D., Mravcsik, M., Pons, J. L. and Barroso, F. O.* **Effects of gravity and kinematic constraints on muscle synergies in arm cycling** JOURNAL OF NEUROPHYSIOLOGY 125(4) pp. 1367-1381. (2021)
3. *Mravcsik, M., Klauber, A., Putz, M., Kast, C., Mayr, W. and Laczko, J.* **Tricycling by FES of quadriceps muscles leads to increased cycling speed over series of trainings of persons with flaccid paraplegia** PROCEEDINGS OF THE 13TH VIENNA FES WORKSHOP pp. 133-135. (2019)

PROSTHETICS

Dr. György CSEREY

Benedek József TASI

Head of Research Group: Dr. György CSEREY, Benedek József TASI

Members of the Group: Márton Bese NASZLADY, Dávid László PELYVA, Dávid HOLLÓ, Veronika KISS, Balázs FORMANEK, Ádám SZABÓ, Márton KLENCZER, Balázs KRÁZ, Zsófia NGUYEN, Boróka GOMBKÖTŐ-MOLNÁR, Krisztina CSEPEI

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Keywords: *prosthetics, biomimetics, humanoid robotics, soft robotics, textile technologies, bionic interfaces*

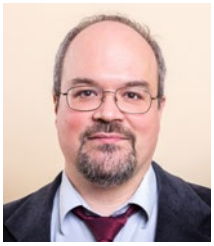
Field of research: info-bionics; mechatronics engineering

The Prosthetics Lab develops biomimetic artificial limbs and wearable biomedical interfaces, and researches technologies required for their industrialization and scalable production. The Lab focuses primarily on humanoid hands for prosthetics and teleoperated robotics, covering all aspects from product & UX design and mechanical & electronical engineering, to additive and subtractive manufacturing, textile- and other material technologies, with a special focus on developing automated design & production workflows using advanced CAD/CAM software and custom production machinery.

Key developments include anatomically correct robotic hands with 3D printed skeletal structure and textile soft and connective tissues, wearable electrophysiological interfaces for multi-channel EMG control and electrical stimulation-based haptic feedback using smart textiles, motion-capture gloves with custom, high-fidelity optical sensors, and a comprehensive 3D-braiding platform consisting of a programmable braiding machine and an associated control software and programming environment, for the automated production of artificial load-bearing tissues.


PFAFF

SENSING-ACTUATING ROBOTICS



Dr. György CSEREY

Dr. Miklós KOLLER

Head of Research Group: Dr. György CSEREY, Dr. Miklós KOLLER

Members of the Group: Dr. Sándor FÖLDI, Dániel HAJTÓ, Boldizsár BALOG, Benedek TASI, Dávid PELYVA, Attila RÉPAI, András BENEDEK, István SZÉKELY, Tamás ENDREI, Péter FODOR, Anna GELENCSÉR-HORVÁTH, Katalin SCHÄFFER, Rizal MAULANA, Eszter BIRTALAN, Réka KISS, Áron Boldizsár KÖVES, João Anastácio da Rocha ALMEIDA

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Keywords: *robotics, prosthetics, machine learning, human-machine interfaces, medical applications*

Field of research: info-bionics; machine learning

Our mission is to apply unique ideas inspired by Biology using Information Technologies. How can we design better protheses? How can you teach a robotic arm to grab objects safely and work effectively with people? What is the functional connection between visual and tactile sensing?

How to measure a person's continuous blood pressure in a non-invasive way? An innovative 3D force sensor developed jointly with PhD students has been purchased by many universities and research institutes for research and development purposes, along with several companies in the robotics industry.

Vision and perception are not only challenging for robots but can also be a challenge for humans in disaster situations, such as in flowing water where the visibility is only a few centimeters. This is why we are developing a VR solution for divers, aiming to make the environment visible and perceivable for them.

The harness-system (actuating strings, fittings) of the soft exoskeleton prototype.

