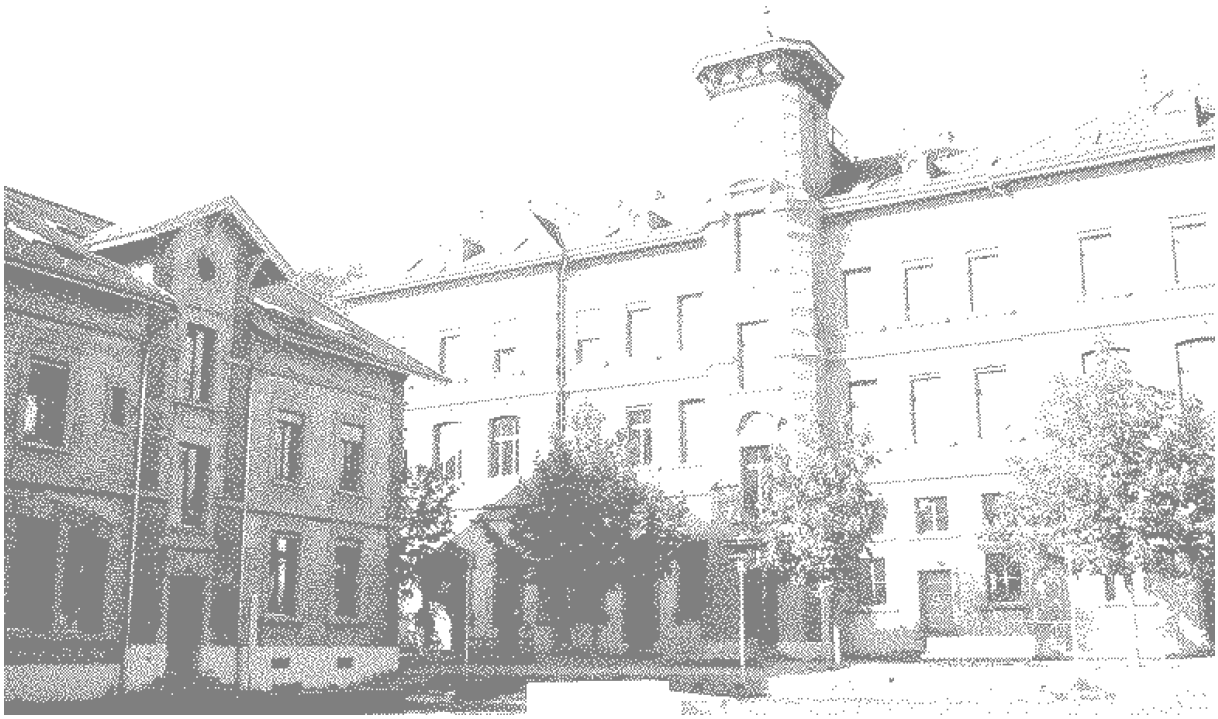
UNIVERSITÄT
BERN

Institut für Informatik
Universität Bern

www.inf.unibe.ch

INF Annual Report 2021/2022



INF Annual Report

Academic Year 2021/2022

September 15, 2022

Contents

1 Institute of Computer Science (INF)

1.1 Address

Neubrückstrasse 10, 3012 Bern, Switzerland
Phone: +41 31 684 86 81
E-Mail: info.inf@unibe.ch
http://www.inf.unibe.ch

1.2 Personnel

Members

Florence Aellen, Jesutofunmi Ajayi, Sigurd Alnes, Orestis Alpos, Ignacio Amores Sesar, Mariarosaria Barbaraci, Michael Baur, Dr. Pierre- Alexandre Beaufort, Lara Biehl, Adam Bielski, Alexander Boll, Prof. Dr. David Bommes, Dr. Peppo Brambilla, Prof. Dr. Torsten Braun, Nathalie Brugger, Patrick Brunner, Marco Buchholz, Prof. Dr. Christian Cachin, Llukman Cerkezi, Hamadi Chihaoui, Bettina Choffat, Riccardo Cusinato, Yannik Dallenbach, Aram Davtyan, Lucas De Sousa Pacheco, Dr. Antonio Di Maio, Negar Emami, Maria Fanger, Dr. Federico Faroldi, Prof. Dr. Paolo Favaro, Mathias Fuchs, Pascal Gadient, Nicolas Gallego-Ortiz, Dr. Sebati Ghosh, Anthony Gillioz, Pinar Göktepe, Roman Gruber, Priska Grunder, Mohammadreza Hazhirpasand, Dragana Heinzen, Martin Heistermann, Dr. Benedikt Hitz-Gamper, Mária Hrabošovà, Adrian Jörg, Denis Kalmykov, Liubov Kamaldinova, Prof. Dr. Timo Kehrer, David Lehnherr, Abdelhak Lemkhenter, Dr. Du Lê Viet, Heng Liu, Dr. Jieting Luo, Alisson Medeiros de Lima, Oscar Meier, Givi Meishvili, Hugo Melo dos Santos, Jovana Micic, Alejandro Nardo, Prof. Dr. Oscar Nierstrasz, Valentin Nigolian, Joel Niklaus, Manuel Ohrndorf, Diego Oliveira Rodrigues, Nitish Patkar, Maurizio Piu, Renato Prisco, Simone Raimondi, Pooja Rani, PD Dr. Kaspar Riesen, Atefeh Rohani, Sepehr Sameni, Eric Samikwa, Alp Eren Sari, Daniela S. Schroth, Alec Schürmann, Dominic Schweizer, Viktor Shipitsin, Kerrie Stauffer, Nathalie Steinhauer, Dr. Thomas Studer, Dr. Nataliia Stulova, PD Dr. Matthias Stürmer, Noe Leon Thalheim, Dr. Ruxandra Tivadar, Dr. Christos Tsigkanos, Prof. Dr. Athina Tzovara, Pablo Valenzuela Toledo, Roland Widmer, Dimitrios Xenakis, Hexu Xing, Luca Zanolini, Lukas Zenger

Administration

Bettina Choffat, Dragana Heinzen, Daniela Schroth (until 30.04.2022), Nathalie Brugger, Priska Grunder (as of 01.04.2022)

Technical staff

Dr. Peppo Brambilla, Martin Heistermann, Orestis Alpos

2 Teaching Activities

2.1 Courses for Major and Minor in Computer Science

Autumn Semester 2021

- Bachelor 1st Semester

  Einführung in die Informatik (Die Dozenten der Informatik, 5 ECTS)

  Grundlagen der Technischen Informatik (T. Studer, 5 ECTS)

  Programmierung 1 (K. Riesen, 5 ECTS)

- Bachelor 3rd Semester

  Diskrete Mathematik (C. Cachin, 5 ECTS)

  Computernetze (T. Braun, 5 ECTS)

  Einführung in Software Engineering (O. Nierstrasz, 5 ECTS)

- Bachelor 5th Semester

  Computergrafik (D. Bommes, 5 ECTS)

  Mensch-Maschine-Schnittstelle (K. Riesen, 5 ECTS)

  Machine Learning (P. Favaro, 5 ECTS)

  Digitale Nachhaltigkeit (M. Stürmer, 5 ECTS)

  Anleitung zu wissenschaftlichen Arbeiten (Die Dozenten der Informatik, 5 ECTS)

- Master Courses

  Concurrency: State Models and Design Patterns (O. Nierstrasz, N. Stulova, 5 ECTS)

  Mobile Communications (T. Braun, 5 ECTS)

Advanced Algorithms (T. Studer, 5 ECTS)

Computer Vision (P. Favaro, 5 ECTS)

Applied Optimization (D. Bommes, 5 ECTS)

Privacy and Data Security (C. Cachin, 5 ECTS)

Seminar: Software Composition (O. Nierstrasz, 5 ECTS)

Seminar: Communication and Distributed Systems (T. Braun, 5 ECTS)

Seminar: Logic and Theoretical Computer Science (T. Studer, 5 ECTS)

Seminar: Machine Learning and Artificial Intelligence (P. Favaro, 5 ECTS)

Seminar: Computer Graphics & Geometry Processing (D. Bommes, 5 ECTS)

Seminar: Cryptology and Data Security (C. Cachin, 5 ECTS)

Seminar: Natural Language Processing (M. Stürmer, 5 ECTS)

- Service Courses

Programmieren für Naturwissenschaften (K. Riesen, 3 ECTS)

Programmieren für Naturwissenschaften (Biologie) (P. Liniger, 3 ECTS)

Grundkurs Programmieren (B. Hitz-Gamper, M. Stürmer, 3 ECTS)

Advanced Python (Bioinformatics, A. Tzovara, 2.5 ECTS)

Spring Semester 2022

- Bachelor 2nd Semester

Datenbanken (T. Studer, 5 ECTS)

Datenstrukturen und Algorithmen (D. Bommes, 5 ECTS)

Computer Architecture ((M. Anwander, 5 ECTS)

Programmierung 2 (T. Kehrer, 5 ECTS)

- Bachelor 4th Semester

  Praktikum in Software Engineering (T. Studer, 5 ECTS)

  Betriebssysteme (T. Braun, 5 ECTS)

  Berechenbarkeit und Komplexität (T. Studer, 5 ECTS)

  Algorithmen, Wahrscheinlichkeit und Information (C. Cachin, 5 ECTS)

- Bachelor 6th Semester

  Anleitung zu wissenschaftlichen Arbeiten (Die Dozenten der Informatik, 5 ECTS)

- Master Courses

  Network Security (T. Braun, 5 ECTS)

  3D Geometry Processing (D. Bommes, 5 ECTS)

  Distributed Algorithms (C. Cachin, 5 ECTS)

  Seminar: Communication and Distributed Systems (T. Braun, 5 ECTS)

  Seminar: Logic and Theoretical Computer Science (T. Studer, 5 ECTS)

  Seminar: Computer Graphics (D. Bommes, 5 ECTS)

  Seminar: Cryptology and Data Security (C. Cachin, 5 ECTS)

  Seminar: Law and Computer Science: Distributed Trust in Finance (C. Cachin, M. Eggen, C. Sillaber, 5 ECTS)

  Seminar: Software Engineering (T. Kehrer, 5 ECTS)

  Seminar: Natural Language Processing (M. Stürmer, 5 ECTS)

- Service Courses

  Programmieren für Naturwissenschaften (K. Riesen, 3 ECTS)

  Grundkurs Programmieren (M. Stürmer, 3 ECTS)

  Advanced Python (Bioinformatics, A. Tzovara, 2.5 ECTS)

  AI for Medical Time Series (Artificial Intelligence in Medicine, A. Tzovara, 2.5 ECTS)

2.2 Students

- Major Subject Students: AS 2021: 291, SS 2022: 314
- Minor Subject Students: AS 2021: 221, SS 2022: 194
- Ph.D. Candidates: AS 2021: 52, SS 2022: 55

2.3 Degrees and Examinations

- PhD: 6
- Master: 16
- Bachelor: 27
- Completion of Minor Studies: 31 (90E:0, 60E:10, 30E:17, 15E:4, 1170 ECTS)
- Semester Examinations AS 2021: 1081 (3922 ECTS)
- Bachelor's/Master's Theses AS 2021: 22 (280 ECTS)
- Semester Examinations FS 2022: 602 (2219 ECTS)
- Bachelor's/Masters Theses FS 2022: 8 (120 ECTS)

2.4 Activities

- Contribution to the "Studies Orientation Day", Bern, September 17, 2021
- Contribution to the "National Future Day for Girls and Boys", Bern, November 11, 2021
- Contribution to the "Bachelor Infotage", December 7+8, 2021 (digital)
- Contribution to the "Master Infotage", March 23 + 24, 2022 (digital)
- Contribution to the "MINT-Day" for Middle school students, Bern, April, 11, 2022 (digital)
- Finals of the Swiss Olympiad in Informatik, May 19 + 20, 2022

3 Cognitive Computational Neuroscience Group

3.1 Personnel

Head:	Ass. Prof. Dr. A. Tzovara	Tel.: +41 31 511 7636 email: athina.tzovara@unibe.ch
Office Managers:	D. Heinzen	Tel.: +41 31 684 4914 email: dragana.heinzen@unibe.ch
Scientific Staff:	Dr. R.I. Tivadar	+41 31 511 7636 email: ruxandra.tivadar@unibe.ch
	F.M. Aellen	+41 31 511 7636 email: florence.aellen@unibe.ch
	S.A. Alnes	+41 31 511 7636 email: sigurd.alnes@unibe.ch
	P. Göktepe-Kavis	+41 31 511 7636 email: pinar.goektepe@unibe.ch
	R. Cusinato	+41 31 511 7636 email: riccardo.cusinato@unibe.ch
External PhD students:	G. Monachino	Email: giuliana.monachino@unibe.ch
	N. Norori	Email: natalianorori@gmail.com
	M. Bechny	Email: bechnymichal@gmail.com
	R. Svihrova	Email: rsvihrova@gmail.com
	Y. Deng	Email: dengyihan@gmail.com

3.2 Overview

The Cognitive Computational Neuroscience group conducts research in the areas of neuroscience, machine learning and computational modeling. We use invasive and non-invasive electrophysiological recordings (scalp and intracranial electroencephalography and single-unit recordings), in combination with machine learning techniques to study neural functions of the human brain. The main areas of focus include: (a) machine learning techniques for neuroscience data and for assisting clinical decision making and (b) studying the neural correlates of sensory processing and predictions.

3.3 Research Projects

Computational techniques for studying auditory processing in coma

When a patient falls into a coma communication with the environment is disrupted and consciousness fades away. However, the brain of coma patients may still be able to process stimuli from the environment, like for example sounds. An open challenge is to understand how neural functions and auditory processing are altered in coma. Previous work has shown that coordination of brain activity, typically indexed through measures of neural synchrony, decreases when consciousness is lost. Moreover, when consciousness is lost, neural activity loses complexity, while the levels of neural noise, indexed by the slope of the electroencephalography (EEG) spectral exponent decreases. Although these properties have been investigated in resting state activity, it remains unknown whether the auditory processing network also suffers from a loss of synchronization or information content. In our work, we focused on acute coma and hypothesized that neural synchrony in response to auditory stimuli would reflect coma severity, while complexity, or neural noise, would reflect the presence or loss of consciousness.
Our study, performed in a group of 67 post-anoxic coma patients, showed that neural synchrony of EEG responses to sounds was stronger for patients that later survived compared to those that did not, but indistinguishable between survivors and healthy controls. Importantly, the level of neural synchrony in the first day of coma was predictive of patients' chances of regaining consciousness and surviving three months later, with a positive predictive value of 87 %. This result suggests that neural synchrony might be useful in the clinics to assist outcome prognosis.
Measures of neural complexity and neural 'noise' were not informative of patients' outcome and had high or low values for patients compared to controls. Our results suggest different roles for neural synchrony and complexity in acute coma. Synchrony represents a precondition for consciousness, while complexity needs an equilibrium between high or low values to support conscious cognition.

