2nd annual ENGINEERING PhD SUMMIT

Intelligent Systems

October 3 2019, BM 5202

11 exceptional graduating PhD students from universities worldwide

► Compete for the EPFL Engineering PhD Summit Prize
► Present their exceptional research work during a 1-day workshop
► Interact with EPFL PhD students during a poster session

https://phdsummit.epfl.ch
Welcome to EPFL!

On behalf of the organizing committee of the EPFL Engineering PhD Summit, we welcome you to EPFL Campus in Lausanne, Switzerland.

The PhD Summit is a workshop for final year PhD students interested in a career in academia. Each year, we invite to campus, on a competitive basis, a group of exceptional graduating PhD students from institutions worldwide.

In this 2nd edition, the Summit is focusing on the theme of «Intelligent systems». Advancements in information technology, artificial intelligence and control, computing capabilities, instrumentation, sensors and actuators have dramatically increased the pace at which intelligent systems enter our daily lives, e.g. in our software, smartphones, cars, robots, and infrastructure.

Last year Ph.D. students working in fields such as robotics, embedded systems, internet of things, artificial intelligence, machine learning, computer games, human-computer interfaces, computational neuroscience, and cognitive science, will present novel research contributions that fit into the general theme of Intelligent Systems.

We have received many outstanding applications from universities worldwide and selected a short list of 11 students from 9 universities.

The candidates will present their research during the Summit and interact with faculty from the School of Engineering, the School of Computer Science and the School of Basic Sciences. Each candidate will also be visiting EPFL laboratories and meeting students and researchers. The Engineering PhD Summit Prize for the best presentation and research impact will be awarded during the summit.

As part of the PhD Summit program, a selection of EPFL students will also present their research work related to “intelligent systems” in a short plenary pitch, and a poster session.

We would like to thank all those involved in the organization of this event for their valuable contributions.

We hope you will enjoy your time at EPFL.

Auke Ijspeert  
PhD Summit Chair

Pascal Frossard  
Associate Dean for Research  
School of Engineering, EPFL

Ali H. Sayed  
Dean of Engineering, EPFL
Selected international candidates

Dong Ma  
University of New South Wales  
Australia

Wei Zhou  
The University of Sydney  
Australia

Jibin Wu  
National University of Singapore

Xiang Zhang  
University of New South Wales  
Australia

Jessica Lanini  
Ecole polytechnique fédérale de Lausanne  
Switzerland

Eric Sillekens  
University College London  
United Kingdom

Laura Moraes  
Federal University of Rio de Janeiro  
Brazil

Pal Saptadeep  
University of California  
Los Angeles  
USA

Nooshin Yousefi  
Rutgers, State University of New Jersey  
USA

Hanzhang Pei  
University of Michigan  
USA

Zhe Wu  
University of California  
Los Angeles  
USA
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“Morphological Computation in Aerial Robotics”

Prof. Dario Floreano (M.A. 1988; M.S. 1992; Ph.D. 1995) is the director of the Laboratory of Intelligent Systems and director of the Swiss National Center of Competence in Robotics. He is member of the Global Agenda Council on Robotics and Smart Devices of the World Economic Forum. He is co-founder of the company senseFly S.A., of the International Society for Artificial Life, and founder of the popular robotics podcast series Talking Robots (which later became RobotsPodcast).

He has been on the advisory board of the Future and Emerging Technologies division of the European Commission, on the advisory board of the Institute for Advanced Studies in Budapest, and on the board of governors of the International Society for Neural Networks. Prof. Floreano is a senior member of the IEEE and received several national and international awards for professional and cultural achievements. Prof. Floreano is or has been on the editorial board of the international journals: Neural Networks (Pergamon), Genetic Programming and Evolvable Machines (Kluwer), Adaptive Behavior (Sage), Artificial Life (MIT Press), Connection Science (Francis & Taylor), Evolutionary Computation (MIT Press), Evolutionary Intelligence (Springer), IEEE Transactions on Evolutionary Computation (IEEE), Autonomous Robots (Kluwer).
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Dong ma
The University of New South Wales, Australia, School of Computer Science and Engineering, Lab. of Prof. Mahbub Hassan

“Energy-autonomous Context Sensing for Energy Harvesting Internet of Things”

Future intelligent systems tend to have autonomous operation and dynamic interaction with the surrounding contexts, which poses challenges on persistent energy supply and ubiquitous sensing capability. The recent emergence of energy harvesting Internet of Things (EH-IoTs) allows operation solely with the energy harvested from the ambient environment. Given that energy production is highly sensitive to the contexts, my research seeks to detect the context directly from the energy harvesting signal, thus eliminating specialized sensors for simplified device architecture and reduced power consumption. By applying basic machine learning, we have already demonstrated the feasibility of detecting human activities from kinetic and solar energy harvesting. Specifically, we exploited the generated AC voltage signal from a kinetic energy harvester to perform activity recognition, gait authentication, and transportation mode detection. We have further exploited the generated photocurrent signal from a transparent solar cell to detect hand gestures.

