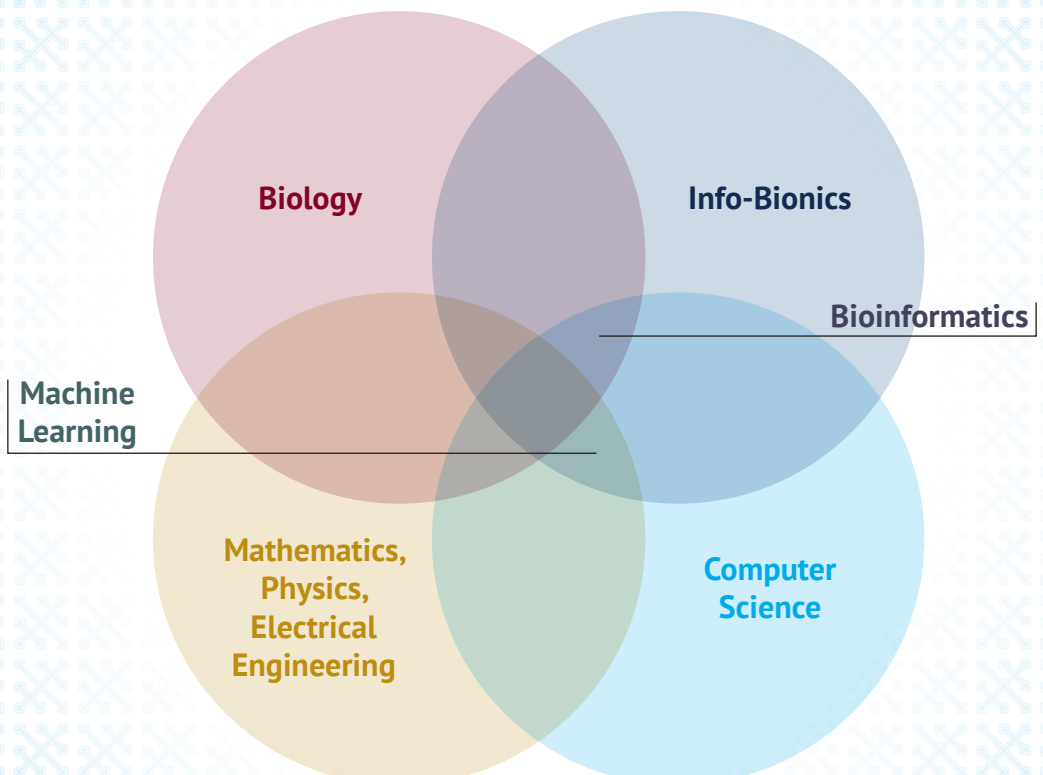
JEDLIK LABORATORIES RESEARCH REPORT

2023

PÁZMÁNY

Pázmány Péter Catholic University
Faculty of Information Technology and Bionics


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

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 three key areas: biology, computer science, and info-bionics, with the involvement of four, sixteen, and thirteen research groups, respectively. The 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.

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 bioinics, biology, electronics and information technology has bloomed in the Jedlik Laboratories and as new multidisciplinary research lines

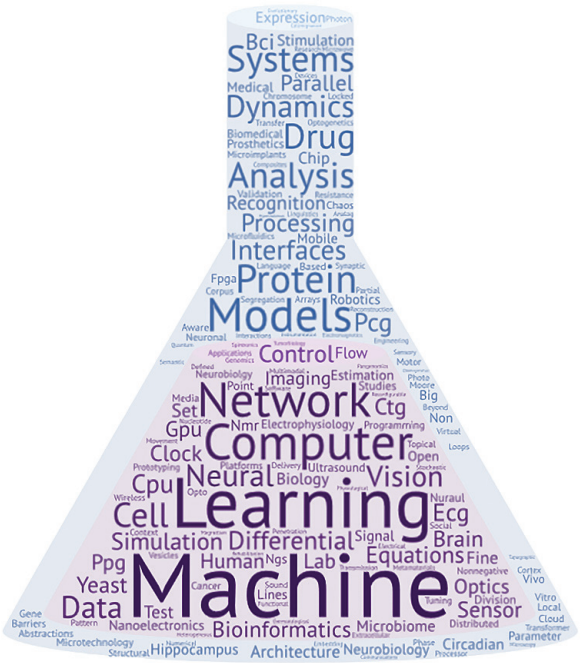
emerged the focus has expanded with bioinformatics, nanotechnology, robotics and artificial intelligence. Now 33 research groups work in the Jedlik Laboratories and we started to reach the maximal capacity what our building can hold, showing how successfully the Faculty expanded. We are committed to preserve the human and scientific heritage of Prof. Roska and to actively develop the conditions of quality research at the Faculty.

July 3, 2023

Prof. Attila Csikász-Nagy

Director of Jedlik Laboratories

Vice Dean for Research and Innovation



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Heterogeneous origins of human sleep spindles in different cortical layers.
JOURNAL OF NEUROSCIENCE 38 : 12 pp. 3013-3025. , 13 p. (2018)

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Csaba Gy., Porod W.
Coupled oscillators for computing: A review and perspective
APPLIED PHYSICS REVIEWS 7 : 1 p. 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
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Juhász J., Gáspári Z., Pongor S.
Structure and Oxidative Folding of AAI, the Major Alfa-Amylase Inhibitor From Amaranth Seeds
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https://www.sciencedirect.com/science/article/pii/S0924857920305008 (2021)

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Papp Á., Porod W., Csaba Gy.
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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 p. 1852 (2021)

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 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)

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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 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., Rózsa B.
Sharp-wave ripple doublets induce complex dendritic spikes in parvalbumin interneurons in vivo.
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Kocsis D., Kichou H., Döme K., Varga-Medveczky Z., Révész Z., Antal I., Erdő F.
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PHARMACEUTICS 14(8):1689. (2022)

Reguly, I. Z., Csercsik, D., Juhász, J., Tornai, K., Bujtár, Z., Horváth, G., Keömley-Horváth B., Kós T., Cserey G., Iván K., Pongor S., Szederkényi G., Röst G., Csikász-Nagy A.
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PLOS COMPUTATIONAL BIOLOGY, 18(1), e1009693. https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1009693 (2022)

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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)

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Cortex-wide response mode of VIP-expressing inhibitory neurons by reward and punishment
ELIFE 11 Paper: 78815 , 30 p. (2022)

Szederkényi G., Ács, G. Lipták, and M. A. Vághy
Persistence and stability of a class of kinetic compartmental models
JOURNAL OF MATHEMATICAL CHEMISTRY, vol. 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 , 13 p. (2022)

LABORATORY OF COMPUTATIONAL NEUROSCIENCE

Prof. Tamás FREUND

Dr. Szabolcs KÁLI

Prof. Zsolt LIPOSITS

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

Members of the Group: *PhD students:* Máté MOHÁCSI, Luca TAR, Gábor FARKAS;
MSc students: Boglárka SZABÓ, Veronika Panna HÁZI

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

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.

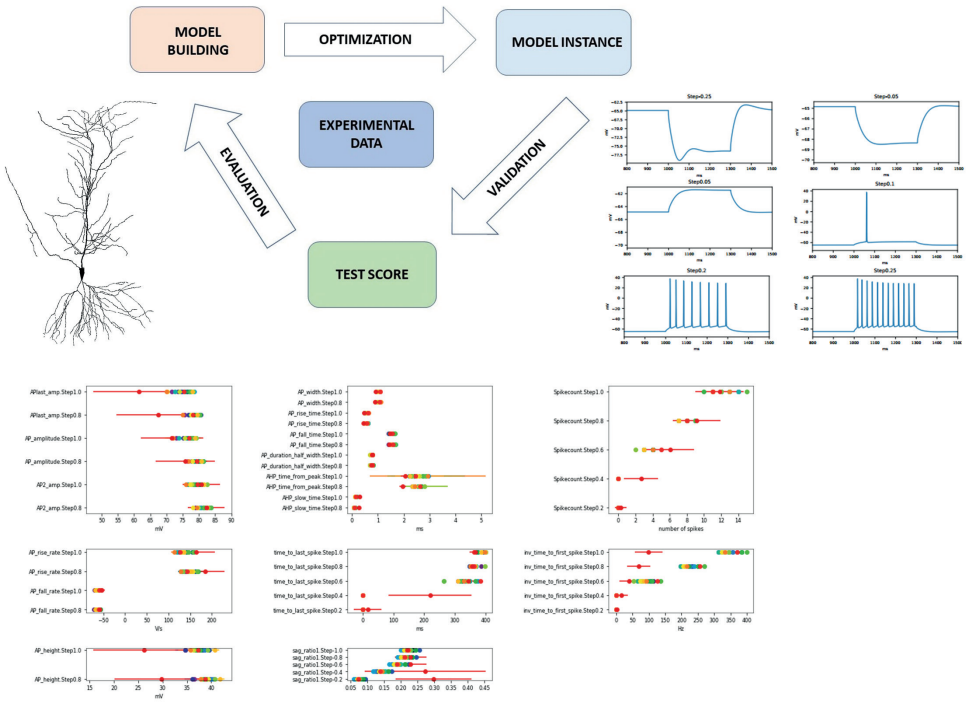

Illustration of a data-driven modeling workflow for building detailed models of neurons. Morphological and biophysical data are used to construct models whose unknown parameters are tuned via automated methods to match electrophysiological recordings. Models are then validated in an automated manner,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

Key publications:

1. *Ecker A, Bagi B, Vértes E, Steinbach-Németh O, Karlócai MR, Papp OI, Miklós I, Hájos N, Freund TF, Gulyás AI, Káli S. (2022) Hippocampal sharp wave-ripples and the associated sequence replay emerge from structured synaptic interactions in a network model of area CA3. Elife 11:e71850. doi: 10.7554/eLife.71850.*
2. *Sáray S, Rössert CA, Appukuttan S, Migliore R, Vitale P, Lupascu CA, Bologna LL, Van Geit W, Romani A, Davison AP, Muller E, Freund TF, Káli S. (2021) 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. doi: 10.1371/journal.pcbi.1008114.*
3. *Káli S, Dayan P. (2004) Off-line replay maintains declarative memories in a model of hippocampal-neocortical interactions. Nat Neurosci. 7(3):286-94. doi: 10.1038/nn1202.*

LABORATORY OF MICRODIALYSIS AND PHARMACOLOGICAL TECHNIQUES

Dr Franciska ERDŐ

Head of Research Group: Dr Franciska ERDŐ

Members of the Group: Members of the group: Dorottya KOCSIS, Anita BÁTHORY-FÜLÖP, Bence BAJUSZ, Kata NÉMETH, Judit VRÁBEL, Norina ZSÁRY.

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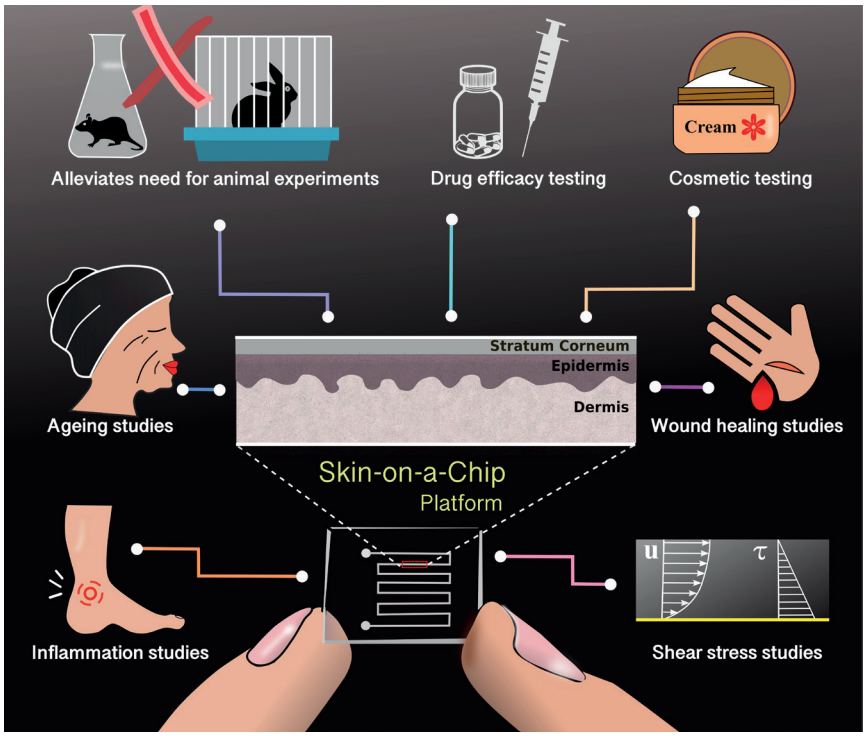
Keywords: *physiological barriers, drug penetration, topical drug delivery, dermatological analysis*

The main focus of our research group is the investigation of drug delivery through the physiological barriers. Beside the traditional drug delivery routes (oral, intravenous, intramuscular etc.) different alternative options of drug administration are tested (intranasal, transdermal, topical). Our aim is to reduce the number the experimental animals and replace the in vivo techniques with in vitro methods. Drug penetration accross the skin barrier is tested both in healthy and diseased conditions. Allergic contact dermatitis, psoriasiform dermatitis, wound healing, UV erythema and other models are under development. The ex vivo skins are analysed for their chemical composition (Raman spectroscopy), permeability (diffusion chambers), histological structure and surface properties (scanning electronmicroscopy). In our recent study artificial skins (3D bioprinted keratinocytes and fibroblasts) were characterized and validated for penetration testing. Beside the traditional static diffusion chambers, the innovative miniaturized skin-on-a-chip microfluidic systems are also used in our experiments. Further area of our interest is the mathematical simulation of penetration processes and prediction of the drug delivery in various situations (inflammation, high temperature, different species etc).