Research staff: Florence Marcelle Aellen, Sigurd Alnes, Athina Tzovara

Financial support: Interfaculty Research Cooperation "Decoding Sleep: From Neurons to Health & Mind" of the University of Bern

Neural mechanisms of auditory processing

The human brain has a remarkable capacity of processing streams of sensory input from our surroundings, like sounds or images. Processing of auditory stimuli occurs at a neural level when we pay attention to incoming sounds, and also when attention is distracted, or when consciousness fades away, for example when someone is asleep. Importantly, our brains have the astonishing capacity of learning new information from streams of repetitive sounds, and anticipate future events before they occur, a crucial skill for survival.
In our work, we are studying the computational and electrophysiological substrates of auditory processing in wakefulness and sleep. We are using signal processing techniques to analyse neural responses to sounds, and quantify their electrophysiological properties, like for example their frequency contents. Moreover, we are studying neural responses to anticipated sounds, which are formed as a result of learning. To this aim, we are recording electroencephalography activity in humans, and combine these recordings with machine learning techniques to extract patterns of neural responses to heard and/or anticipated sounds, like for example a sound that was anticipated but not delivered. Last, we are linking electrophysiological measures of auditory processing to behavioral responses, for example related to subjective expectations or learning.
A better understanding of the neural circuits that underlie auditory processing in healthy conditions can provide insights about its dysfunctions in various diseases, such as in patients with disorders of consciousness or patients who may have impairments in auditory predictions.

Research staff: Ruxandra Tivadar, Pinar Göktepe-Kavis, Athina Tzovara

Financial support: Swiss National Science Foundation (320030_188737)

Machine learning techniques for studying sleep

Diagnosing many sleep disorders is a major challenge due to the lack of specific disease markers and frequently co-occurring sleep disorders and other comorbidities. To evaluate sleep, polysomnography (PSG) recordings are often performed, which measure neural and other physiological signals, like eye movements or muscle activity over the course of a night. Additionally, in the clinics, several clinical tests and demographic measures

are often collected, in order to diagnose sleep disorders. Today, despite a huge progress in computational techniques, a lot of diagnostic procedures rely on visual expertise, like for example sleep scoring. In our work, we are aiming at developing and validating novel machine learning tools to (a) improve diagnosis of sleep disorders and (b) assist and potentially automate sleep scoring.
In particular, we are using unsupervised machine learning to characterise and cluster clinical variables of patients with sleep disorders. To this aim, we have developed a pipeline to analyze clinical data of patients that have visited the sleep laboratory of Inselspital, Bern in the past years. Our approach extracts and imputes missing clinical data, and tests several clustering algorithms. Our main question is to evaluate whether sleep disorders can be unambiguously disentangled with the current set of available clinical markers. In a second study, we are evaluating the potential of supervised machine learning techniques to automate sleep scoring. Although several techniques exist in the literature, the use of machine learning for sleep scoring is still not a reality. In our work, we are investigating the reliability of existing sleep scoring algorithms, and their potential to be applied in clinical PSG data recorded at Inselspital, Bern. Our long-term goal with this project is to develop machine learning tools that can assist sleep medicine, either by improving diagnostic criteria for sleep disorders, or by automating manual and time-consuming procedures.

Research staff: Florence Marcelle Aellen, Athina Tzovara

Financial support: Interfaculty Research Cooperation “Decoding Sleep: From Neurons to Health & Mind” of the University of Bern, NVIDIA Academic Hardware Grant Program.

Computational mechanisms of outcome anticipation

Making decisions is a fundamental neurobiological skill for survival. For example, on a daily basis, we need to make several crucial decisions, regarding our work, or interactions with others and the environment. Evaluating and anticipating the outcome of our actions is crucial for optimizing our decision-making abilities. Outcome evaluation relies on a wide-spread network of brain regions, including mainly frontal cortical areas, such as the ventromedial prefrontal and orbitofrontal cortex. Several studies suggest that even before reaching a decision, multiple possible outcomes are represented in the brain. In particular, recent work in humans has shown

that the neural correlates of anticipated outcome are retrieved before a risky choice is made, in the form of fast, temporally structured patterns of neural activity. However, it remains unknown how the representation of anticipated outcomes is updated dynamically in environments that change over time.
In our studies, we are using electroencephalography (EEG) together with machine learning, to study the neural substrates of anticipated outcomes in dynamic environments. We are recording EEG signals during a decision-making task, and we are building models of outcome representation, evaluating how these unfold over the decision process.

Research staff: Pinar Göktepe-Kavis, Riccardo Cusinato, Athina Tzovara

Financial support: Fondation Pierre Mercier pour la science, 'Neurobiology of outcome representation in Switzerland's citizen-centered society'

Text Based Prediction of ISCD-III Diagnoses

In the current clinical set-up, the diagnosis of patients with sleep disorders fully relies on expert physician knowledge. To this stage, findings and diagnoses related to sleep disorders are described in verbose free text based on results from electrophysiological assessments including polysomnography (PSG), actimetry and vigilance tests. A classification according to ICSD-III (International Classification of Sleep Disorders) is oftentimes missing. However, disease classification is urgently needed for identification of new digital biomarkers from raw data of electrophysiological assessments, as well as markers derived from biological samples.
The aim of this project is to predict patient diagnoses, i.e. codes of ICSD-III, based on information from free-text clinical records. Based on the automatic predictions, we expect the final disease assignments by expert physicians to be both standardized and accelerated. Our hypothesis is that machine learning based approaches will reach a disease prediction accuracy of more than 80
Our aim is to implement a hybrid approach for a classification algorithm for sleep disorders according to ICSD-III, using textual descriptions of findings and diagnosis as input. The project uses a dataset from the sleep database of the Inselspital, Bern, comprising among others freetextual descriptions of diagnoses for a patient. Given the large size of the sleep

database (text corpus), the targeted ICSD-III classification can be decomposed into three types of classification tasks: classification with general rules (high level categories), classification with specific rules (non-trivial pathological categories) and the classification with learning models (both conventional machine learning (ML) with knowledge enrichment and deep learning for additional subcategories and sequence chain). Beyond that, the multi-labels classification (one diagnosis with multiple ICSD-III codes) and the imbalance problem (frequent and rare sleep disease) within the diagnosis will be evaluated and handled with corresponding ML models. Additionally, experiments will be conducted studying the impact of integrating additional structured data from the I-PDOS system for the purpose of ICSD-III classification. Beyond, a comparison between text classification results and classification results derived from night polysomnography recordings only can be compared.

Research staff: Yihan Deng

Personalized disease monitoring and support

Deep Learning algorithms are increasingly used in the medical field as they have the potential to acquire knowledge from a large quantity of data. Physicians can be supported in decision making for both disease diagnosis and treatment optimization. Abnormal events, during continuous patient monitoring, can be identified in real-time. Usually, deep learning algorithms are optimized to reach a generally suitable and stable performance. However, especially in the healthcare domain, it is equally important to personalize machine learning models on individual patients, in order to allow for daily monitoring.
In this project, machine learning techniques will be applied in different clinical scenarios. The focus will be on personalized real-time disease monitoring and identification based on several inputs: demographic and clinical information, both objective and subjective measures, offline or real-time acquired biosignals (for example electrocardiography -ECG-, or electoencephalography) and clinical parameters. The developed techniques will be applied on different sub-projects aiming to improve diagnosis and detection of disease-specific biomarkers in patients with cardiovascular and/or sleep disorders. In a first study, the main application will be a cardiac monitoring and alert system. A personalized algorithm will be developed to monitor the morphology of ECG signals of patients affected by Inherited Arrhythmogenic Diseases (IADs), in order to identify in real-time possi-

ble arrhythmias. Another direction is applying personalized algorithms for cardiac rehabilitation, after cardiovascular disease. A behavioral change support system, developed via wearable devices, could for instance increase adherence to rehabilitation by combining the principles from behavioral psychology, statistical modeling, and modern artificial intelligence algorithms. Last, in a third study, we will design and develop algorithms for the detection of different classes of sleep disorders (e.g. breathing, movement), based on polysomnographic (PSG) data, emphasizing the use of only a minimal number of biosignal channels. Our long-term goal is to scale the developed algorithms for wearables, which could increase the potential for cost-effective early diagnosis of sleep disorders in a broad population.

Research staff: Giuliana Monachino, Radoslava Svihrova, Michal Bechny

3.4 Master's Thesis

- Marco Pesce, University of Bern, Faculty of Medicine, Biomedical Engineering, Master Thesis: "Machine learning-based sleep scoring for the Bernese Sleep Registry", June 2022

3.5 Further Activities

Presentations

Athina Tzovara

- Decoding the brain, lecture. International Conference for Technology and Analysis of Seizures, Bern, Switzerland, July 2022
- Managing code for neuroscience studies, lecture. Experimental Neurology Center, Inselspital, Bern, Switzerland, July 2022
- Detecting auditory regularities in the absence of consciousness or attention, symposium talk. International Conference of Cognitive Neuroscience, May 2022
- Gender equality in academia, lecture. Open Science Workshop, University of Oslo, January 2022

- Improving gender equity in Neuroscience, lecture. Women's Neuro Network initiative, January 2022
- Gender equity in (Swiss) science, lecture. Skills for Scientists, University of Lausanne, December 2021
- Moving towards gender equity in science, lecture. National Honor Society in Neuroscience, Georgia State University, USA, November 2021
- Gender bias in academia: we are the right (wo)man for the job, lecture. University of Oslo, Norway, November 2021
- How can we move toward gender equity in science? lecture. University of Hamburg, Germany, November 2021.
- Computational approaches for studying sleep and pathological loss of consciousness, lecture. Sleep Wake Epilepsy Days, Bern, Switzerland, November 2021
- Gender bias in Neuroscience, lecture. Experimental Neurology Center, Inselspital, Bern, Switzerland, September 2021

Florence Aellen and Athina Tzovara

- Algorithmic decision-making in neuroscience: how can we improve algorithmic interpretability and reduce bias, workshop. Applied Machine Learning Days, EPFL, March 2022

Ruxandra Tivadar

- New Frontiers in Vision Rehabilitation: From Implants to Sensory Substitution, Symposium talk, International Conference of Cognitive Neuroscience, May 2022
- Expectations about sounds but not omissions are mediated by predictability-specific neural templates, Poster presentation, International Conference of Cognitive Neuroscience, May 2022
- Using sensory substitution to enhance visual processes, Santa Clara University, School of Engineering, Department of Electrical and Computer Engineering, March 2022.

Florence Aellen

- Convolutional Neural Networks predict outcome from coma based on auditory ERPs, Oral presentation and Poster presentation, Organization for Human Brain Mapping, June 2022

- The Bern Sleep Database: Clustering of Patients with Sleep Disorders, Poster Presentation, World Sleep Congress, March 2022

Sigurd Alnes

- The auditory brain in sleep and wake: Evidence from intracranial EEG, Bern Sleep Wake Epilepsy Days, Poster presentation, November 2021

- Auditory processing in sleep and wake: Evidence from intracranial EEG, Poster presentation, Organization for Human Brain mapping, June 2022

- Auditory processing in sleep and wake: Evidence from intracranial EEG, Poster presentation, International Conference for Technology and Analysis of Seizures, July 2022

- Neural Synchrony and Complexity to Index Consciousness and Coma Patient Outcome, Poster presentation, Association for the Scientific Study of Consciousness, July 2022

Conference and Scientific Committees

Athina Tzovara

- Committee on Best Practice in Data Analysis and Sharing (COBIDAS) for magnetic resonance imaging (MRI) data, member, 2021-2022

- Organization for Human Brain Mapping (OHBM), member of Diversity and Inclusivity Committee, 2021-2022

- Organization for Human Brain Mapping (OHBM), member of Awards Committee, 2021-2022

- International Conference for Technology and Analysis of Seizures, member of Local Organizing Committee, 2022

Journal Committees

Athina Tzovara

- Handling Editor for open access publishing platform of the Organization for Human Brain Mapping, Aperture Neuro
- Guest Editor for European Journal of Neuroscience

Reviewing Activities

Journal Reviews
Athina Tzovara

- Frontiers in Medicine
- Neuroimage
- Neuropsychologia
- Patterns
- PNAS
- Scientific Reports
- Transactions on Neural Systems & Rehabilitation Engineering

Ruxandra Tivadar

- IEEE Transactions on Haptics
- Scientific Reports

Yihan Deng

- AIIM
- JBI
- IEEE JBHI

Conference Abstracts
Athina Tzovara

- International Conference for Technology and Analysis of Seizures

Grant reviews
Athina Tzovara

- U.S.-Israel Binational Science Foundation

3.6 Publications

Journal Publications

- Ojala KE *, Tzovara A *, Poser BA, Lutti A, Bach DR (2022) Asymmetric representation of aversive prediction errors in Pavlovian threat conditioning, Neuroimage. * Equal contribution. https://doi.org/10.1016/j.neuroimage.2022.119579
- Alnes S, De Lucia M, Rossetti AO, Tzovara A (2021). Complementary roles of neural synchrony and complexity for indexing consciousness and chances of surviving in acute coma, Neuroimage. https://doi.org/10.1016/j.neuroimage.2021.118638
- Aellen FM, Kavis-Göktepe P, Apostolopoulos S, Tzovara A (2021). Convolutional neural networks for decoding electroencephalography responses and visualizing trial by trial changes in discriminant features, Journal of Neuroscience Methods. https://doi.org/10.1016/j.jneumeth.2021.109367
- Tivadar R, Knight RT, Tzovara A (2021). Automatic sensory predictions: a review of predictive mechanisms in the brain and their link to conscious processing, Frontiers in Human Neuroscience. https://doi.org/10.3389/fnhum.2021.702520
- Norori N, Hu Q, Aellen F, Faraci F, Tzovara A (2021). Addressing bias in big data and AI for health care: A call for open science, Patterns. https://doi.org/10.1016/j.patter.2021.100347
- Billings* J, Tivadar* R, Murray MM, Franceschiello B, Petri G (2022). Topological Features of Electroencephalography are Robust to Rereferencing and Preprocessing. Brain Topography. * Equal contribution, https://doi.org/10.1007/s10548-021-00882-w
- Tivadar RI, Arnold RC, Turoman N, Knebel JF, Murray MM (2022) Digital haptics improve speed of visual search performance in a dual-task setting. Scientific Reports. https://doi.org/10.1038/s41598-022-13827-5

Conference Abstracts

- Aellen FM, Van der Meer J, Dietmann A, Schmidt M, Bassetti CLA, Tzovara A. (2022) The Bern Sleep Database: Clus-

tering of Patients with Sleep Disorders. Sleep Medicine. https://doi.org/10.1016/j.sleep.2022.05.295