Wei Zhou
The University of Sydney, Australia, Australian Centre for Field Robotics of Prof. Eduardo Nebot

“Analysing the generalisation and robustness of semantic segmentation for autonomous vehicles”

Intelligent systems require the capability to perceive and interact with the surrounding environment. Semantic segmentation, as a pixel-level classification task, is at the frontier of providing a human-like understanding to intelligent systems enabling them to view and understand the world as we do. Deep learning based semantic segmentation algorithms have shown considerable success for certain tasks in recent years. However, in real-world safety critical applications such as autonomous vehicles, there are still many complexities that restrict the use of this technology. My research has been focusing on analysing the generalisation and the robustness of semantic segmentation for intelligent vehicles. A system validation pipeline has been proposed to tackle the challenges of evaluating and quantifying the performance of semantic segmentation before deploying to intelligent platforms. This method can be used in most urban traffic scenarios without the time and expense of using humans to generate labels by hand.
Jibin Wu
National University of Singapore, Department of Electrical and Computer Engineering, Human Language Technology Lab. of Prof. Haizhou Li

“Efficient and Rapid Pattern Recognition with Spiking Neural Networks”

Humans are remarkably efficient and robust in many perception and cognition tasks, while state-of-the-art digital computers failed to match human brains in terms of computational efficiency and capability. Event-based computation, as observed in the human brain and nervous systems, relies on asynchronous and highly parallel spiking events to efficiently encode and transmit information. Spiking neural network (SNN) is one such class of neural networks motivated by event-based computation. In this talk, I will present our recent research progress in efficient neural coding and novel learning rules for deep spiking neural networks. Meanwhile, considerable applied efforts are devoted to building SNN framework so as to tackle real-world pattern recognition tasks, instances include image classification, environmental sound classification, automatic speech recognition, and speech separation.

Xiang Zhang
University of New South Wales, Australia, School of Computer Science and Engineering, Lab of Prof. Salil Kanhere

“Towards A Data-Efficient Brain Biometric Recognition System in Brain Computer Interface”

Xiang aimed at overcoming the research hurdles and stretching the horizons of interactive intelligent systems by developing novel machine learning algorithms. Xiang developed a set of deep learning frameworks in order to enable and enhance data-efficient brain biometric intelligent recognition in Brain-Computer Interface (BCI) and its applications in terms of healthcare (e.g. neurological disorder diagnosis) and internet of things (e.g., user authentication).

In detail, Xiang designed an Electroencephalography (EEG)-based authentication system by combining Long Short-Term Memory (LSTM) and attention mechanism; proposed a selective attention mechanism by combining reinforcement learning and recurrent neural network for capturing informative high-level features from the raw EEG signals; investigate the semi-supervised problem and proposed a novel adversarial variational embedding approach to harness the deep generative model and generative adversarial networks collectively under a trainable unified framework.
In everyday life humans perform many tasks with other partners which involve coordination, involuntary communication and mutual control adaptation, as the case of carrying objects together with another person. Humanoid robots may help with such activities by collaborating with humans or even substitute them. With this in mind, understanding how humans perform such tasks would be useful not only to better understand human motor control strategies but also to extract useful information for the implementation of robotic controllers. This Thesis aims to investigate if and how the haptic interaction among two subjects cooperating with each other while walking (e.g. while carrying objects) (a) alter their walking gaits, (b) is exploited by humans to understand the intentions of the other partners (e.g. to start/stop walking, accelerate/decelerate, etc.), (c) determine a walking synchronization and (d) whether such a synchronization can improve the overall task (e.g. by reducing the interaction forces). Moreover the feasibility of applying human-human strategies to develop robotic controllers is investigated.