Key publications:

1. *Lukas, U., Rico, J., Coupé, P., SanMiguel,J. C. and György Cserey, Gy.* **Deep Anomaly Generation: An Image Translation Approach of Synthesizing Abnormal Banded Chromosome Images** IEEE ACCESS: 59090-59098 (2022)
2. *Ignácz, A., Földi, S., Sótonyi, P. and Cserey, Gy.* **NB-SQI: A novel non-binary signal quality index for continuous blood pressure waveforms** BIOMEDICAL SIGNAL PROCESSING AND CONTROL 70: 103035 (2021)
3. *Tasi, B. J., Koller, M. and Cserey, Gy.* **Design of the anatomically correct, biomechatronic hand** arXiv:1909.07966. (2019)

SPORT BIONICS AND DATA INTELLIGENCE

Dr. László GRAND

Head of Research Group: Dr. László GRAND

Members of the Group: Péter FODOR, Gergő GALLI, Dominik HOMOKI, Márkus KISS, Anita KRISTÓF, Álmos LANGÓ, Dorka MEGELLAI, Gábor NAGY, Kata SZONDY

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Keywords: *wearable sensors and sensor networks, machine- and deep learning based sport and rehabilitation analytics*

Field of research: info-bionics; machine learning

The goal of our laboratory is to advance sports science and rehabilitation through the research and development of wearable sensors, the application of novel computer vision and machine/deep learning techniques, and cloud-based real-time data analytics. Our mission is to discover and share the correlations behind human performance with athletes, coaches, researchers, and companies, thereby promoting innovation and excellence in the world of sports and rehabilitation.

In our laboratory, we research and use wearable sensors to capture and record data generated during sports activities. By combining computer vision techniques with machine learning and deep learning algorithms, we strive to extract information about the dynamics of sports teams and correlate these with performance.

Our cloud-based data acquisition and processing system allows for the automatic analysis of large data volumes, enabling coaches, athletes, and researchers to gain immediate insights into the processes behind performance, enhance results, and prevent injuries. Additionally, we are committed to researching and developing tools and methods for

evaluating the effectiveness of home-based rehabilitation therapy. Through collaborations with companies and sports clubs, we aim to directly contribute to the industry's advancement with our research findings.

Key publications:

1. *Négyesi, J., Petró, B., Salman, D. N., Khandoker, A., Katona, P., Wang, Z., Almaazmi, A. I. S. Q., Hortobágyi, T., Váczi, M., Rácz, K., Pálya, Z., Grand, L., Kiss, R. M. and Nagatomi, R.* **Biosignal processing methods to explore the effects of side-dominance on patterns of bi- and unilateral standing stability in healthy young adults** FRONT. PHYSIOL. 13 p. 965702, (2022)
2. *2. Uhlár, Á., Ambrus, M., Kékesi, M., Fodor, E., Grand, L., Szathmáry, G., Rácz, K. and Lacza, Z.* **Kinect Azure–Based Accurate Measurement of Dynamic Valgus Position of the Knee—A Corrigible Predisposing Factor of Osteoarthritis** APPL. SCI. 11(12) p. 5536 (2021)
3. *Nagy, G., Komka, Z., Szathmáry, G., Katona, P., Gannoruwa, L., Erdös, G., Tarjányi, P., Tóth, M., Krepuska, M. and Grand, L.* **Multimodal Approach for Kayaking Performance Analysis and Improvement** INT. J. COMPUT. SCI. SPORT 19(2) pp. 51-76 (2020)

HUNGARIAN BIONIC VISION CENTER (ARTIFICIAL INTELLIGENCE LAB)

Dr. Kristóf KARACS

Head of Research Group: Dr. Kristóf KARACS

Members of the Group: Dr. Anna GELENCSÉR-HORVÁTH, András Attila SULYOK, Márton JUSZTIN, Péter HALÁSZ, Bálint LASSÚ, Andrei KONDAKOV, Boglárka SZABÓ

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Keywords: *mobile vision, visual assistance, low-power computing, ambient assisted living, spatio-temporal learning*

Field of research: machine learning; info-bionics

The center, which was founded together with Semmelweis University, aims to help perceiving visual information for visually impaired patients and to improve their quality of life by using medical devices and innovative technology, as well as developing new diagnostic and therapeutic procedures for eye diseases.