- Gnarra O, Van der Meer J, Warncke J, Wenz E, Fragolente L, Khatami R, Schindler K, Tzovara A, Schmidt MH, Bassetti CL (2022) SPHYNCS: Longterm monitoring with Fitbit in patients with narcolepsy and its borderland. Sleep Medicine. https://doi.org/10.1016/j.sleep.2022.05.294

3.7 Organization of Science Outreach Activities

- Nationaler Zukunftstag, Ruxandra Tivadar and Florence Aellen: Das Gehirn: Realität und Simulation, November 2021
- Research of Sigurd Alnes and Athina Tzovara featured: https://www.inselgruppe.ch/de/aktuell/details/news/komapatienten-guenstige-prognose-bei-gleichtakt-der-hirnzellen/
- Research of Ruxandra Tivadar Featured on the news website of the University of Lausanne, L'Actu: https://news.unil.ch/display/1655367819645
- Skills for Scientists PhD workshop on career paths in science: How to become a post-doctoral student, University of Lausanne (UNIL), Ruxandra Tivadar, November 2021

4 Communication and Distributed Systems Group

4.1 Personnel

Head:	Prof. Dr. T. Braun	Tel.: +41 31 684 4994 Email: torsten.braun@unibe.ch
Office Manager:	D. S. Schroth	Tel.: +41 31 684 8681 Email: daniela.schroth@unibe.ch (Until 30.04.2022)
	P. Grunder	Tel.: +41 31 684 8681 Email: priska.grunder@unibe.ch (as of 01.04.2022)
Scientific Staff:	Dr. A. Di Maio	Tel.: +41 31 511 2639 Email: antonio.dimaio@unibe.ch
	J. Ajayi	Tel.: +41 31 511 2638 Email: jesutofunmi.ajayi@unibe.ch
	L. De Sousa Pacheco	Tel.: +41 31 511 7631 Email: lucas.pacheco@unibe.ch
	N. Emami*	Tel.: +41 31 511 2635 Email: negar.emami@unibe.ch
	M. Hrabošová*	Tel.: +41 31 511 7604 Email: maria.hrabosova@unibe.ch (as of 01.02.2022)
	A. Medeiros de Lima	Tel.: +41 31 511 2637 Email: alisson.medeiros@unibe.ch
	E. Samikwa	Tel.: +41 31 511 2634 Email: eric.samikwa@unibe.ch
	D. Xenakis*	Tel.: +41 31 511 7631 Email: dimitrios.xenakis@unibe.ch
	H. Xing*	Tel.: +41 31 511 2632 Email: hexu.xing@unibe.ch
External Ph.D. students:	J. Schärer	Email: jakob.schaerer@abilium.com
	P. Hammler	Email: patric.hammler@unibe.ch
	Y. Farhat	Email: yamshid.farhat@bkw.ch
Joint Supervision Degree Ph.D. Students:		
	H. Santos	Email: hugo.santos@unibe.ch
	D. Oliviera Rodrigues	Email: diego.oliveira@unibe.ch

*With financial support from a third-party credit

4.2 Overview

The research group “Communication and Distributed Systems” has been investigating how multimedia and mixed reality applications and cloud computing services with high demands on quality, reliability, and energy efficiency can be supported by mobile communication systems and networks. Moreover, we are investigating localization mechanisms for wireless devices and new Future Internet paradigms such as Information-Centric Networking (ICN) as well as the Internet of Things (IoT). We are also working on mobility and trajectory prediction of mobile users and vehicles using advanced machine learning mechanisms. Distributed and Federated Machine Learning are emerging approaches for mobility prediction, mixed reality, and IoT. Emerging applications such as immersive communications require both high bandwidth and low delay. Those are supported by mobile edge computing and service function chaining.

4.3 Research Projects

Multi-Echelon Inventory Optimization

This project started in December 2020 in collaboration with the pharmaceutical company Hoffmann-La Roche in Basel and aims to apply Reinforcement Learning (RL) to multiple business domains.
Many business use cases need to cope with uncertainty and can thus be formulated as a Markov Decision Process (MDP), whereas the goal is to optimize a policy by maximizing or minimizing a specific metric of interest. This metric of interest is highly use-case dependent. It may represent the overall expenses in the example of a supply chain use case or the energy consumption in the example of a building automation use case.
Multiple approaches exist that potentially can solve MDPs - however, with the complexity of real-world systems, most of the approaches fail due to the large state- and action space dimensionality and thus its high computational complexity. One promising candidate for optimizing real-world systems is Deep RL for the following reasons: Firstly, RL can rely on a long-studied research branch that has proven to solve MDPs. Secondly, RL works in conjunction with deep neural networks as function approximators and thus has the capability of generalization. This is of significant importance, especially for complex real-world use cases.

In the first project, Deep RL has been applied to a Multi-Echelon Inventory Management use case. The task is to learn an optimal, holistic and dynamic reorder policy that minimizes operating costs. Operating costs occur when supplies are held but not used for sales (holding cost), when a reorder is triggered (reordering cost), in the event of a stock-out (shortage cost), and in the event of exceeding the maximum capacity of a warehouse (overload cost). The optimal reorder policy makes reorder decisions regarding reorder-timing and reorder-quantity under uncertainty, as the demand and the lead-time are stochastic variables.
The first experimental results show promising outcomes and high saving potentials compared to traditional, non-RL-based inventory control systems. This research project is divided into three sections, with each section concluding in one publication. In the first section, the general applicability of RL to an inventory management use case is examined and will be published in an educational Springer book article [Hammler et al., 2022]. Secondly, a broad comparison of non-RL-based and RL-based approaches is executed to compare them with regard to performance, scalability, and reliability characteristics. Thirdly, an approach is developed to improve the scalability characteristics of state-of-the-art RL approaches in conjunction with the inventory management use case.
The other project is the application of Deep RL to building automation use cases. This includes the control of elevators and other building control systems (e.g. ventilation, heating, blinds) to minimize energy consumption while keeping comfort parameters (e.g. waiting time or temperature) within an acceptable range. This project is in preparation and is expected to be started at the beginning of 2023.

Research staff: P. Hammler, T. Braun.

Efficient Distributed and Federated Machine Learning for Internet of Things

IoT systems generate large volumes of data from user devices. The raw data generated by IoT devices are very often private or sensitive and can be too large to transmit over the networks. For example, devices such as medical sensors, microphones, cameras, Google Glass, Apple Watch, gather sensitive data by recording the daily activities of users. This data is essential for ML models in order to deliver personalized and intelligent IoT services. Running ML models entirely on the cloud provides higher scalability but show three main disadvantages: Firstly, the time needed to

send, process, and retrieve data from geographically distant data centers may not satisfy the real-time requirements of latency-critical applications. Secondly, the processing of raw user data on the cloud may expose sensitive information during data transmission, remote processing, and storage. Thirdly, transferring the raw sensor data from the IoT devices to the cloud increases the ingress throughput on the backhaul network.
Because of their proximity to the data, conventional consumer-level devices, such as IoT devices, are a great candidate for the in-the-edge processing of the ML model. However, current state-of-the-art models such as Deep Neural Networks (DNN) have significant demands on memory, computation, and energy. This is incompatible with the resource-constrained nature of IoT devices that is characterized by limited energy budget, memory, and computation capability. Consequently, recent studies have proposed moving ML toward the IoT edge through distributed ML.
The objective of this research is to determine how to efficiently distribute ML tasks across different elements in IoT systems, taking into account computation and communication constraints. Initially, we propose adaptive Early Exit of Computation [Samikwa et al., 2022a], a scheme for distributed ML inference over IoT networks for latency and energy consumption optimization. The computation of inference tasks on the computationally-constrained IoT devices is exited early through a dynamically selected partition point and the remaining part is completed at the edge server.
We then extend our approach to improve the training efficiency in Split Learning by introducing Adaptive REsource-aware Split-learning (ARES) for IoT [Samikwa et al., 2022b]. ARES jointly accelerates model training time and minimizes energy consumption in resource-constrained heterogeneous IoT devices and minimizes the effects of stragglers on the training. ARES utilizes energy-sensitivity measures to mitigate tradeoffs between minimizing the training time and minimizing the energy consumption on IoT devices during training while accounting for variable resources.

Research staff: E. Samikwa, T. Braun.

Mitigating E2E Latency for Future Mobile VR Applications

Perceptual studies show that the Quality of Service (QoS) of large-scale Mobile Virtual Reality (MVR) applications positively correlates to video frame rate and the duration of the immersive experience. These metrics depend on the end-to-end (E2E) latency needed to generate and deliver

a video frame to the Head-Mounted Display (HMD) and the power consumption on the HMD. Recent research shows that Multi-access Edge Computing (MEC) infrastructure can support mobile HMDs to reduce their computing latency. However, its potential to maintain acceptable E2E latency under high mobility conditions to enable advanced immersive experiences for MVR applications remains unexplored. Our research investigates techniques to increase the QoS for future MVR applications to achieve such latency requirements. We aim to reduce the E2E latency, increase the VR streaming quality, and improve the user experience by extending the capability of HMDs to process and play VR streams and reduce their energy consumption. Among those techniques, we examine the refactoring of VR applications through a distributed service chain orchestrator to split VR applications into atomic services and deploy them across HMDs and MEC servers, aiming to jointly minimize latency and energy consumption [Medeiros et al., 2022]. We consider service migration, offloading, and placement to achieve the E2E latency demands for future MVR applications. Furthermore, to deploy VR services and manage MEC resources we use REACT [Medeiros et al., 2021].

Research staff: A. Medeiros, T. Braun.

Network Function Virtualization and Fog Service Support in 5G Networks

Next-Generation Mobile Networks will need to provide connectivity for a wide range of services with heterogeneous performance requirements. Network support for services requiring low latency and high reliability is anticipated to be the most challenging based on current deployments, which often rely on centralized processing (i.e. cloud data-centers) on specialized hardware. Following this, a departure from the current hardware-centric network architecture and a greater focus on network virtualization has been proposed as a means to bring advanced computational capabilities to the network edge through the Edge Computing and Fog Computing paradigms, to improve the ability of the network to support such services.
In this context, we investigate the challenges of orchestrating network services and resources in virtualized & edge-enabled 5G networks. Specifically, we look to new developments that leverage the ongoing softwarization & virtualization of the 5G network, by focusing on services and resources that could be deployed in Edge/Fog Systems.
In our previous work [Schiller et al. 2022b], we investigated the live migration of critical Virtual Network Functions (VNFs) that form the Radio

Access Network (RAN) protocol stack in wireless networks (i.e. evolved NodeB (eNodeB)), and the challenges of doing so in practical, real-time environments. In our current work, we have proposed a solution for the admission control of network slices (i.e. chained VNFs) in softwarized mobile networks.

Research staff: J. Ajayi, T. Braun.

Intelligent Mobility Services

Nowadays, huge amounts of data regarding pedestrian and vehicle mobility traces are available from diverse Location Based Services (LBS), e.g, GPS, wireless access points, smartphone sensors, social media, telecommunication base stations, etc. This data is pivotal for enabling intelligent mobility services such as navigation, localization, and mobility prediction. In this project, we focus on developing improved methods to achieve that. More specifically, the research has been divided into two distinct aspects: localization and mobility prediction. Both these components are discussed below in more detail.

Indoor & Outdoor Localization

Different location-based services come with different positioning accuracy requirements. For outdoor applications (e.g. car navigation), most often, global navigation satellite systems (e.g. GPS) can inexpensively cover the needs. Yet, applications in indoor environments, where satellite signals are not available, are more challenging. Therefore, fusing different signal sources is critical for achieving accurate positioning indoors.
In accordance with the above, we proposed a new methodology for enhancing the positioning accuracy in such systems by taking advantage of signals that are exchanged between mobile devices. With this technique which has been named ARLCL (Anchor-free Ranging-Likelihood-based Cooperative Localization) instead of tracking individually each mobile device, we consider at the same time all exchanged signals, eventually positioning them as a system (or a swarm of devices).
Comparisons based on real Bluetooth Low Energy signals and against the ”Mass-Spring” optimization, which is currently the most-respected approach for tackling the same problem, showed an overall improvement of 16% at the 75th percentile of cases. This improvement is also positively correlated to both the swarm’s size and the signal’s noise, reaching a gain of 81% for the settings of maximal swarm size. Yet, for showing the

applicability of our method to other radio technologies, further experiments are currently conducted using Ultra-Wideband radio signals.

Mobility & Trajectory Prediction

Today society is highly relying on mobility services. Accurate prediction of mobile users' trajectories is essential for improving the quality of service in modern wireless networks and guaranteeing the safety of autonomous driving vehicles. Thanks to today's great availability of location data, mobility prediction services can provide analysis and inference of mobile users' daily behaviors and thus, understanding of the urban dynamics. The main focus of this project is to design advanced machine learning and deep learning models in order to precisely predict the future location, trajectory, and traffic flow of both humans and vehicles.
In this direction, we developed Recurrent Neural Network-based (RNN and LSTM), Convolutional Neural Network-based (CNN), and Attention Neural Network-based (Transformer) trajectory predictors whose neural architectures are designed and optimized depending on a given dataset's mobility features through different neural architecture search mechanisms (e.g., Grid Search, Reinforcement Learning, and Hyperopt Auto-ML). We have tested the impact and robustness of our proposed trajectory predictors on the performance of real network applications e.g., service migration and handover management [Zhao et al., 2022].
Moreover, we proposed a framework, named RC-TL, to cope with scalability issues of large networks and manage overrated computational resource consumption. RC-TL takes advantage of user redundancies through clustering similar trajectory users, training a single model per cluster based on a few users' data, and transferring the pre-trained model to other cluster members [Emami et al., 2022a]. Furthermore, we expanded our work to the field of social-trajectory prediction where the spatio-temporal dependencies among neighbor users can help better predict their trajectories. In this direction, we further proposed a novel system, named INTRAFORCE, that uses Reinforcement Learning to build a Social-Transformer architecture based on the intra-cluster user mobility features [Emami et al., 2022b]. Evaluations show the remarkable outperformance of our designed models with respect to several state-of-the-art individual and social trajectory predictors over diverse matrices: accuracy, mean square error, training time, training parameter size, and computational resource usage.

Research staff: D. Xenakis, N. Emami, T. Braun.