The skin-on-a-chip microfluidic platforms can be used for skin aging studies, for analysing skin disorders and therapeutic strategies and for 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. *Kocsis D, Kichou H, Döme K, Varga-Medveczky Z, 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. 2022 Aug 13;14(8):1689. doi: 10.3390/pharmaceutics14081689.*
2. *Kocsis D, Klang V, Schweiger EM, Varga-Medveczky Z, Mihály A, Pongor C, Révész Z, Somogyi Z, Erdő F. Characterization and ex vivo evaluation of excised skin samples as substitutes for human dermal barrier in pharmaceutical and dermatological studies.Skin Res Technol. 2022 Sep;28(5):664-676. doi: 10.1111/srt.13165.*
3. *Kocsis D, Horváth S, Kemény Á, Varga-Medveczky Z, Pongor C, Molnár R, Mihály A, Farkas D, Naszlady BM, Fülöp A, Horváth A, Rózsa B, Pintér E, Gyulai R, Erdő F.Drug Delivery through the Psoriatic Epidermal Barrier-A "Skin-On-A-Chip" Permeability Study and Ex Vivo Optical Imaging. Int J Mol Sci. 2022 Apr 11;23(8):4237. doi: 10.3390/ijms23084237*

NEUROENDOCRINE RESEARCH GROUP

Prof. Zsolt LIPOSITS

Dr. Imre KALLÓ

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

Members of the Group: Dr. Csaba VASTAGH,
MSc students: Barbara GÖBLYÖS, Bosziljka FEKETE

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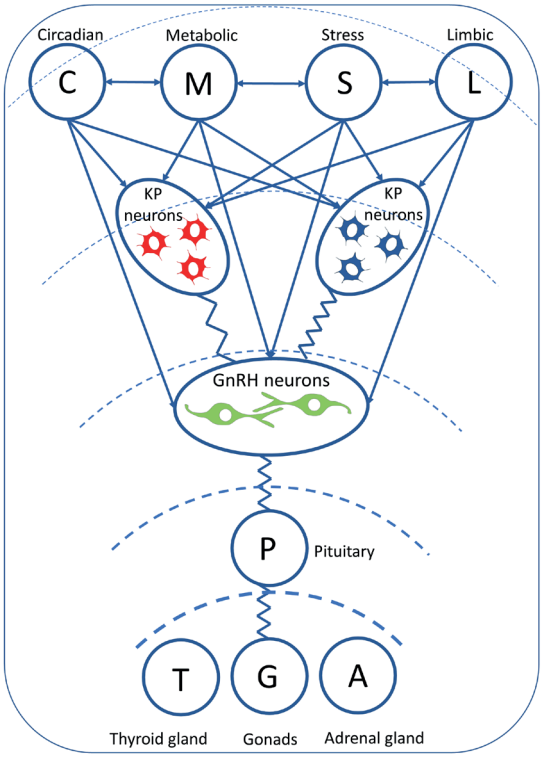
Keywords: *neurobiology, hypothalamus, opto- and chemogenetics, gene expression*

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 followings: 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.

More information at: **koki.hu/szervezet/endokrin-neurobiologia-106248**
List of recent publications: **m2.mtmt.hu/gui2/?type=institutes&mode=browse&sel=institutes21060**



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. *Bálint F, Csillag V, Vastagh C, Liposits Z, Farkas I. Insulin-Like Growth Factor 1 Increases GABAergic Neurotransmission to GnRH Neurons via Suppressing the Retrograde Tonic Endocannabinoid Signaling Pathway in Mice. Neuroendocrinology. 2021;111(12):1219-1230. doi: 10.1159/000514043. Epub 2020 Dec 24. PMID: 33361699.*
2. *Vastagh C, Csillag V, Solymosi N, Farkas I, 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. 2021 Jan 18;13:594119. doi: 10.3389/fnmol.2020.594119. PMID: 33551743; PMCID: PMC7863983.*

TRANSLATIONAL ONCOLOGY

Dr Tamás GARAY

Head of Research Group: Dr. Tamás GARAY

Members of the Group: Gréta BÁNYAI, Nikolett DOBOS, Daniella GÖRÖG, Juhye CHOI, Tamás KÓS, Afrodité NÉMETH, Marcell SZÁSZ

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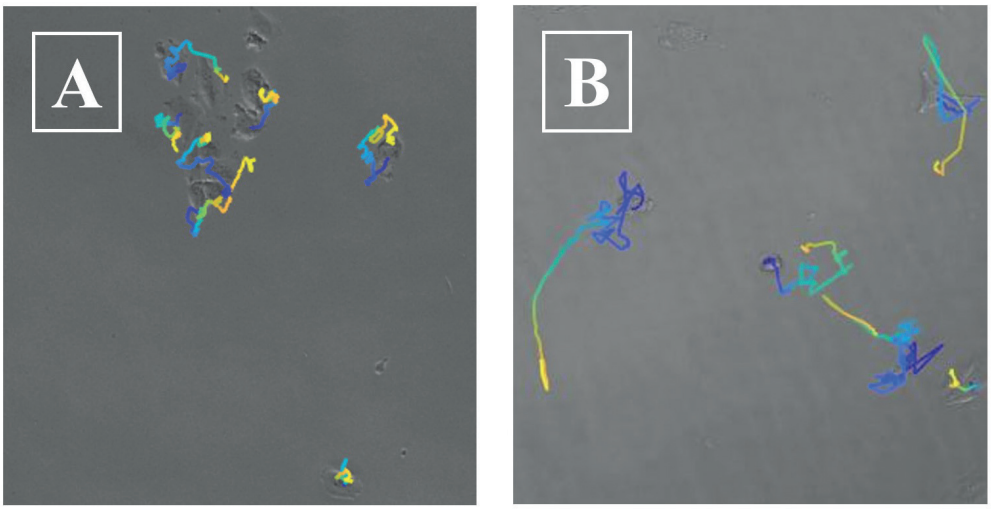
Keywords: *cancer cell-lines, extracellular vesicles, tumorbiology, cellmigration*

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 to 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.



Trajectories of vehicle control (A) and extracellular vesicle treated (B) melanoma cells. EVs used for the treatment are isolated from the supernatant of syngeneic cells with a more aggressive phenotype. Trajectories are drawn by marking the position of the cells and connecting these points during the whole time-lapse videomicroscopy recording. The color of the depicted trajectories refers to the time elapsed in the order of blue-green-yellow.

Key publications:

1. *Marcell Baranyi, Dominika Rittler, Eszter Molnár, Senji Shirasawa, István Jalsovszky, Imre Károly Varga, Luca Hegedűs, Afrodité Németh, Magdolna Dank, Clemens Aigner, József Tóvári, József Tímár, Balázs Hegedűs & Tamás Garay (2020).*
   Next generation lipophilic bisphosphonate shows antitumor effect in colorectal cancer in vitro and in vivo.
   Pathology & Oncology Research, 26, 1957-1969.

2. *Eszter Molnár, Dominika Rittler, Marcell Baranyi, Michael Grusch, Walter Berger, Balázs Döme, József Tóvári, Clemens Aigner, József Tímár, Tamás Garay & Balázs Hegedűs (2018).*
   Pan-RAF and MEK vertical inhibition enhances therapeutic response in non-V600 BRAF mutant cells.
   BMC cancer, 18, 1-11.

NEUROMODULATION RESEARCH GROUP

Dr. Loránd ERŐSS

Head of Research Group: Dr. Loránd ERŐSS
Member of the Group: István ULBERT
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Keywords: *pain, epilepsy, movement disorder therapy*

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. *Clemens Zs, Mölle M, Erőss L, Barsi P, Halász P, Born J Temporal coupling of parahippocampal ripples, sleep spindles and slow oscillations in humans BRAIN 130 pp. 2868-2878. , 11 p. (2007)*
2. *Cash SS, Halgren E, Dehghani N, Rossetti AO, Thesen T, Wang C, Devinsky O, Kuzniecky R, Doyle W, Madsen JR, Bromfield E, Eross L, Halasz P, Karmos G, Csercsa R, Wittner L, Ulbert I The human K-complex represents an isolated cortical down-state. SCIENCE 324 : 5930 pp. 1084-1087. , 4 p. (2009)*
3. *Ujma PP, Halasz P, Kelemen A, Fabo D, Eross L Epileptic interictal discharges are more frequent during NREM slow wave downstates. NEUROSCIENCE LETTERS 658 pp. 37-42. , 6 p. (2017)*

QUANTITATIVE BIOLOGY OF CELL DIVISION LAB

Dr Andrea CILIBERTO

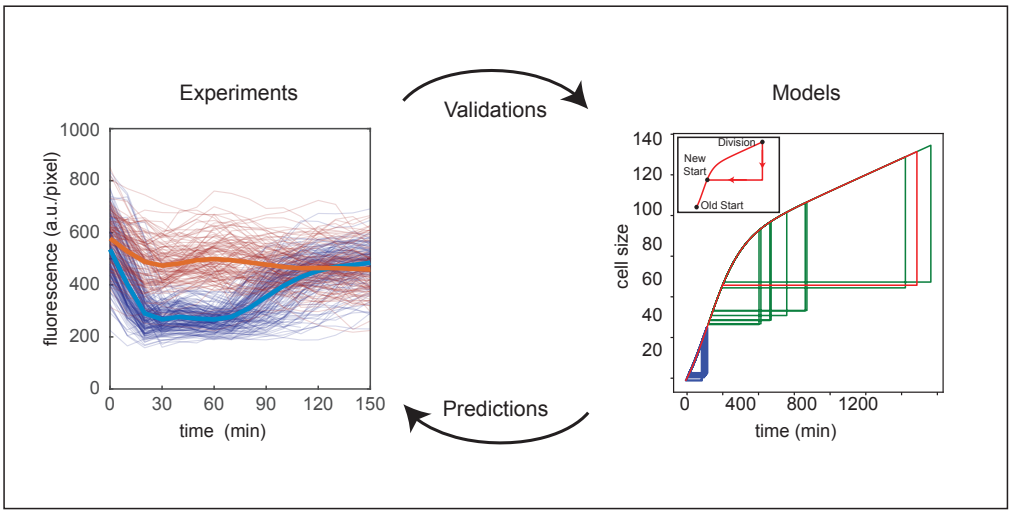
Head of Research Group: Dr Andrea CILIBERTO

Member of the Group: Alma Beatrix STIER, Camilla CANCRINI

Contact: ciliberto.andrea@itk.ppke.hu

Keywords: *chromosome segregation, dynamical systems, drug resistance*

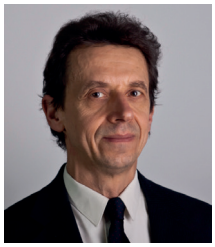
Our group studies cell division, especially in the context of resistance to cancer drugs. We are particularly interested in studying the mechanisms of chromosome segregation, and how its malfunctioning contributes to the emrgence of resistance to treatment. To this aim, we perform cell and molecular biology experiments using yeast and mammalian cells. The data we produce, are used to develop mathematical models which are then used to formulate new experiments. Ours is a joint research lab between IFOM ETS - The AIRC Institute of Molecular Oncology and Pazmany Peter Catholic University. IFOM is a cancer research center based in Milan, Italy.



Key publications:

1. *Pavani M, Bonaiuti P , Chiroli E, Gross F, Natali F, Macaluso F, Póti A, Pasqualato S, Farkas Z, Pompei S, Cosentino Lagomarsino M, Rancati G, Szüts D, Ciliberto A Epistasis, aneuploidy, and functional mutations underlie evolution of resistance to induced microtubule depolymerization, EMBO J 2021, e108225*
2. *Gross, F, Bonaiuti, P, Hauf, S and Ciliberto A. Implications of alternative routes to APC/C inhibition by the mitotic checkpoint complex, PLoS Comp Biol, 14(9): e1006449, 2018.*
3. *Bonaiuti P, Chiroli E, Gross F, Corno A, Vernieri C, Stefl, M, Cosentino Lagomarsino M, Knop M, Ciliberto A. Cells escape an operational mitotic checkpoint through a stochastic process, Current Biology, 28:28-37, 2018.*

MOVEMENT ANALYSIS AND MOTOR CONTROL LAB



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

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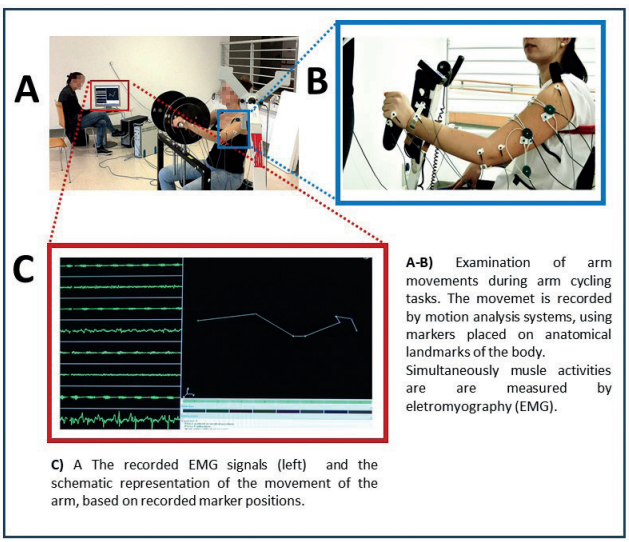
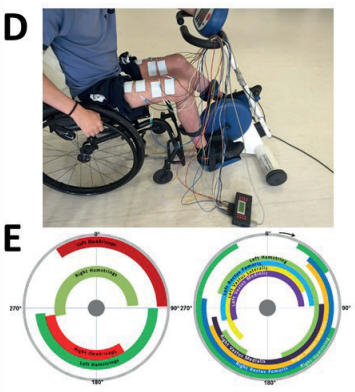
Keywords: *motor control, movement rehabilitation, functional electrical stimulation*

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. In the laboratory we apply an ultrasound based movement analyzing system (ZEBRIS, Ivry, Germany) for recording kinematic and electromyographic data during human limb movements. Ultrasound emitting 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 or research in cooperation with collegaues from the Wigner Research Centre for Physics and apply it in the National Institute for Medical Rehabilitation.



A-B) Examination of arm movements during arm cycling tasks. The movemet is recorded by motion analysis systems, using markers placed on anatomical landmarks of the body. Simultaneously musle activities are are measured by eletromyography (EMG).

C) A The recorded EMG signals (left) and the schematic representation of the movement of the arm, based on recorded marker positions.



D-E) Functional Electrical Stimulation (FES) assisted cycling training of spinal cord injured, paralyzed persons. Muscle activities are generated by electrical stimulation via surface electrodes. **E)** The timing of the muscle's stimulation is represented by the circular diagrams. A FES controller is developed at PPCU. The electrical signals are generated by the controller as a function of crank angle.