Human-human studies are performed to assess the research objectives and replicate them through simple mechanical models. The main features extracted from the human experiments are then used to develop control modules for humanoid robots doing similar tasks with humans or with other robots. Robotic experiments are then used not only to assess the feasibility of using humans strategies in robotic control but also to try to answer some questions related to human behaviour. The obtained results show that most of the subjects analyzed (a) alter their walking gait while mechanically paired with another human subject, (b) communicate their intention through a combination of interaction forces and hand velocity, (c) coordinate their walking gait with their partner, (d) selecting specific quadrupedal animals types of gaits. Moreover human-humanoid robot and humanoid robot-robot experiments are successfully performed and used to show the importance of walking synchronization in reducing the interaction forces and guaranteeing more symmetric motion of the two bipedal agents.
Eric Sillekens
University College London, United Kingdom, Department of Electronic and Electrical Engineering, Optical networks group of Prof. Polina Bayvel

“Model-based machine learning for optical communication systems”

In optical communication systems, we are blessed with very precise models. We can use these models to mitigate the negative impact of physical components that affect transmission, allowing us to transmit more data over longer distances with the same devices.

In the same way that linear regression can design a filter to compensate for the frequency roll-off of components, we can apply machine learning to more complicated models. This allows us to mitigate non-linear impact from complex physical interactions.

The work I’ll be presenting is on time-domain digital back-propagation, which uses experimentally obtained waveforms to train a network that use very small steps to compensate for two physical effects that occur simultaneously. Every step consists of two layers: the first, a convolutional layer that compensates for chromatic dispersion, and the second, a non-linear phase-shift that compensates for a signal-dependent phase shift. The alternating linear and non-linear layers resemble a neural network, allowing us to apply the latest advances in machine learning to improve the performance of our communication systems.

Laura Moraes
Federal University of Rio de Janeiro, Brazil, Systems & Computing Graduate Department (PESC), Artificial Intelligence group of Prof. Carlos Eduardo Pedreira

“Intelligent Tutoring System”

The ability to make inferences about a person’s knowledge is very important in educational settings. These inferences can be used to reveal gaps in knowledge and to diagnose misunderstandings and misconceptions.

My work proposes an ITS (Intelligent Tutoring System) that categorizes Python codes into the concepts needed to solve them and use this information to infer a transparent student model. This student model can then be used by tutors to visualize a student’s inferred knowledge, to recommend new exercises and to guide students in pinpointing their own misconceptions. To achieve this goal, the work was divided in three independent modules: question classification, knowledge tracing and question recommendation. Since student data can be collected in different contexts, the presented work is being constructed in a way that it could be extended to different domains by changing specific blocks.
At the heart of most modern intelligent systems lies highly parallel compute intensive applications such as deep neural networks, graph processing etc. With explosion of data, intelligent systems of the future will need to perform orders of magnitude more computation than that’s required to run today’s largest workloads. For example, language models would need to be 500x larger and would require 1000x larger datasets to train in order to achieve beyond human-level accuracy. This requires high throughput and highly energy efficient computing, and therefore, the need for massively parallel hardware has never been stronger. To build massively parallel processor systems, we have developed a large waferscale integration technique (silicon interconnect fabric, Si-IF), where a large number of bare dies, both compute and memory, can be integrated tightly using very high bandwidth, low latency and highly energy efficient interconnects.

In this talk, I will discuss the challenges of architecting a waferscale system. Using a waferscale GPU case study, I will show that a 40x larger GPU can be built on a wafer compared to today’s largest GPU and discuss in details the various optimizations that need to be done across the stack, from circuits to runtime systems in order to fully exploit the potential of the waferscale integration. Compared to a multiple GPU system interconnected using conventional integration schemes, a waferscale GPU can provide on an average 5.2x performance speedup across a suite of applications. Next, I will discuss waferscale graph processing. Graph applications require very large random-access bandwidth and therefore, we are developing a waferscale graph processor architecture and a prototype hardware to get large gains in performance by leveraging the large interconnect bandwidth on the wafer while providing a simple programming model. Such an architecture is estimated to improve graph processing performance by up to about 22x compared to conventional systems.
Nooshin Yousefi
Rutgers, The State University of New Jersey, USA

“Intelligent system for maintenance policy of complex systems with individually repairable components”

Implementing an appropriate maintenance policy would help us to have a more reliable system and reduce the total costs. Complex systems may have different individual components with different configurations within the system. For systems and components which degrading over time, a failure event happens when the degradation level is greater than a threshold. There are different factors which may affect the degradation speed of components such as environmental condition where the system functioning in. Environmental shocks arrival may increase the degradation level of some components and make them reach their failure threshold sooner. In my research, a multi-components system is considered where each component is degrading over time and subject to environmental shocks. Moreover, each component can be replaced or repaired individually within the system. Therefore, to avoid the system failure an appropriate maintenance policy should be implemented on components which are prone to failure. Using machine learning method, a dynamic maintenance plan is developed for a complex system. The maintenance team can use the proposed intelligent system to find which maintenance action should be implemented on each component at any inspection time which results the lowest cost.