Financial support: Swiss National Science Foundation (SNSF) [Contract No. 184690]

Context Awareness Engine

The Context Awareness Engine project funded by Orange SA explores network context information to discover, reason, and predict network and subscriber situations by appropriate computation and information modeling based on collected network data from various data sources (network nodes, devices, applications). The purpose is to propose recommendations or request actions (context awareness) using advanced machine learning and deep learning algorithms. We aim to find insights from observed phenomena and infer the root causes, such that future situation prediction can be achieved and further exploited to optimize network performance. The project is broken into 2 phases: Phase 1 includes use case definition (WP1) and functional architecture definition (WP2), and Phase 2 includes implementation architecture definition (WP3) and software development and demonstration (WP4).
From August 2021 to September 2022, the CDS group continued expanding the conducted research that was centered on the Orange dataset [Zhao et al., 2022]. We extended the previously proposed individual trajectory predictor [Emami et al., 2022a] to a social trajectory predictor so that, mobile users are not left isolated and the social interaction among them is taken into consideration [Emami et al., 2022b]. Moreover, we developed an attention-based neural network so-called Transformers (TF), which were initially designed for Natural Language Processing tasks, for the task of trajectory prediction. Afterward, we presented Intra-Cluster Reinforced Social Transformer (INTRAFORCE), a mobility predictor that learns the social interaction within clusters of similar mobile users. INTRAFORCE uses a Reinforcement Learning (RL) agent that builds a Social-Transformer architecture based on the intra-cluster user mobility features. We show that RL-designed TF can remarkably increase the prediction accuracy (up to 10%) and decrease the training time (down to 70%) regarding other neural and non-neural network predictors. Moreover, we show that social INTRAFORCE can further decrease the number of training parameters, computational resource cost, training time, and average displacement error while increasing the accuracy with respect to several state-of-the-art social and individual trajectory predictors.

Research staff: N. Emami, T. Braun.

Financial support: Orange Research Contract Number H09194

Software-Defined Service-Centric Networking in Urban Environments

Disruptive applications for mobile devices that can be enhanced by Edge Computing facilities are emerging, such as the Internet of Things, Immersive Media, and Connected and Autonomous Vehicles. These applications have strict requirements in order to properly work that are difficult to be fulfilled with the current computing paradigm in the cloud. In this context, Edge Computing is an architecture expected to aid in meeting requirements imposed on these applications. This architecture aims to introduce computing capabilities in the path between the user and the Cloud to execute tasks closer to where they are consumed, thus mitigating issues, such as latency, and mobility support. The present project aims to create models to understand urban mobility and its impact on mobile applications provisioned at the edge. We aim to model different aspects of mobility and analyze emerging classes of mobile applications. We expect to understand mobility and mobile applications to create better mobility management algorithms and protocols. Lately, we studied how ICN-inspired protocols can improve service provisioning at the edge of the network [Oliveira et al., 2022], and also SDN-enabled handover mechanisms for cellular networks [Oliveira et al., 2021].

Research staff: D. O. Rodrigues, T. Braun

Low Latency Service Function Chaining Orchestration for Distributed Edge Computing

Smart cities will enable the deployment of innovative and smart applications to improve mobility, such as mobility assistance by using Virtual Reality (VR) and Augmented Reality (AR). In this context, enabled by Multi-access Edge Computing (MEC), these computational-intensive and bandwidth-hungry applications consume large loads of MEC resources at low latency with scalability for mobile users. We raise the challenges to provide high scalability by decomposing services into several Service Functions (SF) to share a set of these SFs among users. Specifically, we propose a mobility-aware Service Function Chaining (SFC) orchestrator to automate the service assignment for fixed and mobile services. We suggest a distributed edge computing orchestrator instantiate ordered

SFs into SFCs for sharing users. We expected to provide more scalability than more typical and individually deployed setups for a single user with support for multi-users [Santos et al., 2022]. The Context Awareness Engine project funded by Orange SA explores network context information to discover, reason, and predict network and subscriber situations by appropriate computation and information modeling based on collected network data from various data sources (network nodes, devices, applications). We conducted research to develop a Reinforcement Learning and Transfer Learning mobility predictor with Orange dataset [Zhao et al., 2022]. Finally, the problem of positioning computing and storage capabilities on highly mobile devices was studied in the context of Unmanned Aerial Devices (UAV) networks, in which such devices can provide MEC services for ground-based users. An application scenario and future research directions were studied as a proof-of-concept, obtaining results on the efficacy of such schemes, and management techniques for the positioning of devices and services [Zhao et al., 2021a].

Research staff: H. Santos, T. Braun

Mobility and Cloud Management with Federated and Distributed Learning

Service positioning becomes an increasingly important topic with the emergence of Multi-access Edge Computing (MEC) in modern networked scenarios. The presence of MEC is one of the most important enablers to bringing intelligent capabilities not only for devices but also for network management. The training and deployment of Machine Learning (ML) models enable intelligent services in areas such as Intelligent Transportation Systems (ITS), entertainment, advertisement, and personalization of services in general. In MEC the computing and storage capabilities of the network are distributed across the scenario, such as across an entire region or city. In the first stage of the research, the problem of positioning computing and storage capabilities on highly mobile devices was studied in the context of Unmanned Aerial Devices (UAV) networks, in which such devices can provide MEC services for ground-based users. An application scenario and future research directions were studied as a proof-of-concept, obtaining results on the efficacy of such schemes, and management techniques for the positioning of devices and services [Zhao et al., 2021a, Pacheco et al., 2021b].
In the particular case of vehicular networks and connected vehicles, MEC will be used to train object detection and classification, driving assistance,

and other crucial tasks. However, such scenarios generate large amounts of privacy-sensitive data, which cannot be shared with other devices in the network. Federated Learning is a paradigm for the training of ML models in which devices train models on their local data, and only trained models are shared with the network for aggregation with models from other users and improved performance and reliability. Since no raw data is shared with the network in FL, user privacy can be maintained throughout the ML models' training process.

The training of FL models in very dynamic networks, such as vehicular networks, offers some particular challenges, such as the high mobility of nodes, frequent disconnections, and increased data heterogeneity from different sensors and environments. Furthermore, the centralized nature of the FL aggregation process requires reliable connections to the network infrastructure, which cannot be guaranteed in the vehicular case.

In this project, we propose two mechanisms for improving the performance and reliability of ML models trained in FL to overcome these challenges in vehicular cases. The first proposal is a mechanism to mitigate the negative impacts of data heterogeneity in FL training. Since no raw data is provided to aggregation servers, computing similar trained neural networks for better Independent Identically Distributed (IID) data presence must be done solely based on the neural network weights provided. We propose the Neural-based Federated User SIMilarity (NSIM), a neural network-based predictor which is trained to estimate the similarity of datasets used to train neural networks pairwise. NSIM is able to predict how similar is the data used to train different FL models based on Optimal Transport (OT) and Earth Mover's Distance (EMD). Furthermore, we feed the calculated neural network similarities to a clustering algorithm to aggregate similar neural networks, thus achieving significant improvements in model convergence time and accuracy [Pacheco et al., 2021a].

The second contribution of the project is the development and evaluation of an FL algorithm for vehicular networks called Distributed Optimal-Transport-based Federated Learning (DOTFL). The main contributions of DOTFL are the possibility of vehicle sharing models not only with the network infrastructure but also with neighboring vehicles upon contact, increasing the number of successful model transfers. DOTFL also makes use of NSIM to cluster IID contributions and filter low-quality contributions to the FL model. Simulation results show significant improvements in DOTFL in the convergence time and accuracy of models in vehicular networks for object classification, one of the crucial tasks performed by autonomous and connected vehicles.

Research staff: L. Pacheco, T. Braun

Auditable Internet of Things

The Internet of Things is growing fast. Recent improvements in the interoperability between smart devices enable new applications in the Industrial Internet of Things, Smart City, Smart Home, autonomous driving, and more. All these applications will require smart devices to exchange information with each other. However, the existing Public Key Infrastructures (PKI) do not adapt well to the decentralized architecture of the Internet of Things. Consequently, it becomes more challenging to verify the authenticity of exchanged data when the IoT is growing. Furthermore, many applications require auditability in all processes. To achieve this auditability, it must be possible to prove that a specific smart device has measured a particular value or performed a certain action at a given time. Distributed Public Key Infrastructure (DPKI) based on Distributed Ledger Technology (DLT) is a promising approach to solve these challenges. In this project, we propose the framework Veritaa. Veritaa is a DPKI with a Signature Store. Veritaa comprises the Graph of Trust (GoT) and the Acyclic Block Confirmation Graph (ABCG). The GoT represents signed trust relations between identity claims. The ABCG is an application-specific BlockDAG optimized to store the graph transactions that build the GoT immutably and non-repudiable.

Our initial work was to design, implement, and evaluate the basic Veritaa framework [Schaerer et al., 2021]. Furthermore, to validate Veritaa's applicability for the IoT, we have built a real-world IoT testbed [Schaerer et al., 2022a].

Metrological traceability is used to trace back measurement values to international standards and to assess the accuracy of a given measurement. Calibration certificates document the calibration and uncertainty of a measurement instrument at the time of calibration. The calibration certificates are an important element in making measurements auditable. To enable auditable measurements, we integrated a Distributed Calibration Certificate Infrastructure into the Veritaa framework that enables securing calibration certificate and measurement value signatures on the Graph of Trust [Schaerer et al., 2022b].

Research staff: J. Schärer, T. Braun.

Innovative Electric Network Planning with Advanced Machine Learning Algorithms

In order to reach the energy strategy goals for 2050, a massive penetration of distributed energy sources (ie. solar panels) and a new type of consumers (ie. electric cars) should be integrated into the electric distribution network. Thus, increasing the uncertainty and complexity of generation and load forecasting. Due to these changes, traditional passive ”worst case” network planning methods will lead to extensive capital investments with a high probability that the resulting network would be largely overdesigned and/or underutilized. Actual restrictions & challenges for network operators are the actual & future system uncertainty and the lack of research from a computer science perspective.
In this project, we aim to evaluate new methods for the optimal planning of future electric distribution networks using existing available data and advanced algorithms. The first contribution of the project is to propose a simulation environment that considers the behavior of existing actors (e.g. households, solar panels) and future actors (e.g. electric cars, batteries) to evaluate the impact of different network tariff models in the cost distribution per customer segment and the potential additional network reinforcement for these scenarios
In our work, we propose a new fairness factor, and we evaluate the optimal behavior of flexible actors based on the different tariff models [Farhat et al., 2022b]. In the next phase, we will evaluate optimal energy systems based on the different tariff models. The goal is to identify which tariff model enables end-customers to optimally design their local energy systems which fulfill the requirements of the Swiss Energy Strategy 2050.

Research staff: Y. Farhat, T. Braun, P. Favaro.

Collection of Psychological Measurements via a Smartphone

In this project, we develop a smartphone application for Android and iOS platforms, with the goal of collecting data on the user’s smartphone usage and physical sensors. For example, the user’s smartphone usage is monitored in terms of screen time, call duration, and app usage data. The physical measurements collected by the application are, among others, gyroscope, acceleration, activity detection, air pressure, and pedometer. The project plans to run a data collection campaign on a set of volunteers,

whose psychological profile has been analyzed through a survey. With the collected data, the final goal of the project is to find correlations between the psychological profile of the participants and the measurements collected from our application, to gain new insights into the physical a behavioral features of subjects with certain psychological features.

Research staff: D. Xenakis, E. Samikwa, J. Ajayi, A. Di Maio, T. Braun

Financial support: Faculty of Human Sciences, University of Bern

Networking for Immersive Communications (NICO)

The growing need for immersive communications for use in virtual and augmented reality applications comes with extreme requirements in terms of bandwidth, reliability, and latency. NICO addresses these extreme challenges and requirements by a set of various approaches on protocol, network architecture, and implementation architecture levels. In NICO we intend to come closer to these targets by addressing the following interrelated research challenges, which have to be considered in an integrated way.

1. viewport prediction algorithms in 360◦ video based on sensor-based localization, tracking, and rotation/movement predictions using advanced machine learning (ML) concepts in order to improve users' Quality-of-Experience (QoE),
2. disruptive methods to identify QoE parameters in immersive communications combining system measurements and psychological behaviors,
3. implementation of an advanced integrated hardware and software platform including operating system scheduling for user-level virtualization and the support of hardware accelerators for immersive communication processing in order to support low latencies and high throughput,
4. novel mechanisms to minimize latencies by (extended) caching mechanisms exploiting in-network processing for immersive communications,
5. novel network protocols based on information-centric networking and network coding to support low-latency communication,
6. original algorithms and mechanisms for service migration to minimize latency between mobile users and service entities, including the novel concept of Floating Services.

Our initial goal regarding viewport prediction is to design, implement and evaluate a new algorithm for Multi-Object-Tracking (MOT), as human eyes naturally track moving objects, and this issue plays an important role in viewport prediction.
Furthermore, we started designing and evaluating a new concept of Floating Services (FS) to address the problem of finding and deploying services and to decrease the latency.

Research staff: M. Hrabošová, H. Xing, T. Braun.

Financial support: Swiss National Science Foundation Project No. 204447

Testbeds

The CDS group possesses and operates a cloud infrastructure based on Dell Power Edge Servers. Currently, at the institute, we own five DELL machines: one R320, one R520, two R530, and one R540. These servers support 212 parallel threads (106 cores) and 848 GB of RAM. In addition, we have a dedicated GPU server with 64 parallel threads (32 cores), 4 GPUs GeForce RTX 3090, and 126 GB of RAM. We operate two external Dell PowerVault MD3800i that provide us disk space of 35 TB in Raid 5 and Raid 6. The network backbone is based on Dell N4032 switches with 48x10 GbE-T ports and an 80 Gb/s backbone connection. Together with the Lightweight Directory Access Protocol (LDAP) of the institute our infrastructure provides the members of the CDS group with the following services:

- Mirantis OpenStack 10.0 (IaaS research cloud)
- OwnCloud (shared storage between the CDS members)
- Wiki (information dissemination for the Institute and the CDS group)
- Etherpad (collaborative real-time editor)
- SVN (collaborative version management system)

For administrator purposes we use

- Teampass as a password management system

Finally for monitoring our infrastructure we use

- Nagios

The CDS group has its own IoT testbed that consists of:

- 40 MEMSIC Telsob by Crossbow (now Willow) sensors consisting of:
  - Texas Instruments 16-bit microprocessor (TI MSP 430)
  - 802.15.4 radio interface
  - Fixed Power Supply via the USB Interface
  - Temperature, humidity, and light sensor
  - 1 MB external flash
- 7 MSB-430 Sensor Nodes consisting of:
  - Texas Instruments 16-bit microprocessor (TI MSP 430)
  - CC1020 radio interface
  - Temperature, humidity, and acceleration sensor
  - SD memory interface

Hence, the CDS group built and operates a CDS testbed that consists of 47 nodes. These nodes are placed across the 4 floors of one building of the Institute of Computer Science of the University of Bern. The 7 MSB430 sensor nodes are placed indoors and one node is an outdoor node placed on a top window sill.