At the basic research level our lab focuses on modelling spatio-temporal event interpretation, including vision, the sensory channel that conveys most information for humans. Here we draw inspiration from the operation observed in human vision, but we also work on building stand-alone models aligned with the capabilities of available and soon to be available hardware.

A key principle we have developed is semantic embedding, which refers to the way information of different levels of abstraction, coming from sensors and a priori knowledge, make a contribution to the hierarchical recognition process at the appropriate level. We also develop representations and learning models for learning in partially observable environments.

Our most important project is development of the LetSee mobile app for visually imparied people that helps them in everyday tasks requiring vision.

Obstacle avoidance by PPKE pilot using a phone based visual assistant developed in the lab in the "Sidewalk" task of the Cybathlon Challenge 2023

Key publications:

1. *Sulyok, A. A and Karacs, K.* **Towards Using Fully Observable Policies for POMDPs** PROC. OF 2ND IEEE INTERNATIONAL CONFERENCE ON COMPUTING AND MACHINE INTELLIGENCE (ICMI), Istanbul, Turkey (2022)
2. *Gelencsér-Horváth, A., Kopácsi, L., Varga, V., Keller, D., Dobolyi, Á., Karacs, K. and Lőrincz, A.* **Tracking Highly Similar Rat Instances under Heavy Occlusions: An Unsupervised Deep Generative Pipeline** JOURNAL OF IMAGING 8(4) p. 109 (2022)
3. *Radványi, M. and Karacs, K.* **Peeling off image layers on topographic architectures** PATTERN RECOGNITION LETTERS 135, pp. 50-56. (2020)

LANGUAGE TECHNOLOGY

Prof. Gábor PRÓSZÉKY

Head of Research Group: Prof. Gábor PRÓSZÉKY

Members of the Group: Dr. Borbála NOVÁK, Dr. Attila NOVÁK, Kamran IBIYEV, Mram KAHLA, Dr. Győző YANG ZIJIAN, Dr. László János LAKI

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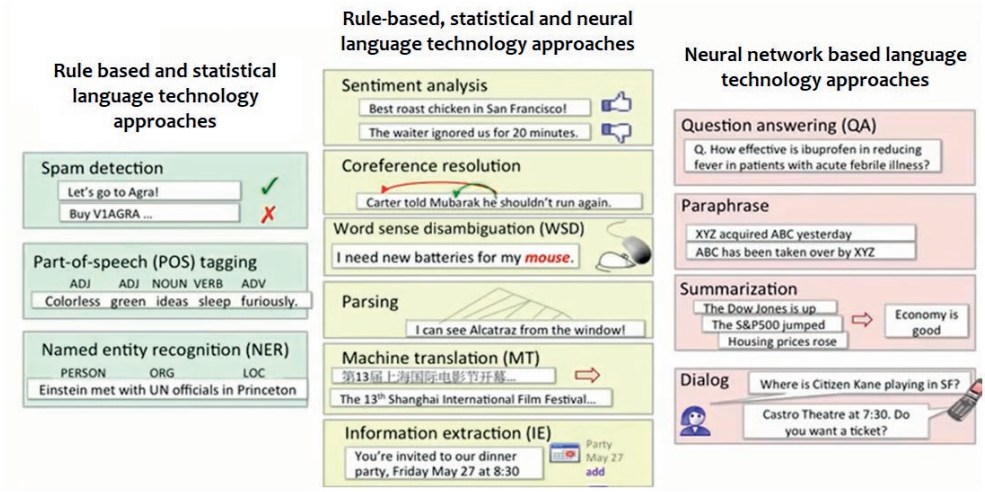
Keywords: *machine learning, neural language models, transformer architecture, fine tuning, corpus linguistics*

Field of research: machine learning; computer science engineering

The Language Technology Research Group of PPKE ITK is primarily, but not exclusively, engaged in the creation of neural models of Hungarian and other languages (currently: Arabic and Azerbaijani), fine-tuning of transformer models for different tasks and creating the necessary text corpora for them. With the help of an agreement with the Hungarian Research Centre for Linguistics the high-capacity computer background required for the above mentioned solutions is provided by the Research centre's Institute of Language Technology and Applied Linguistics.