Key publications:

1. *Mravcsik M, Klauber A, Putz M, Kast C, Mayr W, Laczko J (2019): 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.*
2. *Botzheim L, Laczko J, Torricelli D, Mravcsik M, Pons JL, Barroso FO (2021): Effects of gravity and kinematic constraints on muscle synergies in arm cycling. Journal of Neurophysiology. Vol 125 (4), pp. 1367-1381.*
3. *Radeleczki, B., Mravcsik, M., Bozheim, L., Laczko, J. (2022): Prediction of leg muscle activities from arm muscle activities in arm and leg cycling. The Anatomical Record , 1– 10. https://doi.org/10.1002/ar.25004*

BIOINFORMATICS LAB

Prof. Sándor PONGOR

Head of Research Group: Prof. Sándor PONGOR

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

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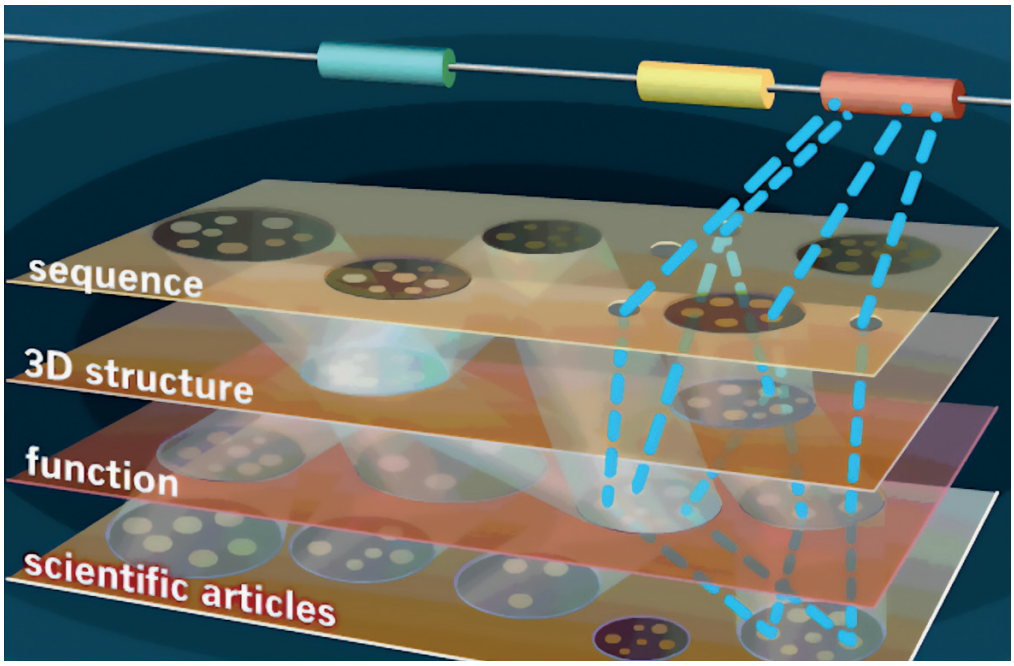
Keywords: *bioinformatics, genomics, NGS, microbiome, machine learning*

The group is primarily interested in the general principles of intercellular communication with special regard to genomics/proteomics of microbial communities. Microbial communities play fundamental roles in health and disease as well as in the stability of the ecosystem. A better understanding of these systems may provide insights into the mechanisms of infections, epidemics as well as environmental and social processes. The stated goal of the group is to develop non-conventional views of biological data that we hope to achieve by developing novel techniques of genome bioinformatics (NGS), data-mining, machine learning, agent-based modeling as well as by the integration of heterogeneous data-sources and high throughput data.



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 clusteing methods within these layers are crucial for effective information transfer.

Key publications:

1. *János Juhász, Balázs Ligeti, Márió Gajdács, Nóra Makra, Eszter Ostorházi, Ferenc Balázs Farkas, Balázs Stercz, Ákos Tóth, Judit Domokos, Sándor Pongor, Dóra Szabó, Colonization Dynamics of Multidrug-Resistant Klebsiella pneumoniae Are Dictated by Microbiota-Cluster Group Behavior over Individual Antibiotic Susceptibility: A Metataxonomic Analysis, Antibiotics 2021, 10(3), 268; https://www.mdpi.com/2079-6382/10/3/268*
2. *Nagy Á., Pongor S., Győrffy B.*
   Different mutations in SARS-CoV-2 associate with severe and mild outcome
   INTERNATIONAL JOURNAL OF ANTIMICROBIAL AGENTS, 106272.
   https://www.sciencedirect.com/science/article/pii/S0924857920305008 (2021)

NEURAL BIOINFORMATICS RESEARCH LAB

Dr Balázs LIGETI

Head of Research Group: Dr Balázs LIGETI

Members of the Group: Regina KALCSEVSZKI, Zsófia MOLNÁR, Babett BODNÁR, Bendegúz FILYÓ, István SZEPESI-NAGY, Judit JUHÁSZ

Contact: ligeti.balazs@itk.ppke.hu

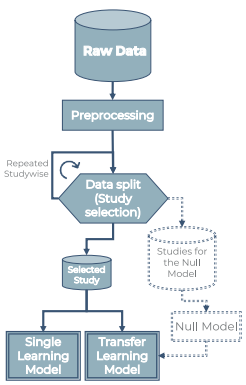
Keywords: *nucleotide and evolutionary context aware neural networks, pangenomics, microbiome research, transfer learning, multimodal learning*

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. We aim to provide neural network-based, universal, reusable representations and algorithms specifically tailored for microorganisms. Our solutions can efficiently handle the fast-growing heterogeneous data and deal with the context-dependence or scarcity of labeled data.

TRANSFER LEARNING IN BIOINFORMATICS

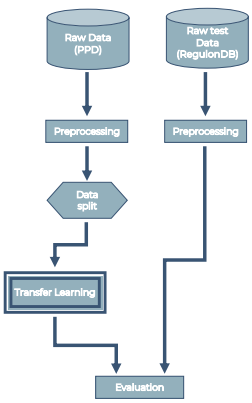
FC neural network model

Disease prediction in human **microbiom** studies

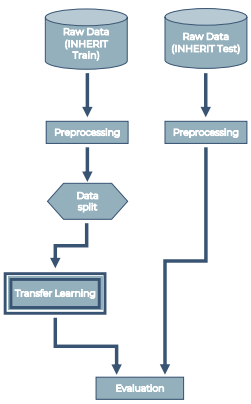


Nucleotide sequence models

Promoter identification



Phage detection



Key publications:

1. *Regina Kalcsevszki, András Horváth, Balázs Gyorffy, Sándor Pongor, Balázs Ligeti, Covid-Outcome2: a tool for SARS-CoV2 mutation identification and for disease severity prediction, https://www.biorxiv.org/content/10.1101/2022.07.01.496571v1.full*
2. *János Juhász, Balázs Ligeti, Mário Gajdács, Nóra Makra, Eszter Ostorházi, Ferenc Balázs Farkas, Balázs Stercz, Ákos Tóth, Judit Domokos, Sándor Pongor, Dóra Szabó, Colonization Dynamics of Multidrug-Resistant Klebsiella pneumoniae Are Dictated by Microbiota-Cluster Group Behavior over Individual Antibiotic Susceptibility: A Metataxonomic Analysis, Antibiotics 2021, 10(3), 268; https://www.mdpi.com/2079-6382/10/3/268*
3. *János, Juhász, Sándor Pongor, and Balázs Ligeti. "Toward a Systematic Genomic Survey of Bacterial Quorum Sensing Genes: Cross Cutting Regulatory and Genomic Concepts." Trends in Quorum Sensing and Quorum Quenching (2020): 31-45.*

STRUCTURAL BIOLOGY AND PROTEOMICS RESEARCH LAB

Dr Zoltán GÁSPÁRI

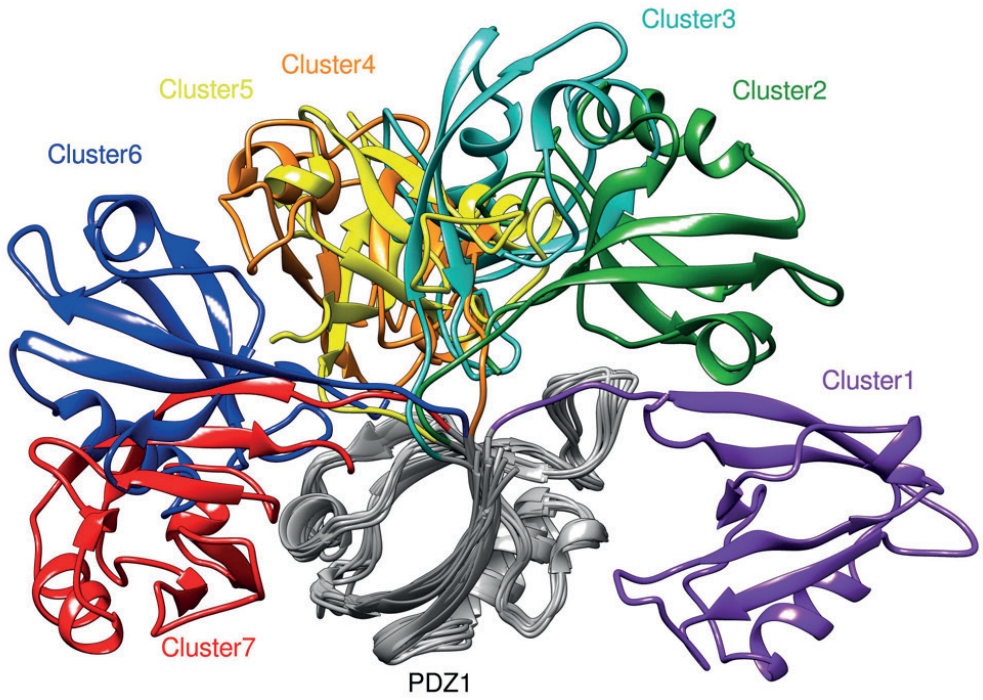
Head of Research Group: Dr Zoltán GÁSPÁRI

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 modeling*

Our research focuses on proteins involved in synaptic signal transduction. We apply experimental and computational methods to decipher the relationships between the structure, dynamics and function of these proteins. Proteins expressed in our laboratory are investigated by various biophysical methods, the results of which are integrated into molecule- and systems-level models to understand the mechanistic details of partner binding of individual compponents as well as the organization of the postsynaptic protein network.



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.; Dobson, L. PSINDB: The postsynaptic protein-protein interaction database DATABASE-JOURNAL OF BIOLOGICAL DATABASES AND CURATION 2022 Paper: baac007 , 8 p. (2022)*
2. *Sánta, Anna; Czajlik, András; Batta, Gyula; Péterfia, Bálint; Gáspári, Zoltán Resonance assignment of the Shank1 PDZ domain BIOMOLECULAR NMR ASSIGNMENTS 16 : 1 pp. 121-127. , 7 p. (2022)*
3. *Kovács, Bertalan; Zajácz-Epresi, Nóra; Gáspári, Zoltán. 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. , 16 p. (2020)*

SYSTEMS BIOLOGY OF MOLECULAR AND CELLULAR NETWORKS

Prof. Attila CSIKÁSZ-NAGY

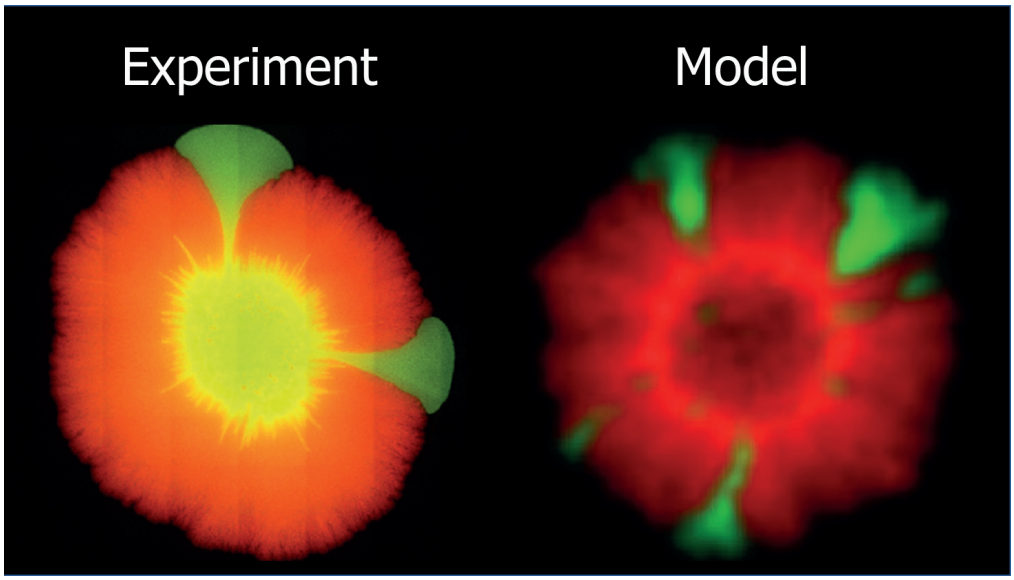
Head of Research Group: Prof. Attila CSIKÁSZ-NAGY

Members of the Group: Dr. Csaba István PONGOR, Dr. János JUHÁSZ, PhD students: Suchana CHAKRAVARTY, Tünde Éva GAIZER, Bence Márk KEÖMLEY-HORVÁTH, Valentina MADÁR, Marcell MISKI, Bíborka PILLÉR, Áron WEBER; MSc students: Luca DÁVID, Nóra GÖRÖG, Máté METZING, Helga SZAKADÁTI

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

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

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 aging, 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. Additionaly, 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 results of an agent-based model, where two differently coloured strains were grown together.

Key publications:

1. *Reguly, I. Z., Csercsik, D., Juhász, J., Tornai, K., Bujtár, Z., Horváth, G., ... & Csikász-Nagy, A. (2022). Microsimulation based quantitative analysis of COVID-19 management strategies. PLoS computational biology, 18(1), e1009693. https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1009693*
2. *Moreno, D. F., Jenkins, K., Morlot, S., Charvin, G., Csikasz-Nagy, A., & Aldea, M. (2019). Proteostasis collapse, a hallmark of aging, hinders the chaperone-Start network and arrests cells in G1. Elife, 8, e48240. https://elifesciences.org/articles/48240*
3. *Dalchau, N., Szép, G., Hernansaiz-Ballesteros, R., Barnes, C. P., Cardelli, L., Phillips, A., & Csikász-Nagy, A. (2018). Computing with biological switches and clocks. Natural Computing, 17, 761-779. https://link.springer.com/article/10.1007/s11047-018-9686-x*

MULTI-PHOTON MICROSCOPY

Dr. J. Balázs RÓZSA

Dr. Balázs CHIOVINI

Head of Research Group: Dr. J. Balázs RÓZSA, Dr. Balázs CHIOVINI

Members of the Group: Dr. Gergely KATONA, Dr. Gábor JUHÁSZ, Dr. Dénes PÁLFI, Zsolt MEZRICZKY, Anna MIHÁLY

Contact: rozsabal@koki.hu

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

3D two-photon measurement of single cell and neuronal network activities in vivo. Understanding brain function requires novel imaging methods such as 3D random access point scanning that can simultaneously read out neural activity on both the dendritic and somatic scales. Our 3D AO scanning method can increase measurement speed and signal-to noise ratio by to 6-9 orders of magnitude, but can have one limiting factor: fluorescence information might be lost during brain movement in awake, behaving animals as the amplitude of brain motion is much larger than the diameter of a single excitation spot. We developed a novel fluorescent imaging technology, which can extend each scanning point to small 3D lines, surface or volume elements, preserving fluorescence information for fast off-line motion correction. Our method effectively eliminates in vivo motion artefacts, allowing fast 3D measurement of over 100 dendritic spines with 3D lines, over 100 somata with squares and cubes, or multiple spiny dendritic segments with surface and volume elements in moving animals. We used this new technology to record activity of pyramidal cells and inhibitory neurons in the moving brain of behaving animals. We revealed a new, broadcasted signalling pathway which activates learning mechanism through the entire neocortex during reward and punishment.