4.4 Bachelor Theses

- Joel Hari: ”Development and evaluation of a low-cost, LoRa-based measurement device for microclimatic assessments in urban environments Bachelor Thesis”, March 2021. https://tinyurl.com/4a5my4z9

4.5 Awards

- 2nd place award at the Brazilian Computer Society Conference 2022 (Allan M. de Souza).
- 1st place award for best Ph.D. thesis at Latin American Computing Conference - CLEI 2022 (Allan M. de Souza).

- 1st place award for best Ph.D. thesis at Brazilian Symposium of Computer Networks and Distributed Systems - SBRC 2022 (Allan M. de Souza).

- 2nd place award for the best Ph.D. thesis in Computer Science defended in Brazil in 2021 (Allan M. de Souza).

- Best Ph.D. Thesis in Joint Alumni in computer science of the Universities Bern, Fribourg, Neuchâtel (JAACS) 2021 for the Ph.D. thesis ”Towards a Personalized Multi-objective Vehicular Traffic Re-routing System” (Allan M. de Souza).

- 1st place award for the poster “Attention-based Neural Networks for Multi-modal Trajectory Prediction” at the Bern Data Science Day workshop (BDSD 2022) (N. Emami, T. Braun).

- 2st place award for the poster “Estimating Data Quality for Federated and Split Learning Systems” at the Bern Data Science Day workshop (BDSD 2022) (L. Pacheco. E. Samikwa, T. Braun).

- 1st place award for the poster “Federated User Clustering for non-IID Federated Learning” at the Conference on Networked Systems (NetSys 2021) (L. Pacheco, T. Braun).

4.6 Further Activities

Memberships

Torsten Braun

- Erweitertes Leitungsgremium Fachgruppe “Kommunikation und Verteilte Systeme”, Gesellschaft für Informatik

- Kuratorium Fritz-Kutter-Fonds

- Expert for Bachelor Theses at Fachhochschule Bern

- Expert for Matura Exams at Gymnasium Langenthal

Editorial Boards

Torsten Braun

- Editorial Board Member of Informatik Spektrum, Springer
- Editorial Board Member of MDPI (Multidisciplinary Digital Publishing Institute) Journal of Sensor and Actuator Networks

Antonio Di Maio

- The Hertz Journal of Engineering
- Frontiers in Communications and Networks

Public events

- **BENEFRI Summer School 2021:** A 3-day seminar together with the HES-SO Fribourg and the University of Neuchâtel, at Leissigen, Switzerland, August 23-25, 2021.

Conference Technical Program Committees

Torsten Braun

- 21st International Conference on Next Generation Wired/Wireless Networks and Systems (NEW2AN), August 26 - 27, 2021, on-line
- 14th conference on Internet of Things and Smart Spaces (ruSMART), August 26 - 27, 2021, on-line
- 33rd International Teletraffic Congress CONGRESS (ITC 33), Aug. 31st - Sep. 3rd 2021, Avignon, France
- Conference on Networked Systems (NetSys 2021), September 13-16, 2021, online
- 18th IEEE International Conference on Mobile Ad-Hoc and Smart Systems (MASS), October 4-7, 2021, online
- 13th IFIP Wireless and Mobile Networking Conference (IFIP WMNC), October 21-22, 2021, online

- IEEE Global Communications Conference (Globecom), December 7-11 2021, Madrid, Spain
- IEEE Consumer Communications and Networking Conference (CCNC), January 8-11, 2022, online
- 1st International Workshop on Secure FunctiON ChAining and FederaTed AI, January 8, 2022, online (co-chair)
- 16th Wireless On-demand Network systems and Services Conference (WONS), March 30 - April 1, 2022, online
- IEEE International Conference on Communications (ICC), 16–20 May, 16-20, Seoul, South Korea
- IFIP Networking 2022 Conference, June 13-16, 2022, Catania, Italy
- IEEE/ACM International Symposium on Quality of Service (IWQoS), June 10-12, 2021, online

Antonio Di Maio

- The 18th IEEE International Conference on Advanced and Trusted Computing (ATC 2021), October 18-21 2021, Atlanta, USA.
- IEEE Symposium on Computers and Communications (ISCC) 2021, MoCS, September 5-8 2021, Athens, Greece.

Project and Person Reviewing Activities

Torsten Braun

- Research Council of Norway
- Luxembourg National Research Fund (CORE Panel chair)
- Academy of Finland (panel vice-chair)
- European Science Foundation
- Swiss National Science Foundation
- Deutsche Forschungsgemeinschaft
- Italian Ministry for University and Research
- Cyprus Research and Innovation Foundation
- Professor selection committee, TU Ilmenau, Germany

Journal Article Reviewing Activities

Torsten Braun

- IEEE Transactions on Aerospace and Electronic Systems
- IEEE Transactions on Intelligent Transportation Systems
- IEEE Transactions on Network Science and Engineering
- IEEE Wireless Communications Magazine
- IEEE Communications Standards Magazine
- ACM Transactions on Multimedia Computing Communications and Applications

Antonio Di Maio

- IEEE Transactions on Vehicular Technologies
- IEEE Transactions on Network and Service Management
- Elsevier Computer Networks
- Elsevier Computer Communications
- Elsevier Information Science
- Elsevier Journal of Network and Computer Applications
- Wiley Engineering Reports
- Wiley Concurrency and Computation: Practice and Experience
- MDPI Sensors
- MDPI Sustainability
- MDPI Applied Science
- MDPI Journal of Sensor and Actuator Networks
- MDPI Energies
- MDPI Cryptography
- Journal of Internet Technology

Ph.D. Committee Memberships

Torsten Braun

- Ana Filipa Simão de Almeida, Evaluation of Ph.D. Thesis Proposal, Doctoral Programme in Computer Engineering, Universidade de Aveiro, Portugal, December 2, 2021

4.7 Publications

Disclaimer: The publication list only includes publications published or accepted during the academic year but does not include submitted papers.

Journal Papers

- Hammler P., Riesterer N., Braun T. (2022). Multi-Echelon Inventory Optimization Using Deep Reinforcement Learning. In *Quantitative Models in Life Science Business*, in press, Springer

- Samikwa E., Di Maio A., Braun T. (2022). ARES: Adaptive Resource-Aware Split Learning for Internet of Things. In *Computer Networks Journal*, September 2022, Elsevier https://dx.doi.org/10.48350/173081.

- Zhao, Z., Emami, N., Santos, H., Pacheco, L., Karimzadeh, M., Braun, T., Braud, A., Radier, B., Tamagnan, P. (2022). Reinforced-LSTM Trajectory Prediction-driven Dynamic Service Migration: A Case Study. In the *IEEE Transactions on Network Science and Engineering*, vol. 9, issue. 4, pp. 2786-2802, April 2022, IEEE https://doi.org/10.1109/TNSE.2022.3169786.

- Schiller E., Ajayi J., Weber S., Braun T., Stiller B. (2022). Toward a Live BBU Container Migration in Wireless Networks. In the *IEEE Open Journal of the Communications Society*, vol. 3, pp. 301-321, February 2022, IEEE https://doi.org/10.1109/OJCOMS.2022.3149965.

- Zhao, Z., Cumino, P., Esposito, C., Xiao, M., Rosário, D., Braun, T., Cerqueira, E., Sargento, S. (2021). Smart Unmanned Aerial Vehicles

as Base Stations Placement to Improve the Mobile Network Operations. In *Computer communications*, vol. 181, issue 4, pp. 45-57, October 2021, Elsevier https://doi.org/10.1016/j.comcom.2021.09.016.

- Zhao Z., Pacheco L., Santos H., Liu M., Di Maio A., Rosario D., Cerqueira E., Braun T., Cao X. (2021). Predictive UAV Base Station Deployment and Service Offloading With Distributed Edge Learning. In the *IEEE Transactions on Network and Service Management*, vol. 18, issue 4, pp. 3955-3972, October 2021, IEEE https://doi.org/10.1109/TNSM.2021.3123216.

- Schaerer J., Zumbrunn S., Braun T. (2021). Veritaa: A Distributed Public Key Infrastructure with Signature Store. In *International Journal of Network Management*, vol. 32, issue 2, September 2021, Wiley https://doi.org/10.1002/nem.2183.

- Medeiros A., Braun T., Di Maio A., Neto A. (2021). REACT: A solidarity-based elastic service resource reallocation strategy for Multi-access Edge Computing. In *Physical Communication Journal*, vol. 47, August 2021, Elsevier https://doi.org/10.1016/j.phycom.2021.101380.

Conference Papers

- Medeiros A., Di Maio A., Braun T., Neto A. (2022). Service Chaining Graph: Latency- and Energy-aware Mobile VR Deployment over MEC Infrastructures. In the *IEEE Global Communications Conference (GLOBECOM 2022, Rio de Janeiro)*, December 2022, (IEEE https://dx.doi.org/10.48350/173200).

- Santos H., Rosario D., Cerqueira E., Braun T. (2022). Multi-criteria Service Function Chaining Orchestration for Multi-user Virtual Reality Services. In the *IEEE Global Communications Conference (GLOBECOM 2022, Rio de Janeiro)*, December 2022, (IEEE https://dx.doi.org/10.48350/173202).

- Farhat, Y., Lipsa, G., Braun, T. (2022). Evaluate the impact of network tariffs on the Swiss energy transition. A fair cost distribution or a driver to reduce expensive network upgrades? In the *12th European Conference on Innovative Smart Grid Technologies (PES ISGT 2022, Novi Sad)*, October 2022, (IEEE https://dx.doi.org/10.48350/173201).

- Emami N., Di Maio A., Braun T. (2022). INTRAFORCE: Intra-Cluster Reinforced Social Transformer for Trajectory Prediction. In the *18th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2022, Thessaloniki), October 2022, IEEE https://dx.doi.org/10.48350/172848*.

- Schaerer J., Braun T. (2022). A Distributed Calibration Certificate Infrastructure. In the *4th Conference on Blockchain Research & Applications for Innovative Networks and Services (BRAINS 2022, Paris), September 2022, IEEE https://dx.doi.org/10.48350/171370*.

- Oliveira R. D., Braun T., Guilherme M., Leandro V. (2022). Mobility-aware Software-Defined Service-Centric Networking. In the *31st International Conference on Computer Communications and Networks (ICCCN 2022, Honolulu)*, July 2022, IEEE https://doi.org/10.1109/ICCCN54977.2022.9868869.

- Schiller E., Surbeck T., Gasparyan M., Stiller B., Braun T. (2022). ICN With DHT Support in Mobile Networks. In the *47th IEEE Conference on Local Computer Networks (LCN 2022, Edmonton)*, August 2022, IEEE https://doi.org/10.1109/LCN53696.2022.9843373.

- Schaerer J., Zumbrunn S., Braun T. (2022). Veritaa-IoT: A Distributed Public Key Infrastructure for the Internet of Things. In the *International Federation for Information Processing Networking (IFIP Networking 2022, Catania)*, July 2022, IEEE https://doi.org/10.23919/IFIPNetworking55013.2022.9829794.

- Emami N., Pacheco L., Di Maio A., Braun T. (2022). RC-TL: Reinforcement Convolutional Transfer Learning for Large-scale Trajectory Prediction. In the *Network Operations and Management Symposium (NOMS 2022, Budapest)*, pp. 1–9, June 2022, IEEE https://doi.org/10.1109/NOMS54207.2022.9789883.

- Samikwa E., Di Maio A., Braun T. (2022). Adaptive Early Exit of Computation for Energy-Efficient and Low-Latency Machine Learning over IoT Networks. In the *19th Annual Consumer Communications & Networking Conference (CCNC 2022, Las Vegas)*, pp. 200-206, January 2022, IEEE https://doi.org/10.1109/CCNC49033.2022.9700550.

- Oliveira R. D., Braun, T., Maia, G., Villas L. (2021). Towards SDN-enabled RACH-less Make-before-break Handover in C-V2X Scenarios. In the *17th International Conference on Wireless and Mobile Computing, Networking and Communications*

(WiMob 2021, Bologna), pp. 337-344, November 2021, IEEE https://doi.org/10.1109/WiMob52687.2021.9606283.

- Pacheco L., Oliveira H., Rosario D., Zhao Z., Cerqueira E., Braun T., Mendes, P. (2021). Towards the Future of Edge Computing in the Sky: Outlook and Future Directions. In the *17th International Conference on Distributed Computing in Sensor Systems (DCOSS 2021, Pafos)*, pp. 220-227, November 2021, IEEE https://doi.org/10.1109/DCOSS52077.2021.00045.

- Pacheco L., Rosario D., Cerqueira E., Braun T. (2021). Federated User Clustering for non-IID Federated Learning. In the *Conference on Networked Systems 2021 (NetSys 2021, Lübeck)*, September 2021, EASST https://dx.doi.org/10.14279/tuj.eceasst.80.1130.1081.

5 Computer Graphics Group

5.1 Personnel

Head:	Prof. Dr. D. Bommes	Tel.: +41 31 631 3301 email: david.bommes@unibe.ch
Office Manager:	D. Heinzen	Tel.: +41 31 631 4914 email: dragana.heinzen@unibe.ch
Scientific Staff:	Dr. P.-A. Beaufort	Tel.: +41 31 511 7601 email: pierre-alexandre.beaufort@unibe.ch
	N. Gallego-Ortiz	Tel.: 41 31 511 7601 email: nicolas.gallego@unibe.ch
	M. Heistermann	Tel.: +41 31 511 7601 email: martin.heistermann@unibe.ch
	D. Kalmykov	Tel.: +41 31 511 7601 email: denis.kalmykov@unibe.ch
	L. Kamaldinova	Tel.: +41 31 511 7601 email: liubov.kamaldinova@unibe.ch
	H. Liu	Tel.: +41 31 511 7601 email: heng.liu@unibe.ch
	V. Nigolian	Tel.: +41 31 511 7601 email: valentin.nigolian@unibe.ch
	S. Raimondi	Tel.: +41 31 511 7601 email: simone.raimondi@unibe.ch

5.2 Overview

The research activities of the Computer Graphics Group are mainly located in the area of *geometry processing*, which is one of the central topics of *computer graphics*. Geometry processing is concerned with the development of concepts and algorithms to represent, generate, analyze, and modify the shape of objects. Resulting from the physical space we live in, omnipresent classes of shapes include curves, surfaces and volumetric bodies embedded in 3D, or 4D for time-varying shapes. Nowadays, such geometric objects are fundamental in numerous disciplines, inducing a strong scientific impact of geometry processing far beyond computer graphics. Applications as for instance numerical simulation in engineering or computational geology, anomaly detection or surgery planning in medicine, shape matching in computational biology, or the design of

smart materials in additive manufacturing (e.g. 3D printing) only become feasible if accurate geometric representations of the involved shapes are available.