Main research areas of our Language Technology Research Group.

Key publications:

1. *Novák, A. and Novák, B.* **Cross-lingual transfer of knowledge in distributional language models: Experiments in Hungarian** ACTA LINGUISTICA ACADEMICA 69(4) pp. 405-449. (2022)
2. *Prószéky, G.* **Guest Editor's Foreword** ACTA LINGUISTICA ACADEMICA 69(4) pp. 399-404. (2022)
3. *Yang, Zijian Gy.* **Neural text summarization for Hungarian** ACTA LINGUISTICA ACADEMICA 69(4) pp. 474-500. (2022)

SMART SENSORY COMPUTING

Dr. András HORVÁTH

Head of Research Group: Dr. András HORVÁTH

Members of the Group: Dóra Eszter BABICZ, Ákos KOVÁCS, Bálint MAGYAR, Gergely SZABÓ

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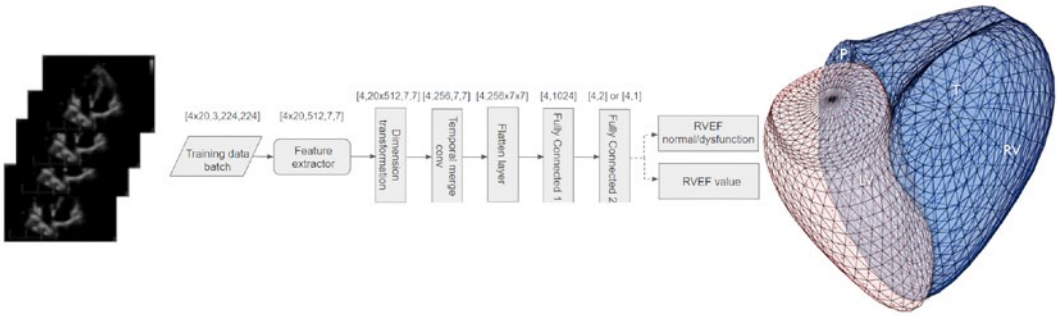
Keywords: *neural networks, machine learning, computer vision*

Field of research: machine learning; computer science engineering

In the Smart Sensory Computing Lab we have a special focus on machine vision and artificial intelligence. Many aspects of our comprehensive research are related to real-life applications, such as:

- Intelligent analysis of medical images (e.g. recognizing cancer cells on microscopic images, automatic eye diagnosis using fundus cameras)
- An internally-developed face recognition-based access control system,
- Intelligent Urban Vision Systems: Which can detect and track vehicles and pedestrians in an urban environment

In our fundamental research, we focus primarily on a deeper understanding of the principles of learning and vision. We pay special attention to improving the generalization capabilities of learning algorithms, particularly neural networks. We draw many valuable insights from the functioning of the human nervous system, which help us develop systems that can draw accurate conclusions from a limited amount of data. Our goal is for these systems to require minimal data collection and to be able to make meaningful and reliable inferences from just a few examples.



Our developed system is capable of creating a three-dimensional model from two-dimensional ultrasound images and estimating its key parameters, such as the heart's ejection fraction.

Key publications:

1. *Tokodi, M., Magyar, B., Soos, A., Takeuchi, M., Tolvaj, M., Lakatos, B. K. ... and Kovács, A.* **Deep learning-based prediction of right ventricular ejection fraction using 2D echocardiograms** CARDIOVASCULAR IMAGING, 16(8) pp. 1005-1018. (2023)
2. *Hatvani, J., Horváth, A., Michetti, J., Basarab, A., Kouamé, D. and Gyöngy, M.* **Deep learning-based super-resolution applied to dental computed tomography** IEEE TRANSACTIONS ON RADIATION AND PLASMA MEDICAL SCIENCES 3(2) pp. 120-128. (2018)
3. *Barna, L., Dudok, B., Miczán, V., Horváth, A., László, Z. I. and Katona, I.* **Correlated confocal and super-resolution imaging by VividSTORM** NATURE PROTOCOLS 11(1) pp. 163-183. (2016)