Hanzhang Pei
University of Michigan, USA, Electrical engineering and computer science, Center for Ultrafast Optical Science of Prof. Almantas Galvanauskas

“Coherent LASER Pulse Stacking Amplification”

Coherent Pulse Stacking Amplification (CPSA), a technique of temporal coherent stacking of laser pulses into a single pulse using interferometric cavities, enables near-complete stored-energy extraction from fiber amplifiers and hence high efficiency and high power laser systems. It requires accurate and adaptive modulation of pulse amplitudes, phases and mirror positions to compensate for external perturbations and systematic errors. An FPGA-based centralized intelligent control system collects feedback signal and adaptively controls all modulations simultaneously, and it finds and stabilizes in a 89-dimensional parameter space at 2% rms peak power using Stochastic Parallel Gradient Descent (SPGD), and eventually optimize the stacking efficiency up to >90% through self-optimization of SPGD parameters. Furthermore, with collaborative effort on reinforcement learning, specifically Deep Deterministic Policy Gradients (DDPG) algorithm, we improved the theoretical limit of pre-pulse contrast from 16dB to >30dB, which meets the desired requirements of the accelerator community.
Model predictive control (MPC) has been applied in real-time operation of industrial chemical plants to optimize process performance accounting for closed-loop stability and control actuator constraints. Since the performance of MPC depends on model accuracy, and machine learning methods (e.g., recurrent neural networks (RNN)) have been widely-used for modeling a general class of dynamical systems, my research work is to develop an machine-learning-based MPC using an ensemble of RNNs. Stability analysis is performed to demonstrate that the MPC using the RNN model stabilizes nonlinear systems at the steady-state provided that the modeling error is sufficiently small. Ensemble regression modeling and parallel computing are employed to improve prediction accuracy of RNN models and computational efficiency of MPC optimization problem in real-time implementation. Additionally, an on-line update of RNN models is incorporated within MPC to capture process nonlinear dynamics in the presence of model uncertainty.
In my doctoral studies, I developed an upper body soft exoskeleton - called the FlyJacket - for bidirectional interaction with drones. This interface allows to control a drone with upper body gestures and receive extended feedback from the drone. To improve the awareness of the operator, information on the state of the drone is intuitively rendered with haptic feedback. The main contributions of my research for the scientific community are the following: I developed design criteria for wearable devices while working on the soft exoskeleton that can be applied to other wearable devices. The results that I obtained on the proprioception and on the tactile perception of the torso while testing the haptic feedback of my device can be used as valuable knowledge about human science or for the design of other haptic feedback devices. The work done on the implementation of a kinesthetic feedback guidance gives insights on the type of force profile, performance improvement, and learning effect such a feedback can provide. Finally, while working on the implementation of tactile feedback to render the sensation of flight, I developed a new tactile actuator that can be used in various other applications such as guidance or recreating other types of forces thanks to its simplicity and low production cost.

In addition to the scientific spreading of knowledge, I displayed my project at twelve national and international public demonstrations with diverse audiences such as users with scientific backgrounds (Cybathlon [2016], with live on Swiss National TV, and World Haptics [2017]), industrial experience (NCCR Industry Days [2016, 2017 and 2018] and CES Las Vegas [2019]), political backgrounds (World Economic Forum [2019]), artistic backgrounds (Future of Story Telling [2018]) and also at general public events (EPFL Open days [2016], London Science museum Lates [2017], Drone Days [2017] and Boston HUBweek [2018]).

We evaluated around 400 people that used the FlyJacket. Of course, this includes many different morphologies and a large age range, estimated to be between twelve to eighty years old. The main result of these demonstrations was always a great fascination for this new technology and a surprise at how easy was the control of the drone. These public demonstrations showed the great adaptability, reliability and good user acceptance of the developed device but also the general public interest for this research.
“Brain-spine interface technologies to alleviate gait deficits after Parkinson's disease”