Currently, the group focuses on the generation of discrete geometry representations in the form of semi-structured meshes with quadrilateral elements for surfaces and hexahedral elements for volumetric objects. Such meshes combine the advantages of unstructured simplicial meshes and fully structured Cartesian grids. In contrast to previous methods, e.g. based on local operations, we focus on (global) variational formulations that enable a superior structure of the resulting meshes. There is empirical evidence that following this approach, for the first time algorithms are able to generate meshes that are comparable to manually designed ones. The variational formulation leads to involved nonlinear mixed-integer optimization problems. Hence, one goal of our research is the design of better formulations and parametrizations of the problem that pave the way for efficient solution strategies. In general, our research is driven by the idea of successively addressing the fundamental research questions that are critical from the practitioners perspective, and eventually come up with practically relevant meshing solutions.

5.3 Research Projects

HexMe If You Can

The HexMe dataset consists of 189 tetrahedral meshes with tagged features and a workflow to generate them. The primary purpose of HexMe meshes is to enable consistent and practically meaningful evaluation of hexahedral meshing algorithms and related techniques, specifically regarding the correct meshing of specified feature points, curves, and surfaces.
The tetrahedral meshes have been generated with Gmsh, starting from 63 computer-aided design (CAD) models from various databases. To highlight and label the diverse and challenging aspects of hexahedral mesh generation, the CAD models are classified into three categories: simple, nasty, and industrial. For each CAD model, we provided three kinds of tetrahedral meshes (uniform, curvature- adapted, and box-embedded).
The mesh generation pipeline is defined with the help of Snakemake, a modern workflow management system, which allows us to specify a fully

automated, extensible, and sustainable workflow. It is possible to download the whole dataset or select individual meshes by browsing the online catalog. The HexMe dataset is built with evolution in mind and prepared for future developments. A public GitHub repository hosts the HexMe workflow, where external contributions and future releases are possible and encouraged. A paper introducing the dataset "Hex Me If You Can" has been published in the Computer Graphics Forum journal, and presented during the Symposium on Geometry Processing in July 2022.

Project page: `https://hexme.algohex.eu/`

Research staff: Pierre-Alexandre Beaufort, Heng Liu, Denis Kalmykov, David Bommes

Financial support: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, project AlgoHex, No. 853343

Flow-based T-Mesh Quantisation

State-of-the-art algorithmic pipelines for the generation of quadrilateral surface meshes and layouts construct as an intermediate step non-conforming patch layouts, so-called T-meshes. To turn such T-meshes into fully conforming quadrilateral meshes, we need to assign integer edge lengths to all arcs of the T-mesh. They should be close to real-valued target lengths and fulfill certain compatibility conditions. This process, known as quantization, is a non-trivial global optimization problem. We can use a valid quantization to reparameterize each patch and obtain conforming pure-quadrilateral meshes or layouts.

Prior work usually performs this crucial quantization task using greedy approaches or commercial (Mixed-)Integer solvers. The former approach is not guaranteed to find an optimal solution, while the latter approach can be solved optimally but has exponential worst-case runtime complexity.

We aim to solve the quantization problem using generalizations of minimum-cost network flow problems. We investigate several flow-based formulations of multiple different quantization problems to demonstrate the modeling flexibility of our approach. Our project also includes multiple methods of solving the resulting flow problems both approximately

and exactly, outperforming existing generic solvers. The result is a quad-meshing pipeline in which quantization runtime is negligible compared to other steps.
This project focuses on quadrilateral surface meshes; however, further generalizations should allow modeling volumetric quantization problems required for hexahedral meshing. Therefore we expect our results to be beneficial in future volume meshing pipelines. Additionally, the studied flow problems also show up in unrelated fields such as computational biology, extending the potential impact of our work.

Research staff: Martin Heistermann, David Bommes

Financial support: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, project AlgoHex, No. 853343

Locally Hexmeshable 3D Frame Fields

In many computational engineering techniques, an essential step is to faithfully discretize geometric objects into volumetric meshes that carry physical properties, such as material. A hexahedral (hex) mesh is one of the most prominent type of mesh used for discretizing volumes, highly valuable to both academic and industrial applications. Although many different hex meshing algorithms have been proposed during the last decades, there is no automatic algorithm capable of robustly generating high-quality hex meshes for general geometric shapes. Among all hexahedral meshing algorithms, frame-field-based techniques show the most promising potential to automatically produce an all-hex mesh with superior quality while being capable of generating meshes aligned to internal structures in addition to the boundary of the volume. It consists of three major steps: (i) Feature-aligned smooth frame-field generation. (ii) Integer-grid map generation guided by the frame field. (iii) Extraction of integer grids that explicitly form a hexahedral mesh. Despite the advantages, frame-field-based hex meshing suffers from robustness issues, which root in two aspects: (i) non-meshable frame field topologies and (ii) the inability to guarantee local injectivity for volumetric maps. Certain singularity graphs are incompatible with an integer-grid parameterization, leading to degeneracies or failure in downstream steps of the meshing pipeline. Non-meshable frame field topology is the central issue that causes the collapse in the integer-grid map.

The non-meshablity of the 3D frame field, from the singular graph point of view, can be categorized as (i) global topological inconsistencies such as wrongly connected singular arcs, and (ii) local topological inconsistencies, e.g., complex singular arc types and non-meshable singular node types. In this project, instead of solving the global inconsistencies, we focus on obtaining frame fields that are locally hex-meshable everywhere in the one-ring neighborhood in the discretized setting. We analyze all types of local defects existing in frame fields which break down into four categories: (i) misalignment of frame field, (ii) invalid singular edge types, (iii) invalid singular nodes, and (iv) zero sectors formed by singular edges and features. Accordingly, we propose a series of repair operations and design a practical algorithm to realize the local hex-meshability of frame fields. On the one hand, it includes both remeshing and relocation of singular vertices to align the singular graph to the frame field and eliminate complex singular edges; on the other hand, it decomposes non-meshable singular nodes by detaching singular arcs and turning points from it until it becomes meshable. After the repair, the only invalid nodes are turning points which can be further split into a pair of valence +1 and valence -1 singular arcs that ends at the boundary. The algorithm results in a 3D frame field that is locally hex-meshable, significantly increasing the robustness of the corresponding hex meshing algorithm.

Research staff: Heng Liu, David Bommes

Financial support: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, project AlgoHex, No. 853343

Fast Frame Field generation in two and three dimensions using a Multi-Grid approach

In geometry processing, many algorithms require the generation of a frame field. For example, in Quad Meshing a two dimensional frame field defined over the surface is used to guide the generation of elements. Similarly, for Hex Meshing, a three dimensional field is used to guide the generation of the hexahedral elements in the whole volume. For this reason, algorithms able to quickly generate high quality fields are required.
In this project we explore a new approach based on a modified MBO method to solve the Heat Equation to generate a frame field both for two and three dimensions. Our work is inspired by the previous work from D.

Palmer et al. on *Algebraic Representations for Volumetric Frame Fields*. In our method we use a Multi-Grid approach based on a tree data structure. This allows us to generate high quality fields adapting the resolution depending on multiple conditions, for example the angle between adjacent frames. To solve the Heat Equation, we use the Divergence theorem to derive an explicit integration method that allow for a very simple computational approach which is trivial to parallelize.
Thereafter, the performance of our method is very competitive, and the final quality of the generated field is better than existing methods, with less time needed for the computation. Because our method focuses on generating high quality fields as fast as possible, a lot of attention has been put into the different stages of the algorithm. In particular, we propose an algorithm for constructing a tree from an existing one that automatically has an optimal memory layout and can be run in parallel. We have refined our algorithm to carefully take all the information of the input domain in consideration to generate a field that aligns as good as possible to the features of the input. We are extensively testing our method in 3D, and our experiments show that we are able to handle very complex models while keeping the time needed for the computation low.

Research staff: Simone Raimondi, Pierre-Alexandre Beaufort, David Bommes

Financial support: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, project AlgoHex, No. 853343

Integrable Frame-Field Optimization for Quad Mesh Generation

Quad meshes are surface representations made of quadrilateral faces only. They are used in applications involving texture transfer in computer graphics and are preferred to triangle meshes in some simulation applications. Vertices in a quad mesh that topologically deviate from a regular grid, i.e. where more or less than four faces meet, are called singularities. The quality of quad meshes is strongly related to the number and position of singularities since they heavily influence the distortion and orientation, scale, and anisotropy of the quadrilaterals.

This project aims to produce algorithms that support designer constraints to control aspects related to quad mesh quality. State-of-the-art methods decompose the generation of quad meshes into frame field generation, followed by its parametrization. Locally, frame fields are two symmetric linearly independent vector fields representing the desired orientations of the quad mesh edges and their lengths. In theory, the integration of the frame field produces a parameterization, whose isolines look like a grid mapped to the surface and follow the designed frame field. Integrable frame fields in this context are closed regarding integration: if you follow the first vector for one step and then the second, you would land at the same point as if you follow the second vector and then step along the first. If this property is satisfied at each point in the domain of the frame field, the frame field is said to be integrable. If a frame field is integrable, its parameterization follows the field everywhere and thus is a good proxy of the resulting quad mesh.

We focus on the computation of integrable frame fields that are meshable with low alignment errors. We have decided to work on the frame-field-based approach because it allows the most flexible setting to consider the user's constraints. Formulating and optimizing integrability energies is a promising approach for the quad meshing problem. In this project, we target a direct optimization of integrability via an elegant formulation in a polar representation of the frame field.

We developed a formulation for optimizeing integrable frame fields conforming to alignment and isotropic sizing constraints. We have studied alternatives to improve singularity positions of integrable fields by including the singularity positions in their tangent plane local coordinate system in the optimization objective function. The problem resulted in being quite rich, and we have gained lots of experimental insights into designing schemes to capture the objective.

Once we are done with relocating existing singularities, we would like to tackle the question of adding or merging singularity pairs in regions that would improve the quality of the quad mesh, and this would complete the toolkit for quad mesh generation of this doctoral project: relocation, creation and merging while optimizing for a low distortion objective constrained to being integrable at every step.

Research staff: Nicolas Gallego-Ortiz, David Bommes

Robust Volumetric Maps

Mapping an arbitrary volumetric domain to another one in an injective way is a challenging problem. If the domain is decomposed into tetrahedra, current methods tend to create “flipped” elements, making the mapping locally non-injective. While most mapping methods generally take a global approach by trying to minimize a particular energy, some others focus on local operations, i.e. changing the mesh’s topology. Such a method called “Progressive Embeddings” focuses on two local operations, namely ”edge collapsing” and ”vertex splitting” to solve this issue on surfaces. By successively collapsing edges, one can reduce a surface mesh to its boundary and a single interior vertex. This interior vertex can then be split in successions, carefully placing the new vertex in a way that does not create flipped triangles. At the end of this second step, the mesh presents the same topology as the original surface but without any flipped triangles, making it an injective mapping. However, this method cannot directly be applied to volumetric domains because collapsing edges can create blocking situations where collapsing additional edges would change the topology of the mesh. Additionally, the “vertex splitting” operation, the basis for the inverse process of “uncollapsing” the mesh reduced to a single interior vertex, cannot be guaranteed to be valid in the original domain. Indeed, we have identified cases where splitting vertices is guaranteed to be impossible, thus making this approach a dead-end. Considering those limitations, we take a purely geometrical approach where “edge collapsing” is replaced by “edge shrinking”. This new operation moves one of the edge’s tips to the same location as the other one, thus shrinking the tetrahedra surrounding the edge. Not modifying the topology, this operation can be used freely for all interior edges, resulting in a mesh where some or all interior vertices are grouped together into one or more “clusters”, where they share the same position.

Those clusters are then “expanded” by pulling a subset of their vertices into a position that guarantees not to create new flipped tetrahedra, while increasing the number of tetrahedra with positive volume.

The main difference between our approach and the original “Progressive Embedding” method is that we do not modify the mesh’s topology in the shrinking sequence, but only during the “expansion” sequence by splitting edges. Since splitting edges is always allowed geometrically and topologically, we no longer have to worry about the validity of our mapping in the original domain.

Additionally, the Progressive Embedding approach relies on undoing the collapse sequence by doing vertex splits in the same, but reversed or-

der, while our method is free to pick any subset of vertices to expand at any step, thanks to the topology-preserving nature nature of edge shrinks. While our method is very close to being functionally sound, we currently have two main challenges to guarantee the success of our method. First, to establish whether or not we can always guarantee to be able to find a subset of a cluster that is expandable. Secondly, to find a method that guarantees to be able to modify a non-star-shaped expansion space of a cluster subset to make it star-shaped and thus to be able to find a new valid position for this cluster subset.

Research staff: Valentin Nigolian, David Bommes

Financial support: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, project AlgoHex, No. 853343

MBO Frame-Field Generation

Hexahedral meshes possess properties that make them desirable for engineering applications. However, for the users to benefit from using a hex-mesh, it must meet strict requirements, which pose significant challenges for current state-of-the-art algorithms for an automatic hex-mesh generation. This is why the industry-grade hex-meshing is currently done semi-manually and therefore takes considerable human time and effort in the modeling pipeline. There are several different approaches to hex-meshing. An example of a promising approach that has been getting more and more attention in the last few years is the frame-field-based method. The big selling point of the technique is that it promises to deliver high-quality meshes that naturally fit the engineering constraints and supposedly better represent the structure of the model. Recent advances improve some of the many robustness issues of the method; however, there is still work to be done. The most critical steps of the pipeline include the frame-field generation and the parametrization of the volume, which is guided by the frame-field. The parametrization is then used to assign the nodes for the resulting hexahedral mesh.
The project aim was to implement a frame-field generation method based on the modified MBO approach following D. Palmer et al. Algebraic Representations for Volumetric Frame Fields. This is the new state-of-the-art family of algorithms enabling improved frame-field quality. In this method,

the frame-field is computed via optimization of the higher-dimensional octahedral field or odeco-field, constrained by the boundary normals and the feature elements of the mesh. To obtain an actual frame field, the corresponding elements must be projected back into the space of frames. The idea of the MBO methods is to minimize the energy functional by iterating two essential steps: the diffusion step and the projection step until the stopping criterion is reached. The diffusion step involves solving a PDE with the abovementioned constraints for the octa- or odeco- field using the implicit scheme. The projection step aims to push each field element back to the algebraic variety it lives on, correcting the error introduced by applying diffusion. It is achieved by solving either a semi-definite problem via MOSEK or alternatively by applying the gradient-descent. It is worth noting that the gradient-descent approach achieves significantly faster performance. As a result of this project, a C++ implementation of the MBO family of methods was done and successfully integrated into an AlgoHex library. Also, a set of benchmarks was performed to validate the result. As a future work for this project, the implementation of the Riemann-Trust-Region solver is proposed.