Selected papers: Munz et al (2023) Cell Judák et al. (2022) Nature Com. Geiller et al. (2022) Nature Katona G et al. (2012) Nature Methods Hillier D. et al. (2017) Nature Neuroscience Holderith et al. (2012) Nature Neuroscience Tønnesen J (2015) Nature Neuroscience Szalay et al. (2016) Nature. Com. Popovic MA (2015) Nature Com. Szadai et al. (2022) eLIFE Geiller et al. (2020) Neuron Wertz et al. (2015) Science Szalay et al. (2016) Neuron Chiovini B. et al. (2014) Neuron Bywalez WG et al. (2015) Neuron Williamson A, et al. (2015) Adv. Mater. Bouhadfane M et al. (2015) eLIFE Katona G. et al. (2011) PNAS Deneux T, et al. (2016) Nature Com Fedor et al. (2022) Adv. Mater. Technologies Szabó et al. (2022) Adv. Mater. Interfaces We have more than 44 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, Rózsa B. Sharp-wave ripple doublets induce complex dendritic spikes in parvalbumin interneurons in vivo. Nat Commun. 2022 Nov 7;13(1):6715. PMID: 36344570 PMCID: PMC9640570 DOI: 10.1038/s41467-022-34520-1*
2. *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. 2022 Nov 23;11:e78815. PMID: 36416886 PMCID: PMC9683790 DOI: 10.7554/eLife.78815*
3. *Geiller T, Sadeh S, Rolotti SV, Blockus H, Vancura B, Negrean A, Murray AJ, Rózsa B, Polleux F, Clopath C, Losonczy A. Local circuit amplification of spatial selectivity in the hippocampus. Nature. 2022 Jan;601(7891):105-109. PMID: 34853473 PMCID: PMC9746172 DOI: 10.1038/s41586-021-04169-9*

SENSING-ACTUATING ROBOTICS LABORATORY

Dr. György CSEREY

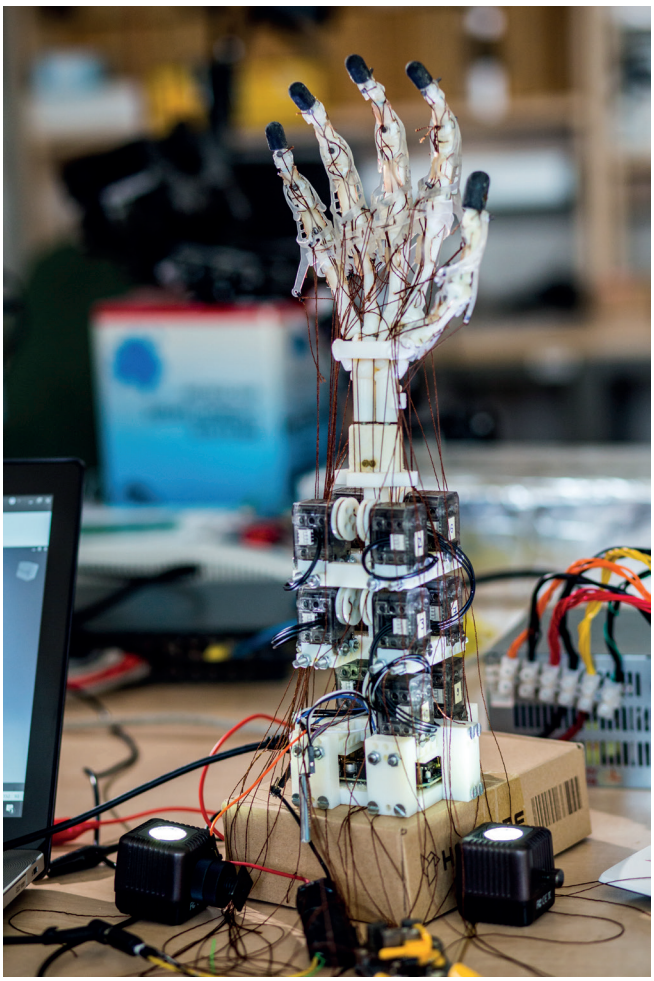
Head of Research Group: Dr. György CSEREY

Members of the Group: Dr. Miklós KOLLER, Dr. Sándor FÖLDI, Dániel HAJTÓ, Boldizsár BALOG, Benedek TASI, Dávid PELYVA, Anna IGNÁCZ, Attila RÉPAI, Bendegúz H. ZOVÁTHI, András BENEDEK, István SZÉKELY, Tamás ENDREI, Péter FODOR, Veronika KISS, Anna GELENCSÉR-HORVÁTH, Katalin SCHAFFER, Maulana RIZAL

Contact: cserey.gyorgy@itk.ppke.hu

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

Our mission is to apply unique ideas inspired by Biology using Information Technologies. How can we design better prosthesis? How can you teach a robot 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 many companies in the robotics industry.



Key publications:

1. *Tasi, Benedek Jozsef, Miklós Koller, and Gyorgy Cserey. "Design of the anatomically correct, biomechatronic hand." arXiv preprint arXiv:1909.07966 (2019).*
2. *Ignácz, Anna, Sándor Földi, Péter Sótonyi, and György Cserey. "NB-SQI: A novel non-binary signal quality index for continuous blood pressure waveforms." Biomedical Signal Processing and Control 70 (2021): 103035.*
3. *Uzolas, Lukas, Javier Rico, Pierrick Coupé, Juan C. SanMiguel, and György Cserey. "Deep Anomaly Generation: An Image Translation Approach of Synthesizing Abnormal Banded Chromosome Images." IEEE Access 10 (2022): 59090-59098.*

INTEGRATIVE NEUROSCIENCE GROUP

Prof. István ULBERT

Domonkos HORVÁTH

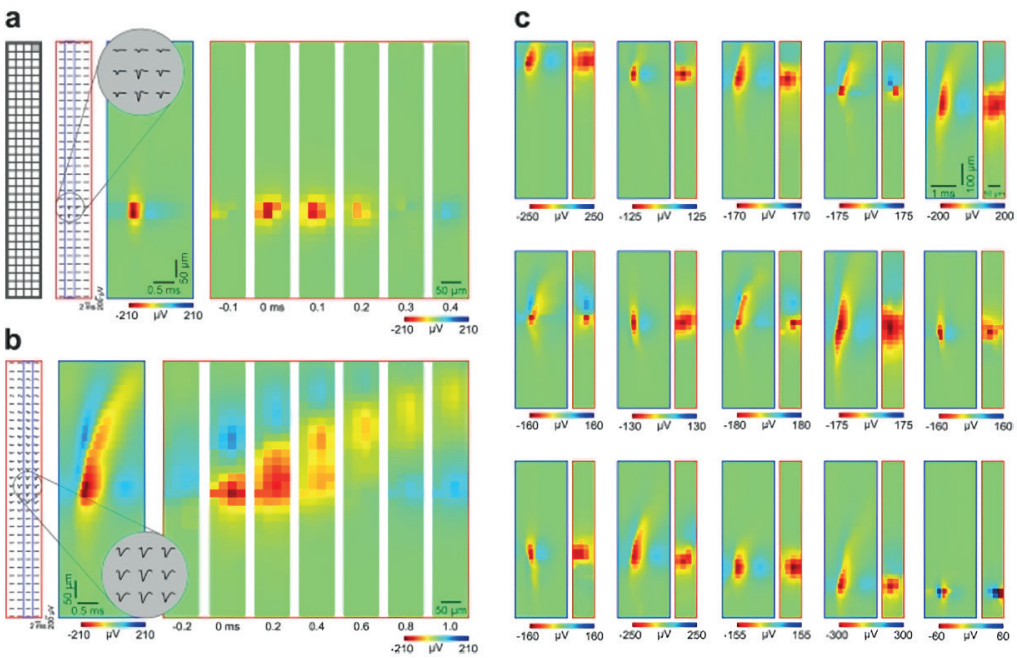
Head of Research Group: Prof. István ULBERT, Domonkos HORVÁTH

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

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

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

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.



Key publications:

1. *Cs Horváth, L F Tóth, I Ulbert and R Fiáth. Dataset of cortical activity recorded with high spatial resolution from anesthetized rats. SCIENTIFIC DATA, 8, 180, 2021.*
2. *KT Hofer, Á Kandrács, K Tóth, B Hajnal, V Bokodi, EZ Tóth, L Erőss, L Entz, AG Bagó, D Fabó, I Ulbert and L Wittner. Bursting of excitatory cells is linked to interictal epileptic discharge generation in humans. SCIENTIFIC REPORTS, 12, 6280, 2022*
3. *M Wahdow, M Alnaanah, W Fadel, A Adolf, C Kollod and I Ulbert. Multi-frequency band fusion method for EEG signal classification. SIGNAL, IMAGE AND VIDEO PROCESSING, 2022. (Accepted, in press) IF: 1.58, Q2*

BIOMICROFLUIDICS LABORATORY

Dr. András József LAKI

Dr. Kristóf IVÁN

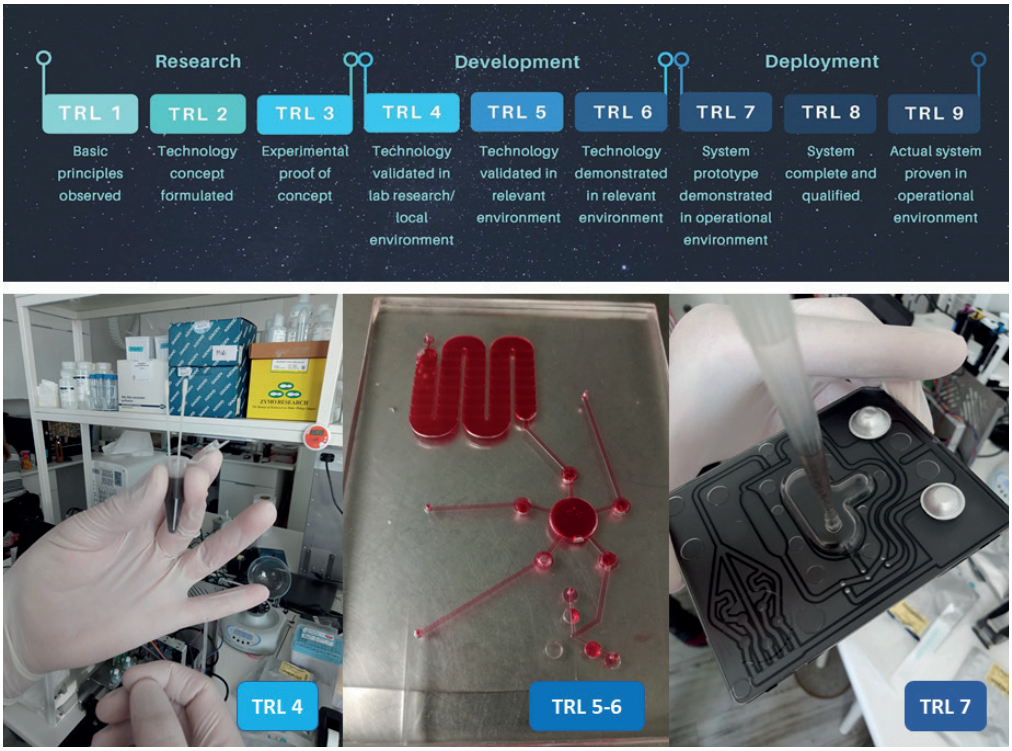
Head of Research Group: Dr. András József LAKI, Dr. Kristóf IVÁN

Members of the Group: Mária LAKI, Márton HARTDÉGEN, Csaba PONGOR, Máté KÁLOVICS, Erik JÁMBOR

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

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

PPKE's Biomicrofluidics research group does design, computational fluid dynamic simulation, fabrication and test of microfluidic devices. We also do research and development for fabrication technology of different devices (soft-lithography, laser ablation, pressure-sensitive adhesive). The main research areas of our research group: food safety (detection and analysis of foodborne pathogens), biomedical diagnostics (filtration and analysis of circulating tumor cells, blood diagnostics), Microfluidic particle separation technologies, and its auxiliary disciplines.



We are able to develop Lab-on-a-chip device from a bacis biological process up to working prototype and finally create a high-production fabricable device.

Key publications:

1. *Miléna Lengyel, Nikoletta Kállai-Szabó, Vince Antal, András J. Laki, and István Antal, "Microparticles, Microspheres, and Microcapsules for Advanced Drug Delivery," Scientia Pharmaceutica, vol. 87, no. 3, p. 20, Sep. 2019.*
2. *Ponmozhi, J. ; Dhinakaran, S. ; Varga-medveczky, Z. ; Fónagy, K. ; Bors, L.A. ; Iván, K. ; Erdő, F. Development of skin-on-a-chip platforms for different utilizations: Factors to be considered MICROMACHINES 12 : 3 Paper: 294 , 25 p. (2021) https://doi.org/10.3390/mi12030294*
3. *Tamás Kós, Kristóf Iván, and András József Laki, "Particle separation with deterministic lateral displacement" presented at Selectbio Lab-on-a-Chip and Microfluidics Europe 2021 conference, Rotterdam, The Netherlands, 28-30 June 2021.*

RESEARCH GROUP FOR IMPLANTABLE MICROSYSTEMS

Dr. Zoltán FEKETE

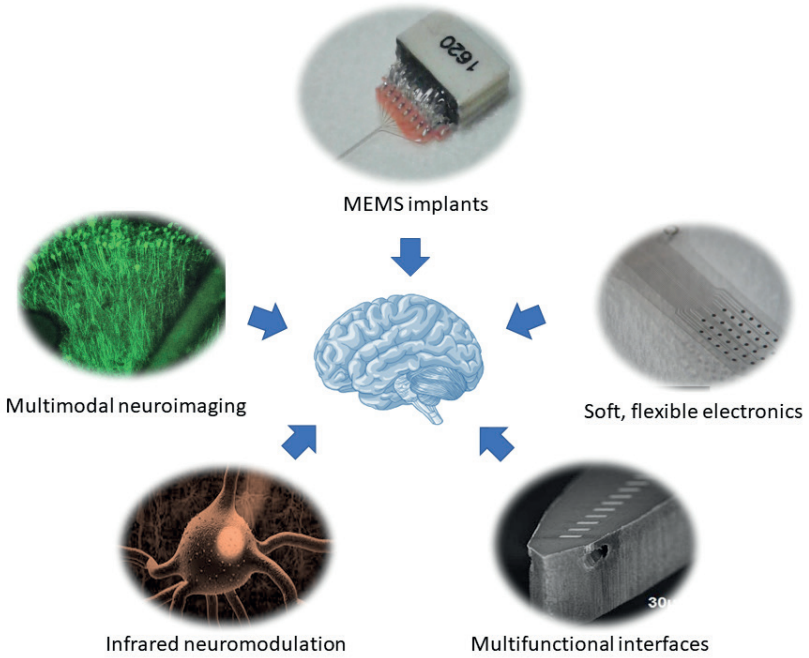
Head of Research Group: Dr. Zoltán FEKETE

Members of the Group: Dr. Ágoston Csaba HORVÁTH, Ágnes SZABÓ, Zsófia LANTOS, Ebrahim ISMAIEL, Levente VÍG, Ákos MÓROCZ, Borbála CSOMAI, Eszter NGUYEN, Dóra PAPP, Csilla KASTALL

Contact: fekete.zoltan@itk.ppke.hu

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

Today's medical devices often benefit from advancements in the field of microelectromechanical systems (MEMS). 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 interrogate cellular communication with high spatial and temporal resolution and are also able to control cellular processes by means of optical and pharmacological stimulation.