More than 90% of individuals with Parkinson’s disease (PD) suffer from considerable locomotor disturbances that affect their quality of life. Gait and balance deficits are thought to be in part due to the disruption of the communication between the brain and spinal cord resulting from the depletion of dopaminergic and cholinergic circuits. These deficits respond poorly to commonly available therapies such as Levodopa and deep brain stimulation (DBS) treatments. Nevertheless, DBS is highly effective in treating the cardinal symptoms of PD, such as tremor, rigidity, and bradykinesia. We previously engineered a wireless brain–spine interface (BSI) that restored this communication after spinal cord injury (SCI). Here, we optimized our BSI technology for PD and show that this treatment alleviates gait and balance deficits in the 1–methyl–4–phenyl–1,2,3,6–tetrahydropyridine (MPTP) nonhuman primate (NHP) model of PD. Furthermore, when combined with DBS, NHPs exhibit higher alertness and locomotor activity. Macaque monkeys were implanted with intracortical microelectrode arrays into the left and right leg primary motor cortex (MI) to record neural activity, and bipolar electrodes into leg muscles to monitor electromyographic signals. One monkey was also implanted with quadripolar DBS leads for electrical stimulation of the subthalamic nucleus. Behavioral recordings revealed that MI activity underlying basic and skilled locomotion remained structurally unchanged following MPTP administration, despite pronounced gait and balance deficits. Projection of muscle activity onto the location of motor neuron pools in the spinal cord showed that walking involves the sequential activation of spatially–restricted regions, and that this activation is altered when PD symptoms appear. To restore the natural dynamics of motor neurons, we designed spinal implants that targeted the proprioceptive feedback circuits located within the dorsal roots projecting to the spinal cord regions containing these motor neurons. We then developed a multi–class asynchronous decoder that directly linked MI modulation to electrical spinal cord stimulation protocols reproducing the spatiotemporal sequence of motor neuron activity during walking. This BSI instantly reduced freezing of gait and improved the walking speed, gait quality and locomotor dexterity. A synergistic interaction between the BSI and DBS enhanced locomotor performance such that the NHP approached healthy locomotion. We demonstrated that the BSI and DBS can be simultaneously applied, opening up the possibility of a combined therapeutic approach in human patients. As such, the subsequent step should be to test the efficacy of the BSI in treating PD patients.
“Combining Ontology Alignment and Representation - Learning Towards Semantic Interoperability”

The general capability of humans to share their thoughts with others and achieve a mutual understanding constitutes an important challenge for cognitive science. Many modern artificial cognitive agents possess a formal description of the conceptualization of their application domain by means of an ontology. Ontology alignment constitutes the task of establishing correspondences between semantically related entities from different ontologies. Ontology alignment is crucial for accomplishing a mutual understanding across heterogeneous artificial cognitive agents enabling them to overpass the boundaries of precisely choreographed interactions.

Traditionally, research in ontology alignment has focused on engineering features from terminological, structural, extensional – ontology instances – and semantic model information extracted from the ontological model. Deriving such features for a given problem is an extremely time-consuming task. To make matters worse, these features do not transfer to other domains. As a complement to feature engineering, attempts have been made to develop machine-learning based algorithms for ontology alignment based on binary classification. Nonetheless, the number of true alignments between two ontologies is several orders of magnitude smaller than the number of all possible mappings, and this introduces a serious class imbalance problem hindering learning.

The work to be presented in my thesis consists one of the first successful attempts of applying representation learning to the problem of ontology alignment achieving state-of-the-art results and generalizing to a great deal of applications domains. In this work, it was shown that terminological embeddings can be learned from external corpora and from synonymy information extracted from semantic lexicons in a way that the embeddings are tailored to ontology alignment. The proposed architecture overpasses state-of-the-art systems without using any kind of structural information; answering an open question whether leveraging the ontological structural information is required for performing ontology alignment. Finally, the most recent work focuses on lifting the restriction of only discovering equivalence relations, that governs most ontology alignment algorithms, by exploiting the statistical regularities laying in ontological assertions. To do so, the hyperbolic space was exploited since it has been proven that it better reflects hierarchical and hierarchical-like structures that ontologies also have. The empirical results show that the proposed model is able to demonstrate comparable or better performance against various state-of-the-art models setting the ground for fully automating the ontology alignment process.
I am broadly interested in multi-objective system-level management of modern multicore servers and multiprocessor Systems-on-chip (MPSoCs) through machine learning for Quality-of-Service (QoS) sensitive time-varying applications. Modern multicore platforms, with numerous runtime design parameters, facilitate application-aware dynamic resource management to meet design objectives and constraints. However, such huge design space, in addition to the dynamic environment as a result of workload variations, make conventional approaches, such as grid search, infeasible or impractical to find the optimal solution. Nevertheless, machine learning, from supervised/unsupervised learning to reinforcement learning has been proved to be a promising solution that is able to reveal hidden interrelations among different runtime design parameters and workload time-varying characteristics. In particular, when prior knowledge or an exact mathematical model is not available or infeasible to derive from the environment, reinforcement learning can employ a software agent that efficiently explores the design space and applies proper actions to satisfy design objectives and constraints. My research, therefore, includes applying model-free reinforcement learning algorithms, such as Q-Learning, for system-level resource management of multicore platforms. In particular, I show how Q-Learning provides a superior solution in dealing with highly dynamic problems, such as real-time video encoding. Moreover, I study and show how multi-agent reinforcement learning can be employed to decompose very large design space to smaller sub-spaces for faster and more precise exploration.