Research staff: Denis Kalmykov, David Bommes

Financial support: European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, project AlgoHex, No. 853343

5.4 Bachelor's Theses

- Marco Cacciatore, "Geodesic distance computation via virtual source propagation in a volumetric setting", October 2021.
- Maksim Fomin, "Foldover-Free Maps: an Evaluation", January 2022.
- Steve Mürset, "Topology preserving Meshing of Medical Data with multiple Materials", September 2021.
- Elias Wipfli, "Hex-Mesh Optimization with Edge-Cone", December 2021.
- Lorenzo Wipfli, "Optimized visualization of OpenVolumeMesh in Blender", October 2021.

- Marcel Zauder, “Creation and modification of 3D meshes in virtual reality”, February 2022.

5.5 Awards

- Best paper award at Symposium on Geometry Processing (SGP) 2022, Patrick Schmidt, Janis Born, David Bommes, Marcel Campen, Leif Kobbelt: *T*inyAD: Automatic Differentiation in Geometry Processing Made Simple.

5.6 Further Activities

Invited Talks

David Bommes

- “Quadrilateral and Hexahedral Mesh Generation with Integer-Grid Maps”. Center for Visual Computing at UCSD, online, June 2022.

Editorial Boards

David Bommes

- Computer Graphics Forum (CGF) Journal, Associate Editor
- Graphical Models (GMOD) Journal, Associate Editor
- Computers & Graphics (CAG), Associate Editor

Conference Organization

David Bommes

- FRAMES 2021, Conference Co-Chair, December 6, 2021, online

Conference Program Committees

David Bommes

- EUROGRAPHICS (EG) 2021 & 2022
- Symposium on Geometry Processing (SGP) 2021 & 2022
- Geometric Modeling and Processing (GMP) 2021 & 2022
- Solid and Physical Modeling (SPM) 2021 & 2022
- Shape Modeling International (SMI) 2021
- Vision, Modeling and Visualization (VMV) 2021 & 2021

Reviewing Activities

David Bommes

- ACM Transactions on Graphics
- ACM SIGGRAPH
- ACM SIGGRAPH Asia conference
- Computer-Aided Design (CAD)
- Computer Aided Geometric Design (CAGD)
- Computer Graphics Forum (CGF)
- Pacific Graphics
- Replicability Stamp
- UniBE Initiator Grants
- UniBE DocMobility

PhD Committee Memberships

David Bommes

- Ahmad Nasikun (PhD Jury), TU Delft, March 21, 2022

Public events

- Study Week on Fascination Informatics 2021: Valentin Nigolian supervised two students in further improving the algorithms for papercraft models that resulted from the 2020 project.

5.7 Publications

Journal Publications

- Hendrik Brückler, David Bommes, Marcel Campen: “Volume parametrization quantization for hexahedral meshing”, ACM Transactions on Graphics, Volume 41(4), (Proc. **ACM SIGGRAPH**), 2022.
- Nico Pietroni, Marcel Campen, Alla Sheffer, Gianmarco Cherchi, David Bommes, Xifeng Gao, Riccardo Scateni, Franck Ledoux, Jean-Francois Remacle, Marco Livesu: “Hex-Mesh Generation and Processing: A Survey”, ACM Transactions on Graphics, 2022.
- Patrick Schmidt, Janis Born, David Bommes, Marcel Campen, Leif Kobbelt: “TinyAD: Automatic Differentiation in Geometry Processing Made Simple”, Computer Graphics Forum, Volume 41(5), (Proc. SGP, **best paper award**), 2022.
- Pierre-Alexandre Beaufort, Maxence Reberol, Heng Liu, Franck Ledoux, David Bommes: “Hex Me If You Can”, Computer Graphics Forum, Volume 41(5), (Proc. SGP), 2022.
- Manish Mandad, Ruizhi Chen, David Bommes, Marcel Campen: “Intrinsic mixed-integer polycubes for hexahedral meshing”, Computer Aided Geometric Design, Volume 98, (Proc. GMP), 2022.

6 Computer Vision Group

6.1 Personnel

Heads:	Prof. Dr. P. Favaro	Tel.: +41 31 684 4451 email: paolo.favaro@unibe.ch
Office Managers:	D. Heinzen	Tel.: +41 31 684 4914 email: dragana.heinzen@unibe.ch
Scientific Staff:	A. Bielski	Tel.: +41 31 511 7605 email: adam.bielski@unibe.ch
	A. Lemkhenter	Tel.: +41 31 511 7603 email: abdelhak.lemkhenter@unibe.ch
	L. Cerkezi	Tel.: +41 31 511 7604 email: llukman.cerkezi@unibe.ch
	A. Davtyan	Tel.: +41 31 511 7604 email: aram.davtyan@unibe.ch
	S. Sameni	Tel.: +41 31 511 7601 email: sepehr.sameni@unibe.ch
	A. E. Sari	Tel.: +41 31 511 7604 email: alp.sari@unibe.ch
	V. Shipitsin	Tel.: +41 31 511 7604 email: viktor.shipitsin@unibe.ch
	H. Chihaoui	Tel.: +41 31 511 7605 email: hamadi.chihaoui@unibe.ch
	R. M. Prisco	Tel.: +41 31 511 7601 email: renato.prisco@unibe.ch
External PhD students:	L. Fiorillo	email: luigifiorillo@gmail.com

6.2 Overview

The Computer Vision group conducts research on the broad areas of machine learning, computer vision, image processing, and imaging and sensor design by employing models, algorithms and analysis tools from optimization theory, probability theory, and applied mathematics. Our general aim is to extract high-level information from images by using digital processing. Such high-level information can be in the form of geometric or photometric quantities about objects in the scene, or semantic attributes such as their category, their function, etc. Currently, our efforts in imaging have been devoted to problems in: inverse imaging (deblurring, blind de-

convolution, super resolution), 3D estimation (multi view stereo, photometric stereo, coded aperture photography), motion estimation (structure from motion, tracking). We are also working extensively in unsupervised learning with the purpose of building useful feature representations of images and other sensing modalities without using human annotation or, more generally, while reducing the human effort. In our approaches a useful representation is one that makes future learning easier (i.e., learning with new data).

6.3 Research Projects

Towards Sleep Scoring Generalization Through Self-Supervised Meta-Learning

We introduce a novel meta-learning method for sleep scoring based on self-supervised learning. Our approach aims at building models for sleep scoring that can generalize across different patients and recording facilities, but do not require a further adaptation step to the target data. Towards this goal, we build our method on top of the Model Agnostic Meta-Learning (MAML) framework by incorporating a self-supervised learning (SSL) stage, and call it S2MAML. We show that S2MAML can significantly outperform MAML. The gain in performance comes from the SSL stage, which we base on a general purpose pseudo-task that limits the overfitting to the subject-specific patterns present in the training dataset. We show that S2MAML outperforms standard supervised learning and MAML on the SC, ST, ISRUC, UCD and CAP datasets. Our work tackles the generalization problem of automatic sleep scoring models. This is one of the main hurdles that limits the adoption of such models for clinical and research sleep studies.

Research staff: Abdelhak Lemkhenter, Paolo Favaro

Financial support: CVG and the Computational Platform Project No. 38-817. This research is supported by the Interfaculty Research Cooperation “Decoding Sleep from Neurons to Health & Mind” of the University of Bern.

MOVE: Unsupervised Movable Object Segmentation and Detection

We introduce MOVE, a novel method to segment objects without any form of supervision. MOVE exploits the fact that foreground objects can be shifted locally relative to their initial position and result in realistic (undistorted) new images. This property allows us to train a segmentation model that achieves state of the art (SotA) performance on several evaluation datasets for unsupervised salient object detection and segmentation. In unsupervised single object discovery, MOVE gives an average CorLoc improvement of 4.5% over the SotA, and in unsupervised class-agnostic object detection it gives a relative AP improvement of 30% on average. Our approach is built on top of self-supervised features (from DINO), an inpainting network (based on the Masked AutoEncoder) and adversarial training with a projected discriminator.

Research staff: Adam Bielski, Paolo Favaro

Financial support: CVG

Sleep Physician Assistant System (SPAS)

The ultimate goal of the project is to develop a platform to empower the sleep physicians and to simplify effectively their work. SPAS will act like a young apprentice, taking care of tedious job and learning continuously from the expert physician. A new personalized approach for the polysomnography (PSG) scoring and a data miner for whole data exploitation will ease the scoring procedure and will improve general diagnosis and treatment. Existing automated and semi-automated scoring software cannot provide personalized scores in the same way as the expert physician's judgement. Sleep scoring is the procedure of classifying PSG recordings (EEG, EOG and EMG). The whole night recording is divided into 30-s windows and the physician has to classify each epoch into one of the five sleep stages: awake W, stage N1, stage N2, stage and stage REM. Since 1960 several techniques have been employed to solve this task automatically. However, up to now, no system has proven to be a valid substitute for the sleep physician. The goal is to improve and optimize the recent deep learning-based scoring systems. SPAS aims to develop an automatic sleep scoring algorithm able to interactively query the sleep physician and

to learn from his knowledge. In order to release an optimized interactive system, we focused on three closely related challenges: clustering sleep recordings – the deep learning architectures need to be trained on subgroups of PSG recordings; confidence estimation methods for sleep scoring neural networks – the system gives in output the final sleep scores along with the degree of confidence; query the physician and update the network – detect the uncertain forecast, the sleep physician corrects the uncertain (not-confident) answers of the network and the network will be updated (fine-tuning) by using this external knowledge. Considering the architecture for an application in real-time, we are developing a scoring network that needs to process only temporal information related to the one preceding and the one succeeding epoch. A reduced memory requirement (less parameters to be trained) and low-latency characteristic may be advantageous in a real-time implementation.

Research staff: Luigi Fiorillo, Paolo Favaro

Financial support: SUPSI

Unsupervised Disentanglement of Factors of Variation

The project aims to develop better-disentangled representations for image data in an unsupervised fashion. We aim to build a better representation employed with downstream tasks: classification, few-shot learning, or domain adaption. However, the downstream task we focus on is classification at the moment. To achieve this, we are experimenting with a couple of different approaches. One is utilizing the assumption that a disentangled image representation should have uncorrelated chunks, and we impose this constraint using a novel approach. Second, we experiment with Masked Image Autoencoders. This self-supervised representation learning method got popular recently. We investigate the effect selection of the mask patches and the performance of the classification after pre-training to get a more compact and disentangled image representation.

Research staff: Alp Eren Sari, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

3D Object Reconstruction without Mask Supervision

In this project, we aim to capture the shape and appearance of real objects given a sparse set of input views (e.g. 8-10 views) and their corresponding pose information. The typical choice for the 3D representation includes meshes, voxels, and point clouds. In this project, we choose meshes as a representation as they are efficient and flexible in terms of vertex transformations. In contrast to existing mesh-based methods, we need no mask supervision for objects that we want to reconstruct. We achieve this by explicitly having two separate meshes, i.e., one for the object and one for the background. We assume that we have an approximate background mesh and we keep it fixed and update only its appearance during training. The method consists of two main steps. First, we learn the coarse shape of an object and then we capture finer details. The method can also model objects with a genus above zero.

Research staff: Llukman Cerkezi, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

Unsupervised Learning of Object Interactions

In this project, we are aiming to answer the question “What would happen if we moved an object somewhere in an environment with other objects?”. The model trained with this incentive should be able to generate/modify a video in a realistic way (dreaming of an alternative outcome), by taking into account object interactions. Achieving the goal implies both discovering the action spaces of the agents and building a precise and reliable predictive model of the environment. This is a necessary building block to do planning to solve downstream tasks. A system that can answer correctly the above counterfactual question should have built a valid causal model of the environment. There is a belief that causal models should generalize better. To solve the first part, we introduce GLASS, a model that learns the action space of a single agent in the scene and further decomposes it into global and local components. Given this decomposition, GLASS is able to generate realistic sequences conditioned on the first frame and the actions taken by the agent. Our model outperforms prior work on a number of synthetic and real datasets. Regarding the second part, given a dataset of videos capturing multiple agents interacting with each other, we aim to learn a transition model, that would predict the next frame of the

video given the current frame. There are plenty of works on video generation in the literature. However, in our project the main focus is made on capturing object interactions occurring in the scene. For this purpose we condition the transition model on a set of abstract action codes assigned to each of the agents in the scene. More precisely, we propose to apply 2D shifts to the pixels on the first frames of the video sequence. This way, we avoid learning to explicitly decompose the scene to objects, which is often believed to be an ill-posed task. Instead, we let the model solve the scene decomposition task implicitly.

Research staff: Aram Davtyan, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

Optimization of Neural Networks from Kalman Filtering Perspective

Optimization is often cast as a deterministic problem, where the solution is found through some iterative procedure such as gradient descent. However, when training neural networks the loss function changes over (iteration) time due to the randomized selection of a subset of the samples. This randomization turns the optimization problem into a stochastic one. We propose to consider the loss as a noisy observation with respect to some reference optimum. This interpretation of the loss allows us to adopt Kalman filtering as an optimizer, as its recursive formulation is designed to estimate unknown parameters from noisy measurements. We call this stochastic optimization method KOALA, which is short for Kalman Optimization Algorithm with Loss Adaptivity. We provide convergence analysis and show experimentally that it yields parameter estimates that are on par with or better than existing state of the art optimization algorithms across several neural network architectures and machine learning tasks, such as computer vision and language modeling.

Research staff: Aram Davtyan, Sepehr Sameni, Llukman Cerkezi, Givi Meishvili, Adam Bielski, Paolo Favaro

Financial support: Swiss National Science Foundation Projects No. 188690 & 165845

Representation Learning by Detecting Incorrect Location Embeddings

In this paper, we introduce a novel self-supervised learning (SSL) loss for image representation learning. There is a growing belief that generalization in deep neural networks is linked to their ability to discriminate object shapes. We then introduce sparsity in the inputs to make the model more robust to occlusions and to speed up the training. We call our method DILEMMA which stands for Detection of Incorrect Location EMbeddings with MAsked inputs. We apply DILEMMA to MoCoV3, DINO and SimCLR and show an improvement in their performance of respectively 4.41%, 3.97%, and 0.5% under the same training time and with a linear probing transfer on ImageNet-1K. We evaluate our method via fine-tuning on common SSL benchmarks. Moreover, we show that when downstream tasks are strongly reliant on shape (such as in the YOGA-82 pose dataset), our pre-trained features yield a significant gain over prior work.