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. *Á. C. Horváth, Ö. C. Boros, L. Komáromi, S. Borbély, P. Koppa, P. Barthó, Z. Fekete, Infrared neural stimulation and inhibition using an implantable silicon photonic microdevice, MICROSYSTEMS & NANOENGINEERING 6 (2020) 44 https://www.nature.com/articles/s41378-020-0153-3*
2. *N. Ebrahimi, C Bi, D J Cappelleri, G. Ciuti, A. T. Conn, D. Faivre, N. Habibi, A. Hošovský, V. Iacovacci, I. S. M. Khalil, V. Magdanz, S. Misra, C. Pawashe, R. Rashidifar, P. Rodriguez, M. Sitti, Z. Fekete, A. Jafari, Magnetic Actuation Methods in Bio/Soft Robotics, ADVANCED FUNCTIONAL MATERIALS 31 (2021) 2005137 https://onlinelibrary.wiley.com/doi/abs/10.1002/adfm.202005137*
3. *F. Z. Fedor, M. Madarász, A. Zátonyi, Á. Szabó, T. Lőrincz, V. Danda, L. Spurgin, C. Manz, B. Rózsa, Z. Fekete, Soft, thiol-ene/acrylate based electrode array for long-term recording of intracranial EEG signals with improved biocompatibility in mice, ADVANCED MATERIALS TECHNOLOGIES 7 (2022) 2100942 https://onlinelibrary.wiley.com/doi/full/10.1002/admt.202100942*

SPORT BIONICS AND ANALYTICS

Dr. László GRAND

Head of Research Group: Dr. László GRAND

Members of the Group: Gábor NAGY

Contact: grand.laszlo.balint@itk.ppke.hu

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

The Lab is dedicated to advancing the field of sports science and rehabilitation through the research and development of wearable sensors, the utilization of novel computer vision and machine/deep learning techniques, and the application of cloud computing for real-time data analytics. Our mission is to provide athletes, coaches, researchers and companies with valuable insights into human performance, fostering innovation and excellence in the world of sports. At our lab, we harness the power of wearable sensors to capture and analyze data related to human movement during sporting activities. These sensors are meticulously designed to provide accurate measurements of physiological and kinematic parameters, allowing us to understand the intricacies of athletes' performance in real-time. In addition to wearable sensors, we leverage advanced camera systems to observe and analyze sport team collaboration. By combining computer vision techniques with machine learning and deep learning algorithms, we gain a comprehensive understanding of the dynamics and interactions within sports teams. This invaluable knowledge enables us to enhance team performance and optimize strategies through data-driven insights. Our lab is also at the forefront of utilizing cloud computing to enable real-time analytics of sport data. By leveraging the power of cloud infrastructure, we can process and analyze vast amounts of data instantaneously, providing coaches, athletes,

and sports scientists with actionable information to enhance performance, prevent injuries, and drive informed decision-making. We take pride in our collaborative research efforts with companies and sport associations, ensuring that our work remains at the forefront of industry advancements.

Key publications:

1. *G. Nagy, Z. Komka, G. Szathmáry, P. Katona, L. Gannoruwa, G. Erdös, P. Tarjányi, M. Tóth, M. Krepuska, and L. Grand, "Multimodal Approach for Kayaking Performance Analysis and Improvement," Int. J. Comput. Sci. Sport, vol. 19, no. 2, pp. 51-76, 2020.*
2. *Á. Uhlár, M. Ambrus, M. Kékesi, E. Fodor, L. Grand, G. Szathmáry, K. Rácz, and Z. Lacza, "Kinect Azure–Based Accurate Measurement of Dynamic Valgus Position of the Knee—A Corrigible Predisposing Factor of Osteoarthritis," Appl. Sci., vol. 11, no. 12, p. 5536, Jun. 2021. Available: https://doi.org/10.3390/app11125536*
3. *J. Négyesi, B. Petró, D. N. Salman, A. Khandoker, P. Katona, Z. Wang, A. I. S. Q. Almaazmi, T. Hortobágyi, M. Váczi, K. Rácz, Z. Pálya, L. Grand, R. M. Kiss, and R. Nagatomi, "Biosignal processing methods to explore the effects of side-dominance on patterns of bi- and unilateral standing stability in healthy young adults," Front. Physiol., vol. 13, p. 965702, Sep. 2022. doi: 10.3389/fphys.2022.965702.*

ACOUSTIC IMAGING AND MEDICAL SIGNALS LABORATORY (AIMS-LAB)

Dr. Márton Áron GODA

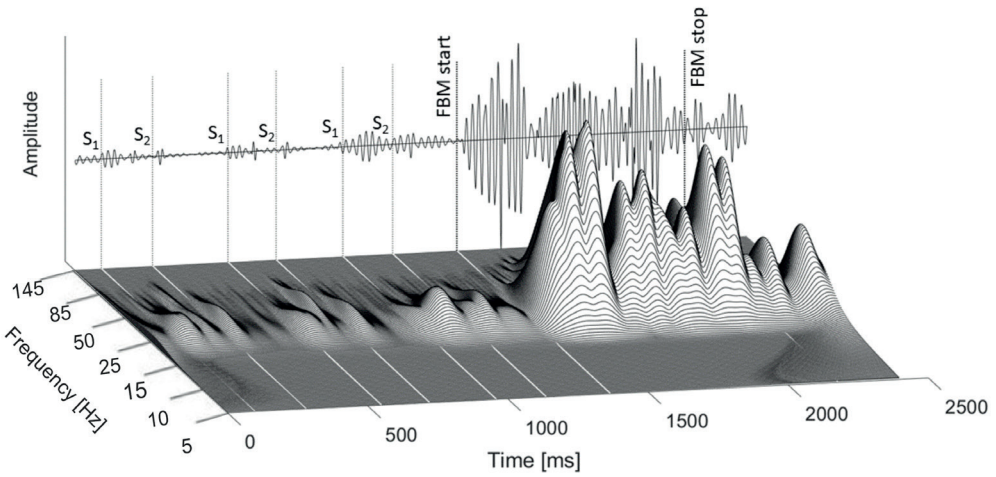
Head of Research Group: Dr. Márton Áron GODA

Members of the Group: Dr. Janka HATVANI (lab researcher), Dr. Miklós GYÖNGY (lab founder), Kristóf MÜLLER (lab assistant)

Contact: goda.marton.aron@itk.ppke.hu

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

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. *M. Á. Goda, T. Telek, and F. Kovács, "Novel phonographybased measurement for fetal breathing movement in the third trimester", Sensors, vol. 21(1), p. 211, DOI: 10.3390/s21010211*
2. *M. Á. Goda, T. Telek, "A Phonography-Based Method Improved by Hidden Markov Model for Fetal Breathing Movement Detection", IEEE Access, vol. 9, pp. 60154-60162, DOI: 10.1109/ACCESS.2021.3072977*
3. *J. Hatvani, A. Horváth, J. Michetti, A. Basarab, D. Kouamé, M. Gyöngy, "Deep Learning-Based Super-Resolution Applied to Dental Computed Tomography," IEEE Transactions on Radiation and Plasma Medical Sciences (in print, 2018).*

HUNGARIAN BIONIC VISION CENTER

Dr. Kristóf KARACS

Dr. Ákos KUSNYERIK

Head of Research Group: Dr. Kristóf KARACS, Dr. Ákos KUSNYERIK

Members of the Group: Anna GELENCSÉR-HORVÁTH, Ákos MADARAS, Gergely PINTÉR

Contact: karacs@itk.ppke.hu

Keywords: *visual assistance, bionic vision, mobile vision, low-power computing, ambient assisted living*

The Vision Centre endeavors to fully restore the vision of individuals with visual impairments and enhance their quality of life through the utilization of medical and technological devices. Additionally, the center strives to pioneer novel diagnostic and therapeutic methods for various eye diseases. The Center's research encompasses four primary directions:

1. Fundamental research aimed at facilitating the advancement of vision-assisting devices.
2. Active participation in international clinical trials involving retinal implants, subsequently integrated within Hungary's medical framework.
3. Execution of clinical trials involving genetic-based methodologies for the restoration of vision.
4. Automation of ophthalmic diagnostics grounded in the analysis of fundus and Optical Coherence Tomography (OCT) images.

Current work in the lab concentrates on sub-programs 1 and 4. Basic research focuses on modelling spatio-temporal event interpretation, including vision, the sensory channel that conveys most information. 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 the latest cameras and bionic processors and their forthcoming variants.

Navigation using a phone based visual assistant at the Cybathlon Challenge 2023

Key publications:

1. *Németh, János; Nyitrai, Beatrix; Karacs, Kristóf; Szabó, Dorottya; Ecsedy, Mónika; Szalai, Irén; Tóth, Gábor; Sándor, Gábor László; Magyar, Márton; Benyó, Fruzsina et al., "OCT-leletek telemedicinális értékelésének pontossága cukorbetegekben", Szemészet 159:2 pp. 64-68. , 5 p. (2022)*
2. *Á. Kusnyerik, U. Greppmaier, R. Wilke, F. Gekeler, B. Wilhelm, H. G. Sachs, K. U. Bartz-Schmidt, U. Klose, K. Stingl, M. D. Resch, A. Hekmat, A. Bruckmann, K. Karacs, J. Németh, I. Süveges, E. Zrenner, "Positioning of Electronic Subretinal Implants in Blind Retinitis Pigmentosa Patients Through Multimodal Assessment of Retinal Structures," Investigative Ophthalmology & Visual Science, vol. 53, no. 7, pp. 3748–3755, June 2012. doi: 10.1167/iovs.11-9409*

APPLIED MATHEMATICS

Prof. Mihály KOVÁCS

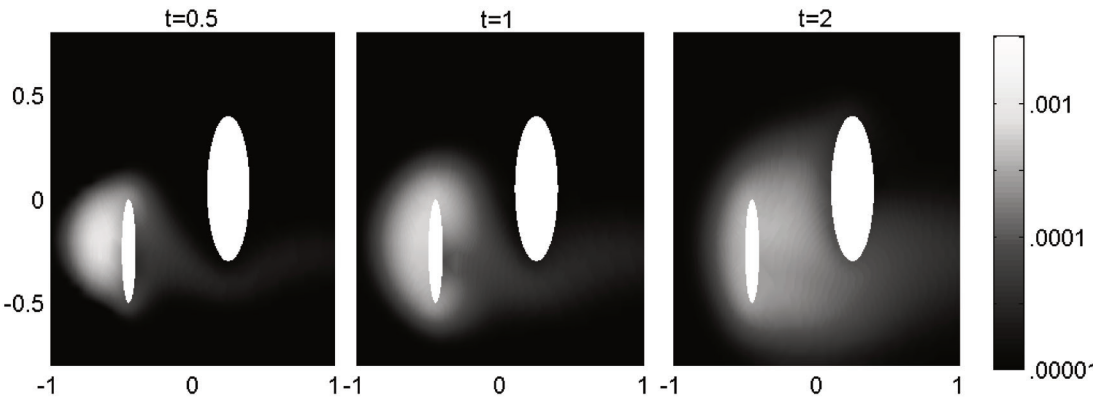
Head of Research Group: Prof. Mihály KOVÁCS

Members of the Group: Mihály András VÁGHY

Contact: kovacs.mihaly@itk.ppke.hu

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

The mathematical model of many time- and space-dependent processes 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.

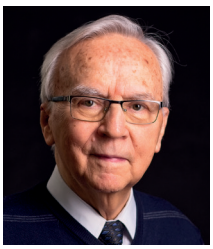


Key publications:

1. *Jansson, Erik; Kovács, Mihály; Lang, Annika. Surface Finite Element Approximation of Spherical Whittle–Mate´rn Gaussian Random Fields. SIAM Journal on Scientific Computing 44 (2022), no. 2, A825– A842.*
2. *Baeumer, Boris; Kovács, Mihály; Sankaranarayanan, Harish. Fractional partial differential equations with boundary conditions. J. Differential Equations 264 (2018), no. 2, 1377--1410.*
3. *Furihata, Daisuke; Kovács, Mihály; Larsson, Stig; Lindgren, Fredrik. Strong convergence of a fully discrete finite element approximation of the stochastic Cahn-Hilliard equation. SIAM. J. Numer. Anal. 56 (2018), no. 2, 708--731.*

LABORATORY FOR NEXT GENERATION COMPUTING HARDWARE

Dr. György CSABA



Prof. Árpád CSURGAY

Head of Research Group: Dr. György CSABA, Prof. Árpád CSURGAY

Members of the Group: Dr. Ádám PAPP, Tamás RUDNER

Contact: csaba.gyorgy@itk.ppke.hu

Keywords: *Beyond Moore devices, nanoelectronics, analog computing, quantum computing*

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.

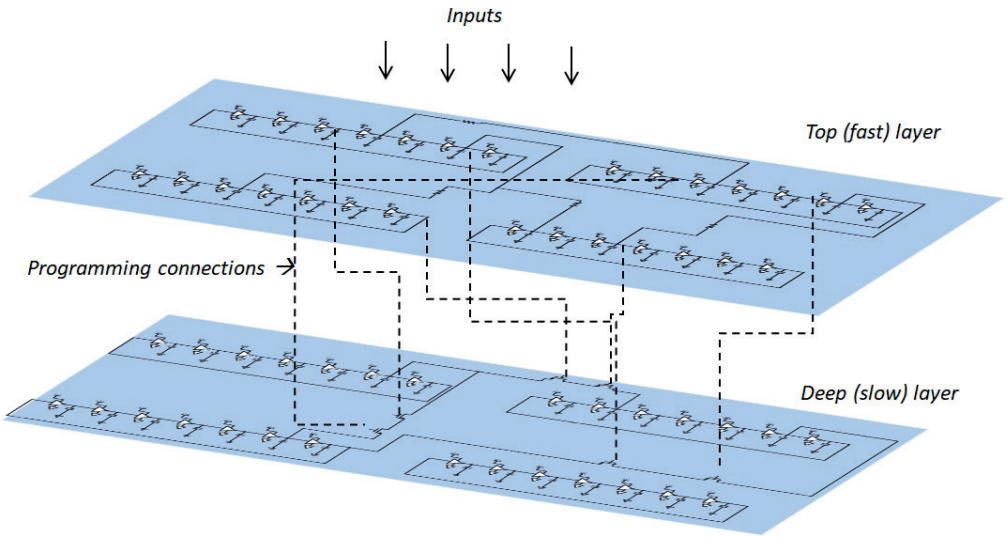


Illustration of a multi-layered ring oscillator network - the type of analog computing device we research in the lab.