Infrared (IR) spectroscopy is a powerful toolkit for compositional analysis of various biochemical compounds and for monitoring their dynamic interactions. Although the IR spectroscopy is a well established method for chemical analysis, it faces major shortcomings, such as low sensitivity which arises from the large mismatch between the molecule and IR wavelength sizes. Moreover, available IR sensor techniques rely on Fourier transform infrared spectrometers (FTIR) or tunable laser sources, which are bulky, expensive, and require trained personnel to operate them, limiting their use for point-of-care applications. To overcome the two upper mentioned challenges of IR spectroscopy we use a nano-photonic approach to create metasurfaces made out of subwavelength dielectric resonators. The resonator geometry is specifically designed to trap and confine the IR light energy in tight hotspots, bridging the gap between the molecule and IR wavelength size and consequently...
significantly improving the sensitivity. In addition, the specific resonator shape provides high spectral selectivity and large spectral tunability. We arranged these resonators in arrays and formed a pixelated metasurface that enabled one to one mapping between spectral and spatial information. Interestingly, when the molecules are deposited on top of the metasurface, the chemically specific absorption fingerprints appear as attenuation of light reflected from the metapixels. The combined signal from all the metapixels form a barcode like absorption map. Strikingly, this imaging-based method can detect chemically specific molecular absorption fingerprints without the need for spectrometry. Additionally, this novel biochemical sensing technique provides large amount of data from hundreds of thousands of pixels, and holds the potential for implementation of artificial intelligence for data analysis, more precisely, deep neural network algorithms that will improve the device performance of molecule identification, quantification and real time interaction monitoring.

Our proposed imaging-based sensor device disrupts the way chemical and biological analysis is carried out by bringing the nanophotonic enhancement for sensitivity and versatility of infrared spectroscopy to a portable instrument that can potentially fit into the palm of your hand.

Alexander Belushkin
BIOnanophotonic Systems laboratory of Prof. Hatice Altug

“Point-of-care biosensor enabled by digital nanoplasmionic imaging”

Current healthcare systems have an urgent need for blood based molecular tests to assist the diagnosis and management of diseases in a rapid and cost effective manner at early stages, when curative interventions are most effective. Diagnostic tests provide clinicians with key insights about health by identifying small amounts of disease-indicating biological markers found in the rich content of patient blood. The recent paradigm shift towards personalized medicine requires screening of multiple biomarkers to improve diagnosis, management and treatment of diseases, such as cancers and inflammatory conditions. Unfortunately, the techniques currently used to detect such biomarkers are expensive, time-consuming, and require complex equipment and trained personnel, therefore can only be performed at clinical laboratories.

In my PhD work, I have developed a portable biosensing device based on novel ultrasensitive nanoplasmionic imaging technology. The unique plasmonic detection mechanism is based on digital imaging of nano-sized gold particles (Au-NP) binding to plasmonic gold nanohole arrays (Au-NHA), and enables highly sensitive and rapid detection of individual disease biomarker molecules directly from patient samples. The portable imager is made of low-cost off-the-shelf components, and its small size (less than 1kg) enables deployment and operation in on-site clinical settings. Moreover, the plasmonic sensors are produced with a cost-effective wafer-scale manufacturing. The compactness and low-cost of this novel device make it a promising solution to provide a rapid and accurate tool assisting on-site biomarker screening towards personalized medical care.
“Roombots - self-reconfigurable modular robot”

The Roombots project is a self-reconfigurable modular robot (SRMR) made in the Biorobotics Laboratory. SRMRs have various advantages over traditional fixed morphology robots that can be summarized in three main points: Versatility, robustness and low cost. The most prominent capability is the shape changing. A SRMR ideally can create any arbitrary shape. Thus, they can adapt to changing demands in time. Having standardized building modules is also preferred for manufacturing reasons. Because mass manufacturing a single type of building block is expected to be cheaper and faster than custom designing dozens of task specific robots. Moreover, replacing a broken module is much easier than detecting and repairing a problem in a big system. SRMRs can in principle self-repair through detecting broken modules and replacing them autonomously.

SRMRs can be considered as the “Swiss Army knife” of robotics. Because, a generic module can collaborate with other modules to perform many different tasks, ideally almost everything. We envision Roombots being used to create intelligent environments (house or work) to enable new functionalities. For example in a futuristic scenario, Roombots create make a bed to sleep on. In the morning, they can self reconfigure into a table and chairs for the breakfast, then into a sofa for the rest of the day. Modules can attach to existing furniture, move around the house and manipulate objects. SRMRs can be particularly useful for elderly or handicapped people.