APPLIED MATHEMATICS

Dr. Mihály KOVÁCS

Head of Research Group: Dr. Mihály KOVÁCS

Members of the Group: Mihály András VÁGHY

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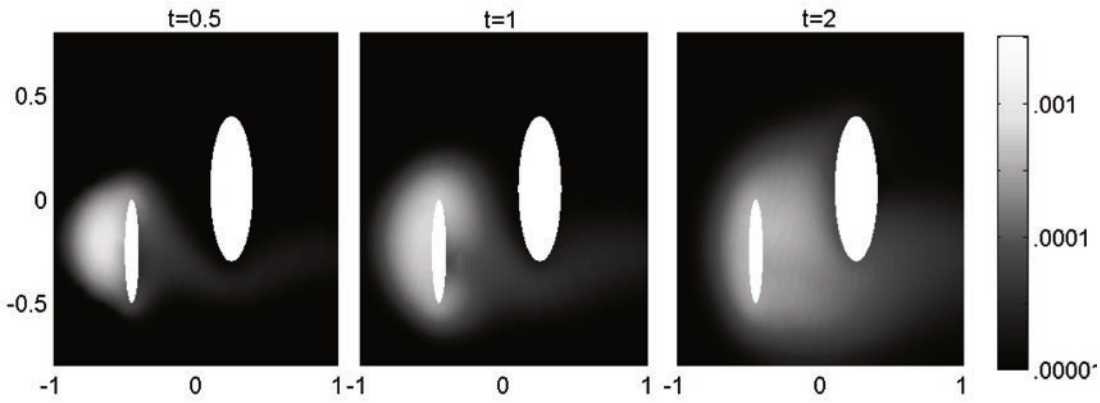
Keywords: *partial differential equations, stochastic differential equations, numerical analysis, non-local differential equations*

Field of research: mathematics, physics, electrical engineering

The mathematical model of many time- and space-dependent processfies is described by partial differential equations. If there is uncertainty in the equation, then the uncertainty can be modeled using stochastic partial differential equations. If a process taking place in a given location and/or at a given time instance is also affected by events further away in space and/or time, then the process can be described using non-local differential equations. The focus of the group's work is the mathematical theory and numerical analysis of the above equations. Recent research topics include the applications of stochastic partial differential equations to generate Gaussian random fields on metric graphs to provide input for various statistical models. The solution of these models require finite element solutions of elliptic problems on metric graphs which became large when the size of the network grows. To speed up the solution and lessen the memory requiremets one may emply domain decomposition methods which is also one of the current research focus of the group.



Fractional dispersion along flow lines around obstacles

Key publications:

1. *Bolin, D., Kovács, M., Kumar, V. and Simas, A. B.* **Regularity and numerical approximation of fractional elliptic differential equations on compact metric graphs** MATH. COMP. 93 pp. 2439-2472. (2024)
2. *Kovács, M. and Vághy, M. A.* **Nonlinear semigroups for nonlocal conservation laws** PARTIAL DIFFER. EQU. APPL. 4 paper 32. (2023)
3. *Baeumer, B., Kovács, M. and Sankaranarayanan, H.* **Fractional partial differential equations with boundary conditions** J. DIFFERENTIAL EQUATIONS 264(2) pp. 1377-1410. (2018)

FUNCTIONAL ELECTROMAGNETIC STRUCTURES

Prof. Zsolt SZABÓ

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Members of the Group: András ESZES