Key publications:

1. *Csaba, Gyorgy, and Wolfgang Porod. "Coupled oscillators for computing: A review and perspective." Applied physics reviews 7, no. 1 (2020): 011302.*
2. *Csaba, Gyorgy, and Wolfgang Porod. "Noise immunity of oscillatory computing devices." IEEE Journal on Exploratory Solid-State Computational Devices and Circuits 6, no. 2 (2020): 164-169.*
3. *Raychowdhury, Arijit, Abhinav Parihar, Gus Henry Smith, Vijaykrishnan Narayanan, György Csaba, Matthew Jerry, Wolfgang Porod, and Suman Datta. "Computing with networks of oscillatory dynamical systems." Proceedings of the IEEE 107, no. 1 (2018): 73-89.*

LABORATORY OF FUNCTIONAL ELECTROMAGNETIC STRUCTURES

Prof. Zsolt SZABÓ

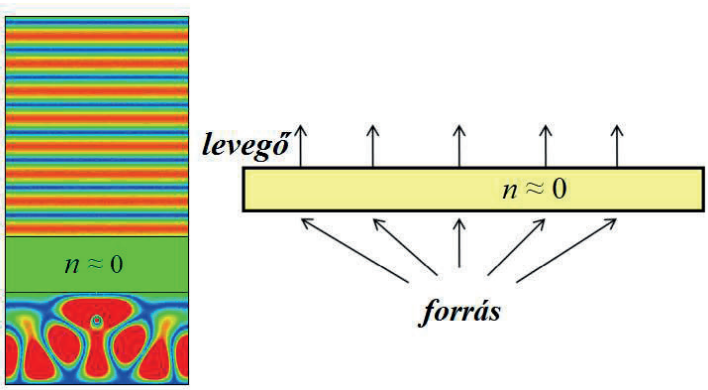
Head of Research Group: Prof. Zsolt SZABÓ

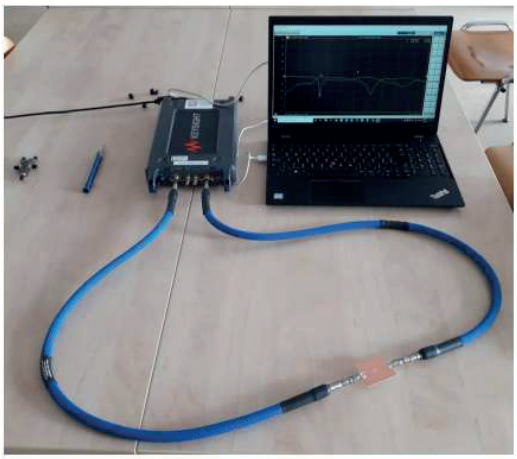
Members of the Group: András ESZES, Máté KÁLOVICS

Contact: szabo.zsolt@itk.ppke.hu

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

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.





The electromagnetic behavior of a metasurface with near zero refractive index.

Key publications:

1. *Zs. Szabó, G. -H. Park, R. Hedge and E. -P. Li, "A Unique Extraction of Metamaterial Parameters Based on Kramers–Kronig Relationship," in IEEE Transactions on Microwave Theory and Techniques, vol. 58, no. 10, pp. 2646-2653, Oct. 2010.*
2. *D. Li, Zs. Szabo, X. Qing, E. -P. Li and Z. N. Chen, "A High Gain Antenna With an Optimized Metamaterial Inspired Superstrate," in IEEE Transactions on Antennas and Propagation, vol. 60, no. 12, pp. 6018-6023, 2012.*
3. *M. Kálovics, K. Iván and Zs. Szabó, "Microfluidic Mixing Device With Integrated Dual-Band Microwave Sensor", in IEEE Sensors Journal, vol. 23, no. 14, pp. 15350-15360, 2023.*

OPTICS AND NANOELECTRONICS LAB

Dr. György CSABA

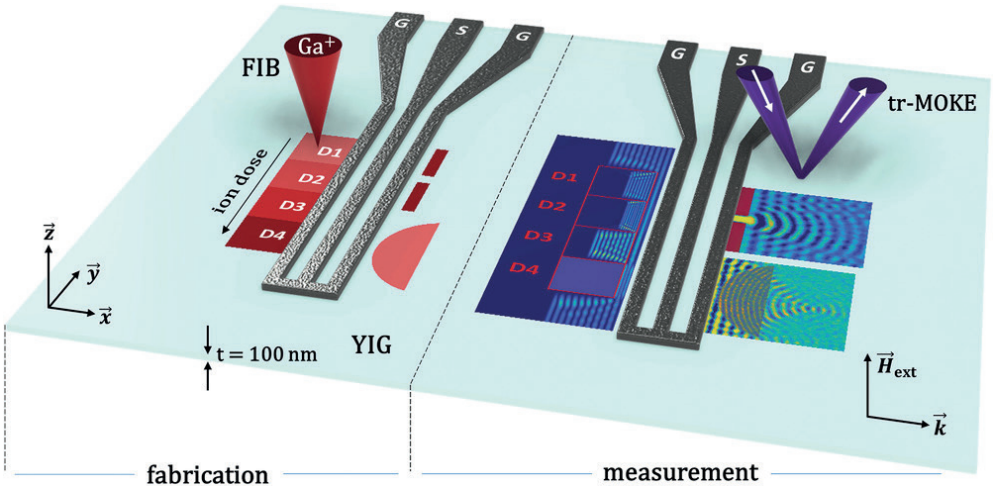
Dr. Ádám PAPP

Head of Research Group: Dr. György CSABA, Dr. Ádám PAPP

Contact: csaba.gyorgy@itk.ppke.hu

Keywords: *optics, nanoelectronics, spintronics, magnetism*

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 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. From Kiechle, Martina, Adam Papp, Simon Mendisch, Valentin Ahrens, Matthias Golibrzuch, Gary H. Bernstein, Wolfgang Porod, Gyorgy Csaba, and Markus Becherer. "Spin-Wave Optics in YIG Realized by Ion-Beam Irradiation." Small (2023): 2207293.

Key publications:

1. *Papp, Ádám, Wolfgang Porod, and Gyorgy Csaba. "Nanoscale neural network using non-linear spin-wave interference." Nature communications 12, no. 1 (2021): 6422.*
2. *Papp, Ádám, Martina Kiechle, Simon Mendisch, Valentin Ahrens, Levent Sahin, Lukas Seitner, Wolfgang Porod, Gyorgy Csaba, and Markus Becherer. "Experimental demonstration of a concave grating for spin waves in the Rowland arrangement." Scientific Reports 11, no. 1 (2021): 1-8.*
3. *Kiechle, Martina, Adam Papp, Simon Mendisch, Valentin Ahrens, Matthias Golibrzuch, Gary H. Bernstein, Wolfgang Porod, Gyorgy Csaba, and Markus Becherer. "Spin-Wave Optics in YIG Realized by Ion-Beam Irradiation." Small (2023): 2207293.*

ARTIFICIAL INTELLIGENCE AND SPATIAL-TEMPORAL SEMANTICS LAB

Dr. Kristóf KARACS

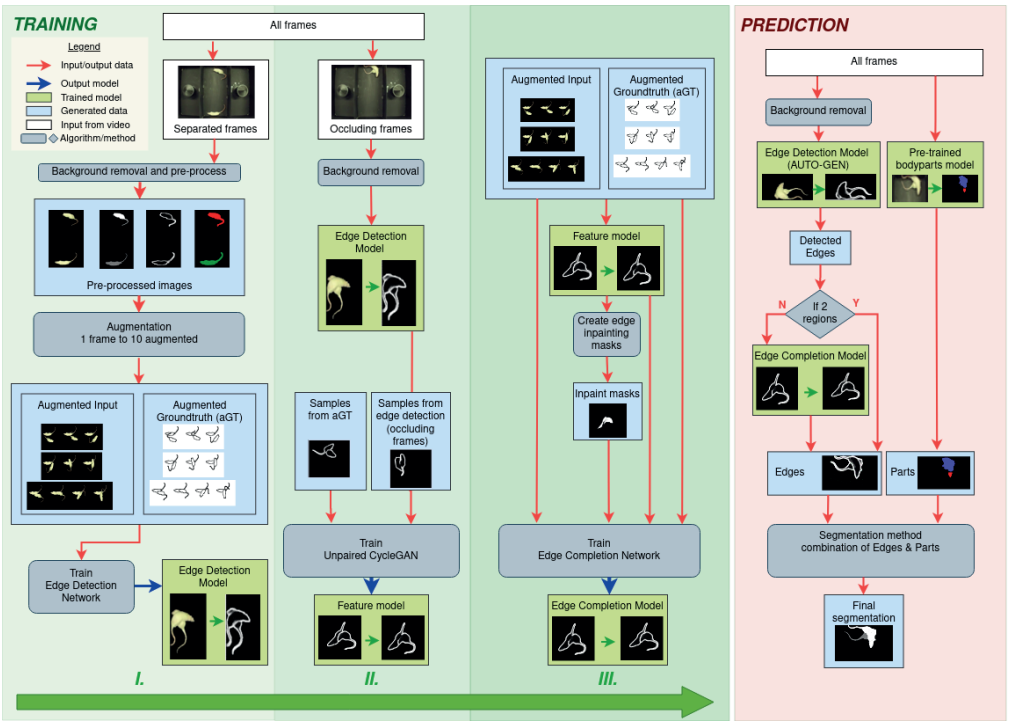
Head of Research Group: Dr. Kristóf KARACS

Members of the Group: Anna GELENCSÉR-HORVÁTH, András Attila SULYOK, Subham SHOME, Hyeon YU

Contact: karacs@itk.ppke.hu

Keywords: *semantic embedding, spatio-temporal learning, sensory processing, topographic processing*

The laboratory focuses on environmental understanding tasks related to sensory processing. As sensors are getting smaller, they are being incorporated in a wide variety of devices. In the classical approach to processing, data is collected from sensors as external units. With the increased amount of data, transmitting all the data not only to the cloud, but even to another processor requires an unrealistic amount of bandwidth and power. Processing locally, as close to the sensor as possible, requires appropriate knowledge and architectural organization. The key principle we have developed is semantic embedding. This means that the hierarchical recognition process must be designed in such a way that information coming form different levels of abstraction that have a contribution to the recognition process can be used at the appropriate level.

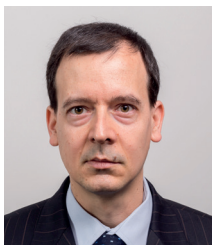


Training and inference pipelines of an animal tracking composite AI system.

Key publications:

1. *A. Gelencsér-Horváth, L. Kopácsi, V. Varga, D. Keller, Á. Dobolyi, K. Karacs, A. Lőrincz, "Tracking Highly Similar Rat Instances under Heavy Occlusions: An Unsupervised Deep Generative Pipeline," Journal of Imaging, vol. 8, no. 4, p. 109, Apr. 2022, doi: 10.3390/jimaging8040109*
2. *M. Radványi, K. Karacs, "Peeling off image layers on topographic architectures," Pattern Recognition Letters, vol. 135, pp. 50-56, 2020, 10.1016/j.patrec.2020.04.023*
3. *A. A. Sulyok, K. Karacs, "Towards Using Fully Observable Policies for POMDPs", in Proc. of 2nd IEEE International Conference on Computing and Machine Intelligence (ICMI), Istanbul, Turkey, Jul. 2022*

ANALYSIS AND CONTROL OF DYNAMICAL SYSTEMS RESEARCH GROUP



Prof. Gábor SZEDERKÉNYI

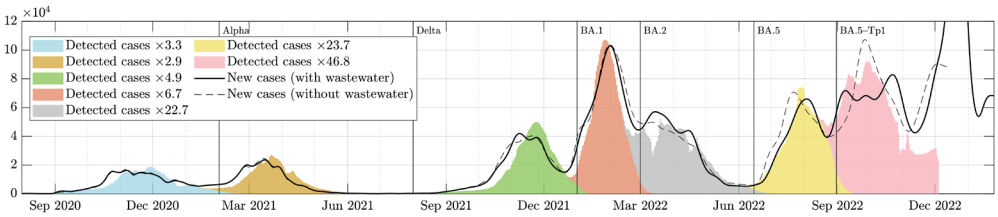
Head of Research Group: Prof. Gábor SZEDERKÉNYI

Members of the Group: Dr. Péter POLCZ, Balázs CSUTAK, Mihály András VÁGHY, Gergely HORVÁTH, Nawar AL-HEMEARY, Dávid SOMOGYI, Botond PRÁGAI

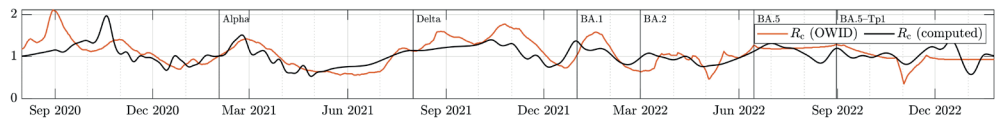
Contact: szederkenyi@itk.ppke.hu

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

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.



Daily number of new infections



Time dependent effective reproduction number

Results of the model-based estimation of epidemiological data during the COVID-19 pandemic in Hungary using hospital statistics and wastewater information. The data reconstruction problem is solved through system inversion traced back to nonlinear trajectory tracking control. Top figure: estimated real number of daily new infections and the related underdetection rates for the different waves and virus variants. Bottom figure: estimated time-dependent effective reproduction number compared to the published data series of Our World in Data.