“SparseFool: a few pixels make a big difference”

Deep Neural Networks have achieved extraordinary results on image classification tasks, but have been shown to be vulnerable to attacks with carefully crafted perturbations of the input data. Although most attacks usually change values of many image's pixels, it has been shown that deep networks are also vulnerable to sparse alterations of the input. However, no computationally efficient method has been proposed to compute sparse perturbations. In this paper, we exploit the low mean curvature of the classifier’s decision boundary, and propose SparseFool, a geometry inspired sparse attack that controls the sparsity of the perturbations. Extensive evaluations show that our approach computes sparse perturbations very fast, and scales efficiently to high dimensional data. We further analyze the transferability and the visual effects of the perturbations, and show the existence of shared semantic information across the images and the networks. Finally, we show that adversarial training using PGD examples can only slightly improve the robustness against sparse additive perturbations computed with SparseFool.
Deep neural nets are widely used, powerful tools for statistical modelling. However, they are plagued by a lack of interpretability, or insight about their functionality in human-understandable terms. Providing interpretability to such black-box models will help neural net practitioners understand biases of the model which are not easily revealed by metrics such as accuracy. Uncovering such biases can help practitioners to subsequently improve the performance of these models.

In our research, we focus on gradient-based representations as a way to address this problem. First, we propose full-gradients, one such gradient-based representation which completely captures the local behavior of neural nets. Using this, we propose ``saliency'' maps for convents which highlight portions of the input are deemed crucial by the neural net in its decision making. Experimental results show a high degree of fidelity of these saliency maps with the underlying neural net behavior. Second, we use these representations to improve performance on a distillation task, where a `student' neural net is trained to mimic the responses of a `teacher' neural net. Experimental results show that these representations help performance, especially when the number of training data points is small.

Driving is a challenging task despite of how naturally it may come to some experienced drivers, and it is a very hard one to automatize. As any inexperienced driver could tell, the complexity of driving is caused by the need of (i) being constantly looking around perceiving and understanding what is happening and how the context is likely to evolve, (ii) efficiently identifying and planning our behavior in advanced so that we reach our goals, and (iii) acting on the pedals and the steering wheel so that our plans are accurately executed. These three major tasks match the fundamental research topics concerning autonomous driving, namely, perception and prediction, motion planning, and control.

Despite of the great importance all those topics have, we focus on motion planning for being the one at the heart of autonomous driving technology. Motion planning is indeed the union of often inaccurate perceived information, relatively efficient low level controllers, the traffic context with which the vehicle interacts, and, in the near future, inter-vehicle communication systems.

In this thesis, we explore three major challenges concerning motion planning that connected automated vehicle (CAVs) will face while sharing the road with unconnected vehicles (also
called mixed traffic), and assess the proposed strategies in simulated roundabout scenarios. Specifically, we aim to formalize a framework where decisions based on explicit communication with other CAVs, and probabilistic planning when facing unconnected vehicles can be combined. We first explore distributed simulation-based decision-making for CAVs in fully connected scenarios, aiming at improving the intersection throughput through explicit cooperation. Then, we relax the connectivity assumptions and address implicitly cooperative decision-making, aiming at improving the traffic performance by cooperating with unconnected cars. Finally, we investigate a computationally efficient and safe motion planning strategy built on an inaccurate and uncertain perception and prediction system that suffers from occlusions.

In summary, our study provides new insights on the complexity of motion planning in mixed traffic, and propose a pragmatic model-based decision-making approach that paves the way towards an integral feasible solution.

“Learning and Adaptive Data Analysis via Maximal Leakage”

A fundamental problem in learning theory is to provide (learning) algorithms that generalize well. Good generalization capabilities ensure the accuracy of an algorithm in predicting outcomes for previously unseen data. This guarantees that its behavior during testing matches its performances when deployed in the real world. Our contribution brings an Information-Theoretic point of view on the issue. The main idea is the following: if the output of a learning algorithm depends too much on the input then it will not generalize well. The intuition has been translated more rigorously by connecting generalization error and an information measure, known in the literature as Maximal Leakage. The Maximal Leakage between two random variables quantifies the amount of information that one random variable leaks about the other. We show that keeping the Maximal Leakage between input and output bounded allows us to control how much the latter depends on the former and thus, provide generalization. Moreover, we show that such a measure is robust to post-processing and behaves well under composition: we can bound the leakage of a sequence of algorithms if each of them has bounded leakage. Thanks to these properties we show that having a bounded leakage provides more robust generalization guarantees than classical approaches.
Stefania Ebli  
Laboratory for Topology and Neuroscience of Prof. Kathryn Hess Bellwald