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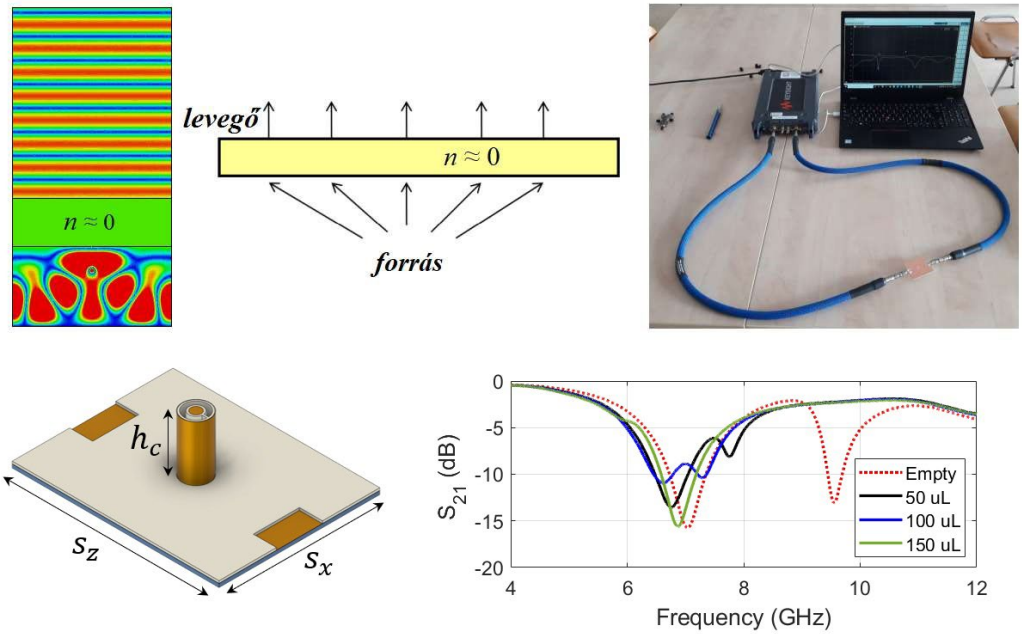
Keywords: *electromagnetics, metamaterials, composites, optics, microwave engineering*

Field of research: mathematics, physics, electrical engineering; info-bionics

In our laboratory structures with special electromagnetic properties, often called metamaterials are designed, fabricated and characterized. The fundamental idea behind the metamaterial research is that the interaction of electromagnetic waves with matter is governed not only by the chemical composition, but structuring can produce novel properties, which are not available in bulk form. We can design structures from microwave and mm wave frequencies to the optical wavelengths. The designed structures can find their applicabilty in several industries, e.g. in telecommunications by increasing the performance of antennas, they can be applied as novel sensing platforms for biomedical and environmental applications or as metasurfaces for subwavelength imaging.

Our metamaterial research has resulted in an accumulated knowledge in subwavelength resonators, which are particularly suitable for sensing applications. Recently, we have created several sensors working in the microwave regime for microfluidic applications. For example, a microfluidic mixer is combined with a complementary split ring resonator (CSRR), to enable the in-situ monitoring of the mixing of two liquids. Since dual-band devices are more reliable and provide additional information about the sample under test, the first two resonant frequencies of the CSRR are utilized for sensing. As another

example a dual-principle sensor is presented, whose operation is based on changes in electrostatic capacitance and resonance shifts at microwave frequencies. In this case the fluidic part is made by 3D printing.



The electromagnetic behavior of a metasurface with near zero refractive index. The measurement setup of a subwavelength resonator. The geometry and the microwave response of the dual-technology fluidic level sensor.

Key publications:

1. *Kálovics, M., Iván, K. and Szabó, Zs.* **Microfluidic Mixing Device With Integrated Dual-Band Microwave Sensor** IEEE SENSORS JOURNAL 23(14) pp. 15350-15360 (2023).
2. *Li, D., Szabo, Zs., Qing, X., Li, E-P. and Chen, Z. N.* **A High Gain Antenna With an Optimized Metamaterial Inspired Superstrate** IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION 60(12) pp. 6018-6023 (2012)
3. *Szabo, Zs., Park, G-H., Hedge, R. and Li, E-P.* **A Unique Extraction of Metamaterial Parameters Based on Kramers–Kronig Relationship** IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES 58(10) pp. 2646-2653 (2010)