Key publications:

1. *G. Szederkényi, B. Ács, G. Lipták, and M. A. Vághy, "Persistence and stability of a class of kinetic compartmental models," JOURNAL OF MATHEMATICAL CHEMISTRY, vol. 60, pp. 1001–1020, 2022.*
2. *T. Péni, B. Csutak, G. Szederkényi, and G. Röst, "Nonlinear model predictive control with logic constraints for COVID-19 management," NONLINEAR DYNAMICS, vol. 102, no. 4, pp. 1965–1986, 2020.*
3. *G. Lipták, K. M. Hangos, M. Pituk, and G. Szederkényi, "Semistability of complex balanced kinetic systems with arbitrary time delays," SYSTEMS & CONTROL LETTERS, vol. 114, pp. 38–43, 2018.*

MACHINE PERCEPTION AND GEO-INFORMATION COMPUTING

Prof. Csaba BENEDEK

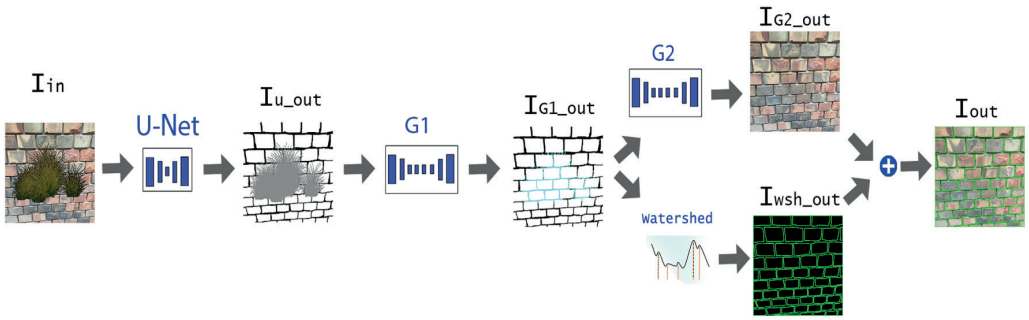
Head of Research Group: Prof. Csaba BENEDEK

Members of the Group: Lóránt KOVÁCS, Örkény H. ZOVÁTHI, Yahya IBRAHIM, Marcell KÉGL, Vilmos MADARAS, Gábor SZENTIRMAI

Contact: benedek.csaba@itk.ppke.hu

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

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 SZTAKI Machine Perception Research Laboratory.



Key publications:

1. *Ö. Zováthi, B. Nagy and Cs. Benedek: "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, vol. 110, pages 102767, 2022, IF: 7.672 https://doi.org/10.1016/j.jag.2022.102767*
2. *B. Nagy, L. Kovács and Cs. Benedek: "ChangeGAN: A deep network for change detection in coarsely registered point clouds," IEEE Robotics and Automation Letters, vol. 6, no. 4, pp. 8277 - 8284, 2021, IF: 4.321, DOI: 10.1109/LRA.2021.3105721*
3. *Cs. Benedek: "Multi-level Bayesian Models for Environment Perception," Springer International Publishing, 202 pages, ISBN 978-3-030-83654-2, 2022 https://doi.org/10.1007/978-3-030-83654-2*

SMART SENSORY COMPUTING LAB

Dr. András HORVÁTH

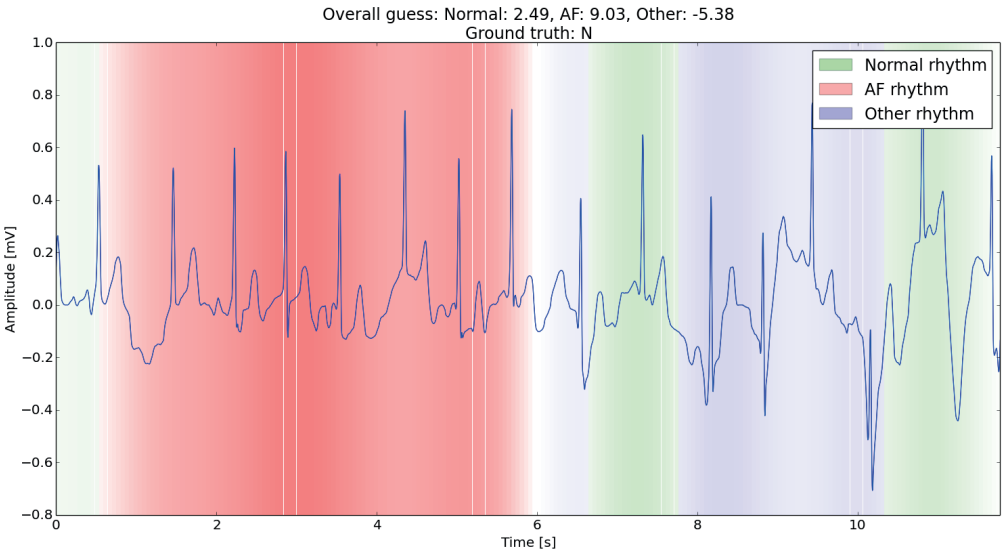
Head of Research Group: Dr. András HORVÁTH

Members of the Group: Dóra Eszter BABICZ, András FÜLÖP, Jalal AL-AFANDI, Ákos KOVÁCS, Bálint MAGYAR, Gergely SZABÓ

Contact: horvath.andras@itk.ppke.hu

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

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, A cell phone app helping visually impaired people to get ariybd, Vision systems for smart cities that identify vehicles and pedestrians as well as predict dangerous situations. In our theoretical research we primarily focus on understanding the principles of learning and vision. A key challenge is improving the generalization ability of learning algorithms and more specifically neural networks.



We put a strong emphasis on explainable AI, understanding machine learning models and the visualization of their decisions. This allows us not only to make decisions with the models we create in practical applications, but also to reason these decisions and communicate them towards doctors in medical applications. These saliency maps and reasoning can help doctors focus there attention on the necessary parts of the data and on important problems.

Key publications:

1. *Barna, L., Dudok, B., Miczán, V., Horváth, A., László, Z. I., & Katona, I. (2016). Correlated confocal and super-resolution imaging by VividSTORM. Nature protocols, 11(1), 163-183.*
2. *Hatvani, J., Horváth, A., Michetti, J., Basarab, A., Kouamé, D., & Gyöngy, M. (2018). Deep learning-based super-resolution applied to dental computed tomography. IEEE Transactions on Radiation and Plasma Medical Sciences, 3(2), 120-128.*
3. *Lou, Q., Pan, C., McGuinness, J., Horvath, A., Naeemi, A., Niemier, M., & Hu, X. S. (2019). A mixed signal architecture for convolutional neural networks. ACM Journal on Emerging Technologies in Computing Systems (JETC), 15(2), 1-26.*

DATA. MEDIA. COMMUNITY

Dr. Gergely LUKÁCS

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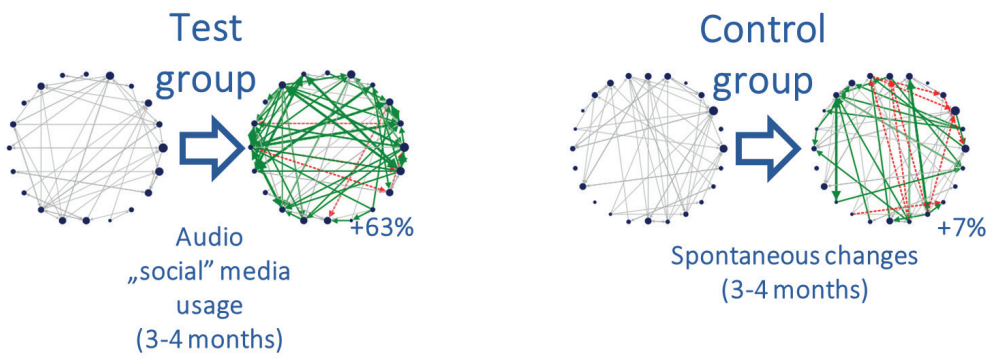
Keywords: *big data, machine learning, social media, sound analysis*

Database management, machine learning and data mining became central issues in recent years. The laboratory covers a wide range of relevant topics and systems, from relational database management systems, over cloud-based big data systems to data curation, business intelligence and machine learning tools. The lab infrastructure supporting includes a high-performance server, a storage server and powerful workstations. Concerning the application areas, our long-term vision is applications supporting and strengthening human ties. Cooperation with sociologists, psychologist and media professionals is crucial for us. We have been involved in assessing the effect of an audio-based social media system on (offline) social networks and the analysis of social networks among clinical pastoral care professionals. Currently, we are working on speech-music playlist generation, a technical precondition for customized, audio social media. Thesis works are also prepared on the analysis of data collected by Google, Facebook, Instagram.



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, Timea; Lukács, Ágnes; Járay, Márton; Lukács, Gergely Identification of social network patterns among Hungarian clinical pastoral care professionals p. 0 (2018) XXXVIII Sunbelt Conference 2018-06-26 [Utrecht, Hollandia], Utrecht, Hollandia, 2018.06.26-07.01.*
2. *Lukács, Gergely; Jani, Mátyás Analyzing speech and music blocks in radio channels: Lessons learned for playlist generationIn: Robles, R; Tallon-Ballesteros, A J; Pit, Pichappan (szerk.) Eleventh International Conference on Digital Information Management (ICDIM) New York, Amerikai Egyesült Államok: IEEE (2016) pp. 179-184. , 6 p.*
3. *Jani, M; Lukács, G; Takács, G Experimental investigation of transitions for mixed speech and music playlist generation In: Proceedings of the 4th ACM International Conference on Multimedia Retrieval, ICMR 2014 Association for Computing Machinery (ACM) (2014) pp. 392-398. , 7 p.*

LANGUAGE TECHNOLOGY RESEARCH GROUP

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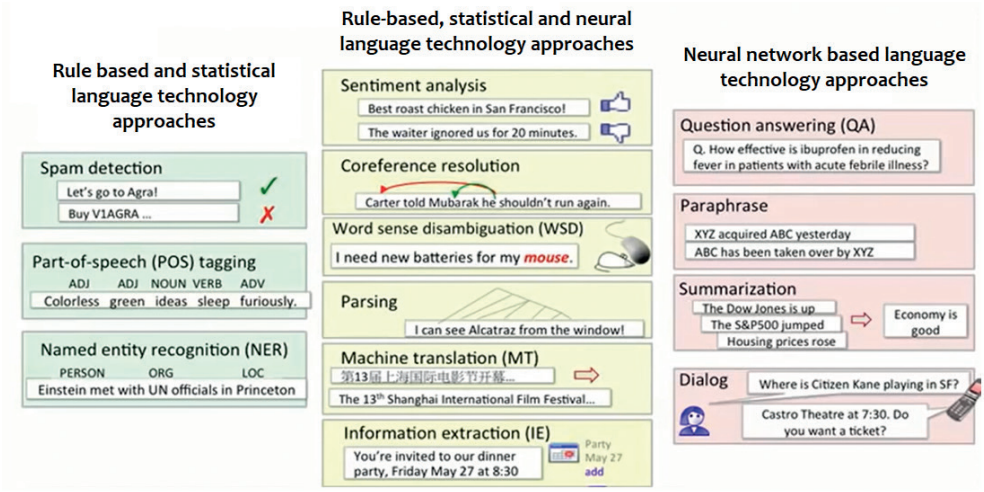
Keywords: *machine learning,neural language models, transformer architecture, fine tuning, corpus linguistics*

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.

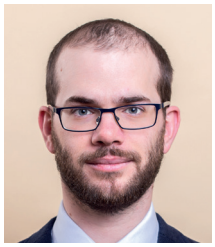


Main research areas of our Language Technology Research Group

Key publications:

1. *Novák, Attila; Novák, Borbála. Cross-lingual transfer of knowledge in distributional language models: Experiments in Hungarian. Acta Linguistica Academica, Volume 69: Issue 4, 405-449 (2022)*
2. *Prószéky, Gábor. Guest Editor's Foreword. Acta Linguiustica Acdemica, Volume 69: Issue 4, 399-404 (2022)*
3. *Yang, Zijian Győző Neural text summarization for Hungarian Acta Linguistica Acedmica, Volume 69: Issue 4. 474-500,. (2022)*

HIGH PERFORMANCE COMPUTING LAB



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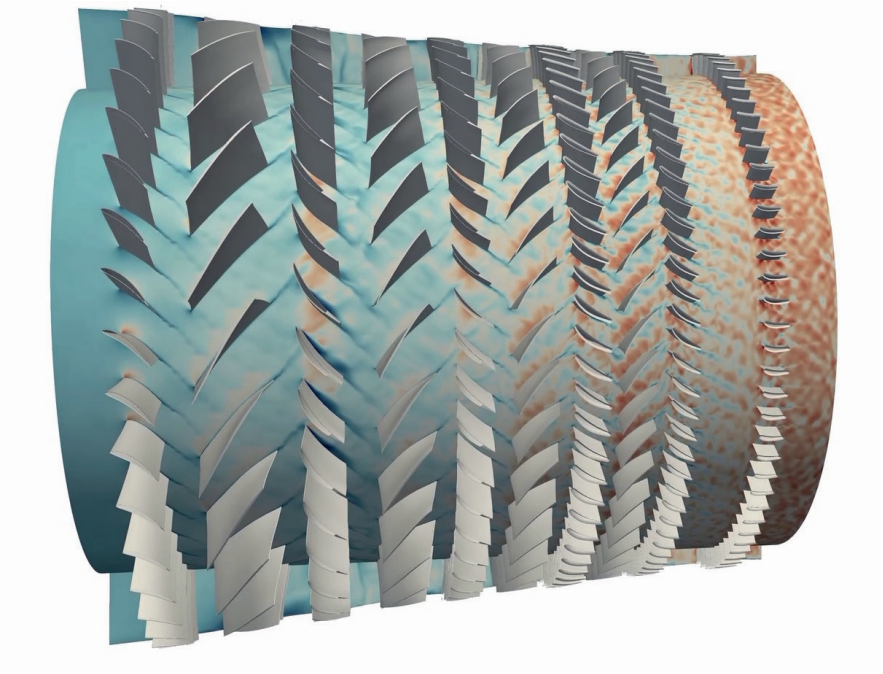
Keywords: *programming abstractions, CPU, GPU, distributed computing, parallel computing*

The lab works on the maintenance and efficient utilisation of parallel hardware platforms at the faculty, and studies the mapping of high-level algorithmic constructs to low-level hardware instructions that perform well. Our group uses the OP2 and OPS Domain Specific Languages to conduct research into the performance, portability, and productivity of mainly computational fluid dynamics applications.