“Simplicial Neural Networks”

In this work, we generalize graph convolutional neural networks to data that live on a class of topological spaces called simplicial complexes. These are natural multi-dimensional generalizations of graphs which encode more than just pairwise relationships, namely higher-order relationships between nodes (represented geometrically as filled triangles, tetrahedra, and so forth). We define an appropriate notion of convolutions for such data, which we leverage to construct the desired convolutional neural networks. This allows us to consider richer data than traditional methods, including $n$-fold collaboration networks and vector field data.

Orion Afisiadis  
Telecommunications Circuits Laboratory of Prof. Andreas Burg

“Enabling the Wireless Communication of Intelligent IoT Systems”

Intelligent systems need to be context aware and to obtain ubiquitous sensing and wireless communication capabilities. To this end, the Internet of Things (IoT) will consist of low-power devices that are expected to connect wirelessly with each other (or with centralized gateways). Several specialized communications protocols have been proposed for IoT applications, such as LoRa, Sigfox, Weightless, and NB-IoT. LoRa specifically is a low-rate, low-power, and high-range modulation that uses chirp spread-spectrum for its physical layer. LoRa supports multiple spreading factors, coding rates, and packet lengths, to support a very wide range of operating signal-to-noise ratios (SNRs). Since LoRa uses the ISM band, interference from other technologies using the same band is a potential problem. More importantly, LoRa relies on LoRaWAN for the MAC layer, which uses an ALOHA-based channel access scheme in which collisions are not explicitly avoided. These collisions lead to same-technology inter-user interference which may ultimately become the capacity-limiting factor in massive IoT scenarios. For this reason, it is of great interest and importance to study and improve the performance of LoRa under same-technology interference.

Several real-world deployments of LoRa have been tested, but in order to assess the network scalability of LoRaWAN to future network densities that are expected to be orders of magnitude larger, evaluations through network simulators need to be performed. Existing frameworks in network simulators treat the SNR and the signal-to-interference ratio (SIR) independently. Such an independent treatment of the SNR and the SIR is not particularly realistic and can lead to either over- or under-estimations of the survival probability of LoRa packets. In order to correctly evaluate and improve the scalability of LoRa networks, network simulators need to work under a unified signal-to-interference-and-noise ratio (SINR) framework. In our work therefore, we derive expressions for the frame-error-rate (FER) of LoRa under this new complete and unified interference and noise model. This is a first step.
toward the goal of proposing improved LoRa receivers which will allow to overpass the expected wireless network congestion of IoT devices. Under this scope, our work aims to improve the wireless communication backbone that supports the uninterrupted evolution of intelligent systems.

Aleksei Triastcyn  
Artificial Intelligence Laboratory of Prof. Boi Faltings  
“Generating Artificial Data for Private Deep Learning”

We propose generating artificial data that retain statistical properties of real data as the means of providing privacy for the original dataset. We use generative adversarial networks to draw privacy-preserving artificial data samples and derive an empirical method to assess the risk of information disclosure in a differential-privacy-like way. Our experiments show that we are able to generate labelled data of high quality and use it to successfully train and validate supervised models. Finally, we demonstrate that our approach significantly reduces vulnerability of such models to model inversion attacks.

Panayiotis Danassis  
Artificial Intelligence Laboratory of Prof. Boi Faltings  
“Anytime Heuristic for Weighted Matching Through Altruism-Inspired Behavior”

We present a novel anytime heuristic (ALMA), inspired by the human principle of altruism, for solving the assignment problem. ALMA is decentralized, completely uncoupled, and requires no communication between the participants. We prove an upper bound on the convergence speed that is polynomial in the desired number of resources and competing agents per resource; crucially, in the realistic case where the aforementioned quantities are bounded independently of the total number of agents/resources, the convergence time remains constant as the total problem size increases. We have evaluated ALMA under three test cases: (i) an anti-coordination scenario where agents with similar preferences compete over the same set of actions, (ii) a resource allocation scenario in an urban environment, under a constant-time constraint, and finally, (iii) an on-line matching scenario using real passenger-taxi data. In all of the cases, ALMA was able to reach high social welfare, while being orders of magnitude faster than the centralized, optimal algorithm. The latter allows our algorithm to scale to realistic scenarios with hundreds of thousands of agents, e.g., vehicle coordination in urban environments.