OPTICS, MAGNONICS AND NEW GENERATION HARDWARE

Dr. György CSABA

Dr. Ádám PAPP

Prof. Árpád CSURGAY

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Keywords: *optics, spintronics, magnonics, quantum engineering, neuromorphic computing devices*

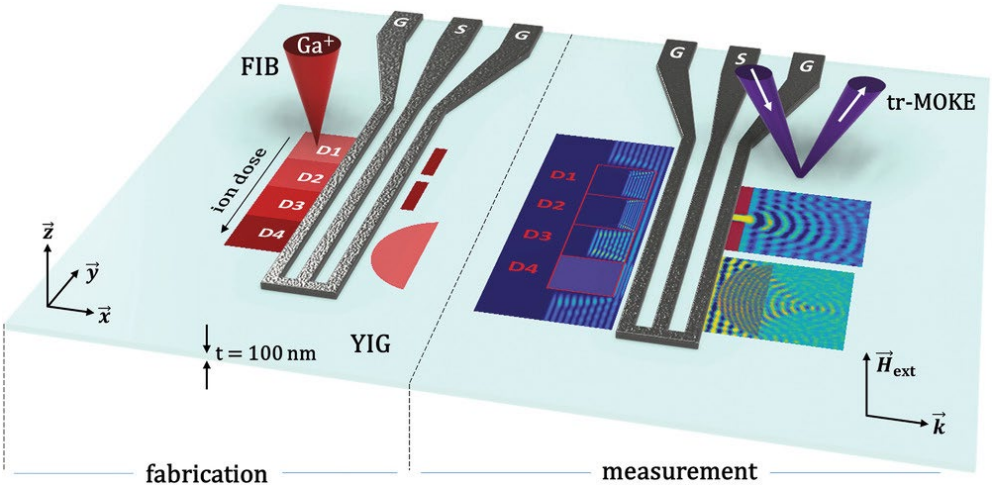
Field of research: mathematics, physics, electrical engineering

Our lab experimentally studies magnetic nanostructures and analog circuits, for the development of next-generation computing devices. Our main instrument is a unique TR-MOKE setup (Time-resolved Magneto Optical Microscope), that measures dynamic behavior nanomagnets and spin waves at high frequencies. Besides magnetic studies, we can perform a wide range of optical and high-frequency electrical measurements.

Our research group works on the design and development of Beyond Moore computing devices. After the end of Moore's law (the exponential scaling of microelectronic circuits), these devices will allow the future growth of computing power.

Our specialty is physics-inspired computing, when realizing a complex physical process gives the result of the computation. We work on analog circuits (oscillator-based computing), magnonic devices and quantum computing.

Our lab has close collaborations with the Technical University of Munich, where cutting edge nanofabrication tools make the samples that we measure here.



Fabrication and measurement of a magnonic computing system – as done in collaboration with our colleagues at TU Munich. Kiechle, Martina, Adam Papp, Simon Mendisch, Valentin Ahrens, Matthias Golibrzuch, Gary H. Bernstein, Wolfgang Porod, Csaba György és Markus Becherer. "Spin-Wave Optics in YIG Realized by Ion-Beam Irradiation." Small 19, no. 21 (2023): 2207293.

Key publications:

1. *Rudner, T., Porod, W. and Csaba, Gy.* **Design of oscillatory neural networks by machine learning** FRONTIERS IN NEUROSCIENCE 18: 1307525 (2024)
2. *Kiechle, M., Papp, A., Mendisch, S., Ahrens, V., Golibrzuch, M., Bernstein, G. H., Porod, W., Csaba, Gy. and Becherer, M.* **Spin-Wave Optics in YIG Realized by Ion-Beam Irradiation** SMALL 19(21): 2207293 (2023)
3. *Papp, Á., Porod, W. and Csaba, Gy.* **Nanoscale neural network using non-linear spin-wave interference** NATURE COMMUNICATIONS 12(1): 6422 (2021)

INDEX

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