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. *Balogh, G. D., Flynn, T. S., Laizet, S., Mudalige, G. R., & Reguly, I. Z. (2021). Scalable Many-Core Algorithms for Tridiagonal Solvers. Computing in Science & Engineering, 24(1), 26-35.*
2. *Sulyok, A. A., Balogh, G. D., Reguly, I. Z., & Mudalige, G. R. (2019). Locality optimized unstructured mesh algorithms on GPUs. Journal of Parallel and Distributed Computing, 134, 50-64.*
3. *Mudalige, G. R., Reguly, I. Z., Prabhakar, A., Amirante, D., Lapworth, L., & Jarvis, S. A. (2022, September). Towards Virtual Certification of Gas Turbine Engines With Performance-Portable Simulations. In 2022 IEEE International Conference on Cluster Computing (CLUSTER) (pp. 206-217). IEEE.*

APPLICATIONS OF KILOPROCESSOR ARRAYS

Prof. Péter SZOLGAY

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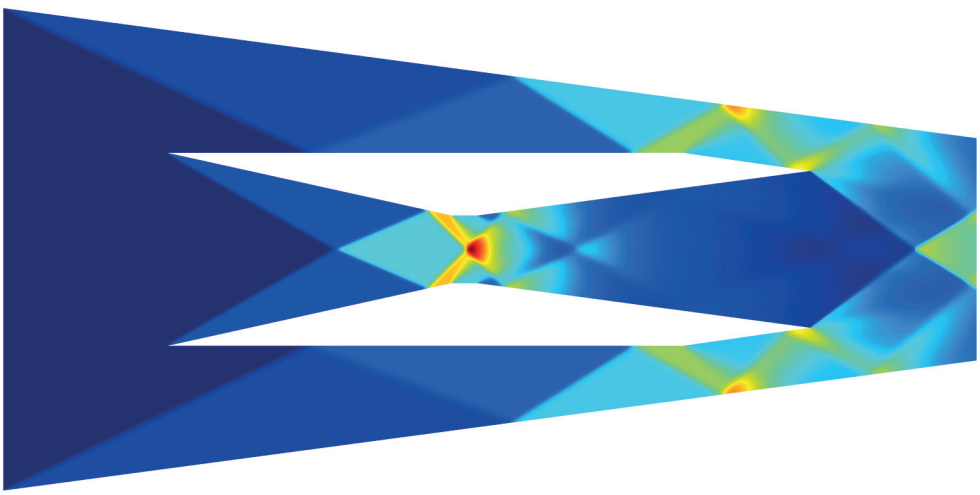
Keywords: *parallel computing, processor arrays, heterogeneous architectures, FPGA, reconfigurable computing*

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 medical signal processing to the acceleration of search in bioinformatics databases and the display of the results of the calculation. 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, Attila; Nagy, Zoltán; Benois-Pineau, Jenny; Szolgay, Péter: de Rugy, Aymar: Domenger, Jean-Philippe Hybrid FPGA–CPU-Based Architecture for Object Recognition in Visual Servoing of Arm Prosthesis JOURNAL OF IMAGING 8: 2 p. 44 (2022)*
2. *Z. Nagy; Cs. Nemes; A. Hiba; Á. Csík; A. Kiss; M. Ruszinkó; P. Szolgay: "Accelerating unstructured finite volume computations on field-programmable gate arrays", 2014, Concurrency and Computation: Practice and Experience, Vol: 26, Issue: 3, pp. 615-643.*
3. *Zarandy, A; Horvath, A; Szolgay, P: CNN Technology-Tools and Applications IEEE CIRCUITS AND SYSTEMS MAGAZINE 18: 2 pp. 77-89. , 13 p. (2018)*

SOFTWARE-DEFINED INFORMATION AND COMMUNICATIONS SYSTEMS

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Keywords: *software-defined systems, chaos-based wireless communications, phase-locked loops, virtual instrumentation*

Software Defined Informatics (SDI) represents a paradigm shift in modern information processing and communications technologies where each application is implemented exclusively in software. The software is run on an arbitrary computing platform and the transformations between the real-world analog signals and digital data streams processed on the digital computing platform are performed by universal hardware tools.

The SW implementation provides tremendous flexibility and different applications can be run in parallel. We aim to develop the general theory of SDI concept.

Up-to-date ICT systems require mobile radio communications devices with ultra-low-power consumption. Our lab has introduced the idea of non-coherent chaos-based data communications and the DCSK modulation which has been accepted as a worldwide standard. Now we are working to further develop the DCSK technology.

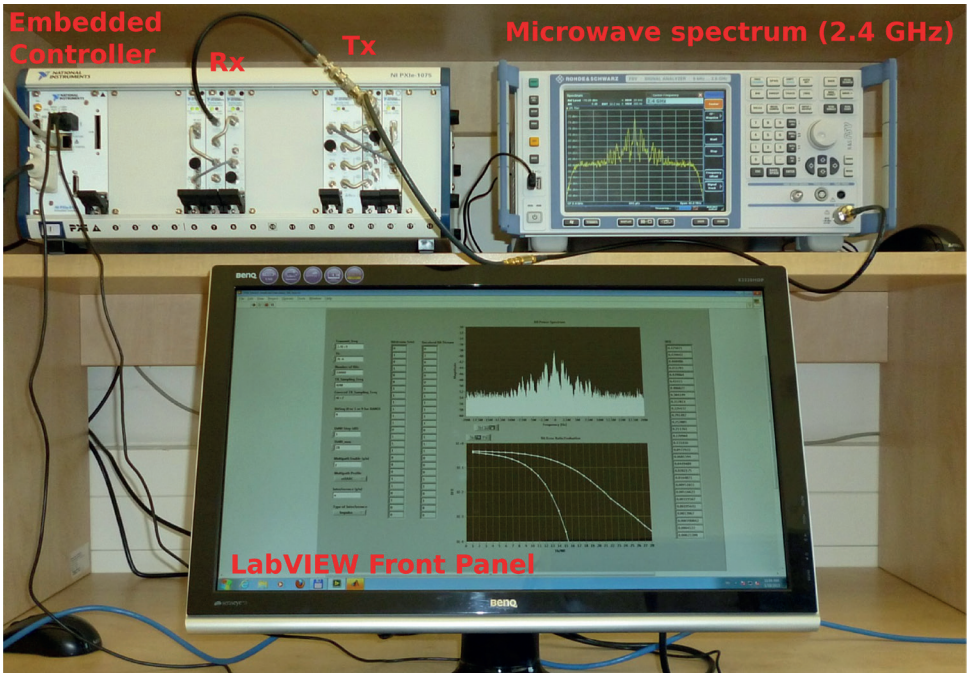

Photo of the PXI-based universal SDI platform used in the lab. The PXI chassis and a stand-alone microwave spectrum analyzer can be seen at the top-left and top-right, respectively, of the photo while the monitor in the bottom displays the measured results. The picture shows an automated BER performance evaluation of a chaos-based FM-DCSK communications system over a multipath noisy radio channel.

Key publications:

1. *G. Kolumbán, "SDE implementation of chaos-based communications systems," In: Stoop, Ruedi; Fortuna, Luigi; Buscarino, Arturo (eds.) "Advances on Nonlinear Dynamics of Electronic Systems," World Scientific (2019) pp. 41-45.*
2. *X. Cai, W. Xu, L. Wang and G. Kolumbán, "Design and Performance Analysis of a Robust Multi-Carrier M-Ary DCSK System: A Noise Suppression Perspective," in IEEE Transactions on Communications, vol. 70, no. 3, pp. 1623-1637, March 2022, doi: 10.1109/TCOMM.2022.3144276.*
3. *C. Bai, X. -H. Zhao, H. -P. Ren, G. Kolumbán and C. Grebogi, "Double-Stream Differential Chaos Shift Keying Communications Exploiting Chaotic Shape Forming Filter and Sequence Mapping," in IEEE Transactions on Wireless Communications, vol. 21, no. 7, pp. 4954-4972, July 2022, doi: 10.1109/TWC.2021.3135043.*

MOBILE SENSOR PLATFORMS AND MULTIMODAL SENSING NETWORKS

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

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.

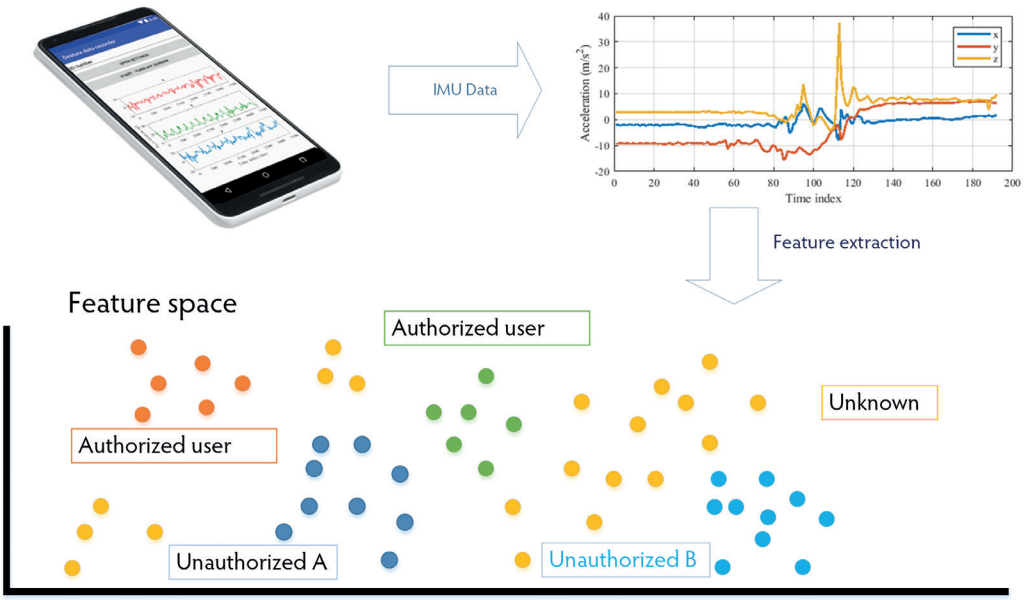

Illustration of the workflow, how open-set recognition is applied to IMU sensor readings of a smart mobile phone. The proposed method can distinguish known users and separate them from unknown (unknown to the system during the training phase) patterns.

Key publications:

1. *Németh, D.I.; Tornai, K. Electrical Load Classification with Open-Set Recognition. Energies 2023, 16, 800. https://doi.org/10.3390/en16020800*
2. *Kálmán Tornai; Walter J. Scheirer, Gesture-based User Identity Verification as an Open Set Problem for Smartphones In: Proceedings of the 12th IAPR International Conference On Biometrics: p. 1. (2019)*
3. *Kálmán Tornai, Lóránt Kovács, András Oláh, Rajmund Drenyovszki, István Pintér, Dávid Tisza, János Levendovszky: Classification for consumption data in smart grid based on forecasting time series; Electric Power Systems Research; Elsevier (2016)*

UAV VISION LAB

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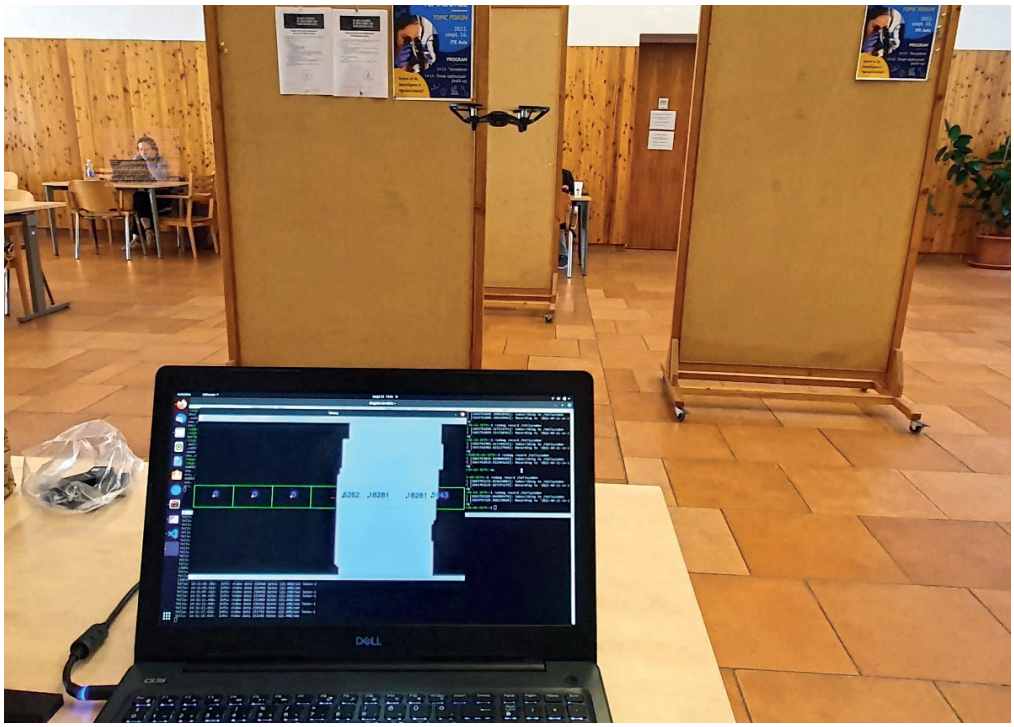
Keywords: *UAV, computer vision, sense-and-avoid,embedded systems, bio-motivated algorithms*

The UAV Vision Lab aims to research topics at the intersection of unmanned aerial vehicles and computer vision. In the case of unmanned aerial vehicles, an unavoidable research question is how to solve the computations needed to solve a given problem with the lowest possible power consumption and preferably with small and affordable tools. One of the main topics is camera-based collision avoidance, where we want to detect and track distant aircraft on one or more camera images. In addition to better detection and tracking, the aim is to have a collision avoidance system with the lowest possible power consumption and size since the calculations must be done onboard the aircraft in real time. Another area of research is ergonomic control of aircraft, where we want to develop control methods that allow aircraft to be piloted in a more natural, faster-learning, or even more accurate way than is currently possible. The third major area is indoor applications, where we will also rely on machine vision to investigate what tasks can be done well without external reference systems, using only sensors on board the aircraft. For instance, in 3D cave mapping, we would like to use cameras, IMU and LiDAR to produce a more accurate 3D map of cave passages than is currently available, thus facilitating the exploration of new paths or helping cavers. In addition, students will develop a simulator for collision avoidance, ergonomic drone control, virtual drone fence, neuromorphic collision avoidance, visual indoor navigation, and 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. *Zsedrovits T, Bauer P, Jani Mátyásné Pencz B, Hiba A, Gőzse I, Kisantal M, Németh M, Nagy Z, Vanek B, Zarándy A, Bokor J Onboard visual sense and avoid system for small aircraft IEEE AEROSPACE AND ELECTRONIC SYSTEMS MAGAZINE 31 : 9 pp. 18-27. Paper: 7590295 , 10 p. (2016), doi: 10.1109/MAES.2016.150129*
2. *Hiba A, Sántha L M, Zsedrovits T, Hajder L, Zarandy A Onboard Visual Horizon Detection for Unmanned Aerial Systems with Programmable Logic ELECTRONICS (SWITZ) 9 : 4 Paper: 614 , 18 p. (2020), doi: 10.3390/electronics9040614*
3. *M. Pethő and T. Zsedrovits, "UAV obstacle detection with bio-motivated computer vision," 2021 17th International Workshop on Cellular Nanoscale Networks and their Applications (CNNA), Catania, Italy, 2021, pp. 1-4, doi: 10.1109/CNNA49188.2021.9610823.*

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Kiadja a Pázmány Egyetem eKiadó
Budapest, 2023

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