Research staff: Sepehr Sameni, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

Event-based Image Intensity Reconstruction

Event-based vision is a novel approach to Computer Vision using a non-traditional type of sensor. This field is not mature (approximately 10 years of research have passed after the first commercially available event-based sensor). The main distinction is the way of a scene recording: using an event-based camera we can only register the difference of logarithms of intensities (illuminances) of each pixel independently. This gives us the ability to record with extremely high dynamic range and frame rate. With fast and qualitative image intensity reconstruction as a preprocessing step, we can use current state-of-the-art algorithms working with the regular images as input and improve the quality of the whole system simultaneously preserving the advantages of event sensors. However, it is not possible to reconstruct real intensities theoretically. Moreover, there is no well-descriptive model of noise that gives us low-quality of reconstructed images. One of the ways is to restore pseudo-intensity levels using grayscale images as prior information. Another one is to consider joint estimation based on grayscale frames as low-frequency information and events as

high-frequency information. In the both cases we pay our attention to fuse the information from both types of sensors properly. In the end, the designed encoder-decoder-like model must combine different natures in the hidden space and predict the high-quality next frames based on the previous frame and events between timestamps without common-known artefacts such as the ghost effect and bleeding edges.

Research staff: Viktor Shipitsin, Paolo Favaro

Financial support: CVG

6.4 Ph.D. Theses

- Givi Meishvili, "Learning Representations for Controllable Image Restoration.", March 2022.

6.5 Master's Theses

- Seyedeh Sharareh Mirzargar, "Machine Learning Based Prediction of Mental Health Using Wearable-measured Time Series", July 2022.

6.6 Bachelor's Theses

- Aaron Sägesser, "Revisiting non-learning based 3D reconstruction from multiple images", October 2021.

- Lars Ziegler, "Home Monitoring by Radar", March 2022.

6.7 Memberships

Paolo Favaro

- Member of IEEE

- Member of ELLIS

6.8 Further Activities

Evaluation Committes

Paolo Favaro

- Tampere University Research Assessment Exercise 2022
- SNF Ambizione Committee 2021
- University of Saarland 2021
- EPFL PhD Thesis Isinsu Katircioglu, Nov 2021

Invited Talks

Paolo Favaro

- “Unsupervised Segmentation Learning with MOVE”, Google Computational Imaging Workshop, August 2022
- “Towards Scalable Learning”, Swiss Faculty Retreat, March 2022.
- “Deep Learning: Overview and Insights”, BeDSI, December 2021.
- “KOALA: A Kalman Optimization Algorithm with Loss Adaptivity”, University of Oxford, September 2021.

Seminars Given by External Speakers

- Chenyang Tao, “Simpler, Faster, Stronger: Supercharging Contrastive Learning with Novel Mutual Information Bounds”, October 1, 2021.
- Jiajun Wu, “Understanding the Visual World through Code”, November 5, 2021.
- Grigorios Chrysos, “(Conditional) image generation with high-degree polynomial expansions”, December 3, 2021.
- Andrey Malinin, “Tackling the Challenge of Uncertainty Estimation and Robustness to Distributional Shift in Real-World applications”, January 14, 2022.

- Arash Vahdat, “Tackling the Generative Learning Trilemma with Accelerated Diffusion Models”, February 10, 2022.
- Alaa El-Nouby, “Are Large-scale Datasets Necessary for Self-Supervised Pre-training?”, March 11, 2022.
- Greg Yang, “Tuning Large Neural Networks via Zero-Shot Hyperparameter Transfer”, April 8, 2022.
- Dmitry Dylov, “CV applications in medicine and biology”, June 3, 2022.
- Thomas Kipf, “Slot Attention: Recent progress towards object discovery in real-world video & 3D scenes”, July 22, 2022.
- Katja Schwarz, “3D-Awareness and Frequency Bias of Generative Models”, September 2, 2022.
- Tony Licata, “Assessment of Movement and Pose in a Hospital Bed by Ambient and Wearable Sensor Technology in Healthy Subjects”, September 9, 2022.

Conference Program Committees and Reviews

Paolo Favaro

- CVPR 2022 Area Chair
- CVPR 2022 NTIRE Workshop Program Committee

Abdelhak Lemkhenter

- NeurIPS 2022 Reviewer
- CVPR 2022 Reviewer
- ICLR 2022 Reviewer

Aram Davtyan

- CVPR 2022 Reviewer

Journal Committees

Paolo Favaro

- Associate Editor for IEEE Transactions on Pattern Analysis and Machine Intelligence

Refereed Conference Proceedings

- A. Bielski, P. Favaro “MOVE: Unsupervised Movable Object Segmentation and Detection“, in Conference on Neural Information Processing Systems (NeurIPS), 2022
- A. Davtyan, P. Favaro, “Controllable Video Generation through Global and Local Motion Dynamics”, in European Conference on Computer Vision (ECCV), 2022.
- Z. Zhang, P. Favaro, Y. Tian and J. Li,, “Learn to Zoom in Single Image Super-resolution”, in IEEE Signal Processing Letters, 2022., 2022.
- A. Davtyan, S. Sameni, L. Cerkezi, G. Mieshvilli, A. Bielski, P. Favaro, “KOALA: A Kalman Optimization Algorithm with Loss Adaptivity”, in AAAI Conference on Artificial Intelligence, 2022.
- A. Lemkhenter , P. Favaro, “Towards Sleep Scoring Generalization Through Self-Supervised Meta-Learning”, in IEEE Engineering in Medicine and Biology Society, 2022.
- L. Fiorillo, P. Favaro, F. D. Faraci, “DeepSleepNet-Lite: A Simplified Automatic Sleep Stage Scoring Model with Uncertainty Estimates”, IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2021.

Technical Reports

- A. Lemkhenter, A. Bielski, A. E. Sari, P. Favaro, “Generative Adversarial Learning via Kernel Density Discrimination”, under review. 2021.

7 Cryptology and Data Security Group

7.1 Personnel

Head:	Prof. Dr. Ch. Cachin	Tel.: +41 31 684 8560 email: christian.cachin@unibe.ch
Office Manager:	B. Choffat	Tel.: +41 31 684 8426 email: bettina.choffat@unibe.ch
Scientific Staff:	Dr. S. Ghosh	email: sebati.ghosh@unibe.ch (as of 01.11.2021)
	Dr. Du Lê Viet	email: duc.leviet@unibe.ch (as of 15.10.2021)
	O. Alpos	email: orestis.alpos@unibe.ch
	I. Amores Sesar	email: Ignacio.amores@unibe.ch
	M. Barbaraci	email: mariarosaria.barbaraci@unibe.ch (as of 01.07.2021)
	D. Lehnherr	email: david.lehnherr@unibe.ch (as of 01.10.2021)
	J. Mićić	email: jovana.micic@unibe.ch
	N. Steinhauer	email: nathalie.steinhauer@unibe.ch (until 31.07.2021)
	L. Zanolini	email: luca.zanolini@unibe.ch

7.2 Overview

The Cryptology and Data Security Group broadly investigates security and privacy in a digital world. Concrete topics include cryptographic protocols, distributed consistency, consensus, and cloud-computing security, with applications to blockchains, distributed ledger technology, cryptocurrencies, and their economics.

Security and privacy are at stake in the information society, threatened by the enormous developments in networks, cloud, and mobile. Information technology has already revolutionized many aspects today's life. Finding a balance between the practical convenience of being "always online", current business practices, the changing demands of society, and the privacy and security concerns of individual people represents one of the great open questions of our time. Cryptography and data security provide techniques to answer this question.

7.3 Research Projects

Advanced blockchain consensus protocols

Blockchains are trustworthy distributed networks, maintained by many nodes using distributed a consensus process and relying on cryptographic techniques. Some systems regulate which nodes may participate in the consensus protocol, but others leave this completely open and operate without any central authority. Cryptocurrencies rely on blockchains and hold substantial value.
The participating nodes validate transactions executed by the network and append information to the blockchain, which also takes the form of a ledger. A distributed *consensus protocol* tolerating faults and adversarial attacks ensures that the nodes agree on a unique order in which entries are appended. Advanced cryptographic algorithms play an important role for achieving consistency and privacy. Guaranteeing security and safety for blockchain networks requires mathematical models and sophisticated arguments, drawn from theoretical computer science, cryptography, and the theory of distributed computing.
Based on earlier work on Byzantine-fault tolerant (BFT) consensus for, we are exploring consensus protocols and security mechanisms, and apply them to blockchain systems.
The current research broadly addresses two questions.

Generalized and asymmetric trust. In traditional consensus protocols, all involved nodes adhere to a global, symmetric trust assumption, typically only expressed through bounds on the number of faulty processes. Most systems deployed today thus count the influence of all nodes in the same way, for example, as when relying on the assumption that a strict 2/3-majority of the nodes are correct. Moreover, all nodes in the system make the same trust assumption.
However, whom one should trust may be a subjective choice. Going beyond this symmetric notion of trust, we are currently exploring models for *asymmetric trust*. Several practical blockchain systems have recently suggested to let each participating node express its own subjective trust assumption. In this model of *asymmetric trust*, every node is free to choose which others it trusts and which ones might collude against it.
In our work, we have laid the foundations of this model and discovered applications to real-world networks.

Research staff: Orestis Alpos, Christian Cachin, Luca Zanolini.

Financial support: Swiss National Science Foundation (SNSF), grant agreement Nr. 200021_188443.

Blockchain consensus protocols. The consensus protocol used by a blockchain network determines its speed and its security. Whereas the performance can be measured through experimentation, assessing the security requires formal models and analyses. For gaining confidence in a protocol, mathematical insight into their structure must be gained.
We have analyzed several existing protocols and discovered weaknesses in them. Moreover, we are interested in developing additional features for such protocols: one prominent aspect is fairness. A blockchain network processing financial transactions should be resistant to front-running, which is a type of insider attack that harms innocent users. An *order-fair consensus* protocol prevents this as much as possible.

Research staff: Ignacio Amores-Sesar, Christian Cachin, Jovana Mićić.

Financial support: Swiss National Science Foundation (SNSF), grant agreement Nr. 200021_188443.

Scalability of consensus protocols.

Today's blockchain networks typically execute all transactions serially. This severely limits their throughput because every participating node processes every transaction. In the sense of the classic state-machine-replication paradigm, this serialization is compelling and appears to be necessary. However, the resulting systems cannot handle a large volume of transactions. By partitioning the state space through sharding, it appears possible to scale out a system and to increase its throughput without reducing its security.
It has recently been observed that an asset transfer as implemented in Bitcoin and other UTXO-style cryptocurrencies only requires a minimal level of synchronization. Interestingly, consensus is not necessary.
These results point to a rich set of underlying methods that we are exploring for increasing the scalability of consensus. Related to this, so-called conflict-free replicated data types (CRDTs) have been introduced earlier for studying cloud-computing platforms. They permit the parallel execution of operations with eventual consistency. Concurrent execution of general transactions seems also possible to some extent on blockchain platforms.

But so far, no fundamental understanding exists of the data layout methods, programming paradigms, and computing abstractions that would enable this.
Another important area of research concerns cryptographic methods for authenticating data that are suitable for concurrent operations.

Research staff: Christian Cachin, Sebati Ghosh, Duc V. Le, David Lehnherr.

Financial support: Protocol Labs (`https://protocol.ai`), donation; Swiss National Science Foundation (SNSF), grant agreement Nr. 200021_188443.

Generalizing blockchain consensus protocols

Although many consensus protocols are in operation today, the need for deeper, scientific understanding still applies. In particular, this holds for the so-called permissionless protocols. These methods are probabilistic and follow a *longest-chain model*, as pioneered by Bitcoin's Proof-of-Work. In the interest of ecologically friendly decentralized systems, many other sybil-resistance mechanisms than Proof-of-(useless-)Work have been considered – rightfully so. Their diversity brings up the question of an underlying structure and common pattern that would permit to unify the different existing approaches.
In particular, we are interested in formalizing the fundamental notions that generalize such consensus protocols, based on an abstract resource. Access to the resource limits the influence that one single node may have in the protocol, typically by relying on aspects external to the protocol. We are formalizing how a provable investment of resources can exercise power in a consensus algorithm in the language of modern cryptography. It allows to prove the security of many existing protocols formally and opens up the avenue to new systems that improve existing ones.

Research staff: Christian Cachin, Duc V. Le, Jovana Mićić, Luca Zanolini.

Financial support: Protocol Labs (`https://protocol.ai`), donation; Ripple University Blockchain Research Initiative and Ripple Impact Fund, donation; Swiss National Science Foundation (SNSF), grant agreement Nr. 200021_188443.

Distributed cryptography

Distributed programs running without trusted coordinator, such as the *smart contracts* executed by a blockchain network, cannot perform cryptographic operations today because no single node can hold a secret key. As one faulty node alone may leak any secrets it knows, keys cannot simply be distributed among the participating nodes. *Distributed cryptography*, also known as *threshold cryptography*, provides well-known methods to secure cryptosystems in the model of distributed and fault-tolerant replicated computations on nodes subject to Byzantine faults.
Our research in the realm of distributed cryptosystems aims to provide such cryptographic operations for smart contracts. We have explored consensus protocols with generalized quorums, which encapsulate flexible trust structures motivated by practice. For realizing them, methods to specify the trust models are needed. We have developed efficient implementations for trust assumptions expressed by a monotone Boolean formula or by a monotone span program.
Ongoing work extends these trust models to distributed cryptosystems.

Research staff: Christian Cachin, Noah Schmid, Nathalie Steinhauer, Mariarosaria Barbaraci.

Financial support: Interchain Foundation, 6340 Baar, Switzerland.

7.4 Master's Theses

- Dominique Roux, "Implementation of a threshold post-quantum signature scheme", Spring 2022.
- Marcel Würsten, "Filecoin consensus: Performance analysis", Spring 2022.
- Riccardo Zappoli, "Secure execution on a blockchain,", Spring 2022.
- Timo Bürk, "Blockchain consensus protocols based on stake", Spring 2022.
- Paula Raseni, "Consensus zoo", Fall 2021.
- Peter Allemann, "Randomness and games on Ethereum", Fall 2021.

7.5 Bachelor's Theses

- Marko Cirkovic, "Cryptographic primitives for on-chain tumbler designs", Spring 2022.
- Matteo Biner, "Fair transaction order in Hedera Hashgraph", Spring 2022.
- Peter Brühwiler, "A concurrent DEX on Cardano", Fall 2021.
- Gillian Cathomas, "Multiparty computation on blockchain", Fall 2021.
- Benjamin Helmy, "Exploring blockchain-based decentralized exchanges", Fall 2021.

7.6 Awards

- Christian Cachin, IACR Fellow *For far-reaching contributions in the fields of cryptography and distributed systems, and for outstanding service to the IACR*, 2022.

7.7 Further Activities

Talks

Christian Cachin

- "Beyond asymmetric byzantine quorum systems." **Invited talk**, Workshop on the Science and Engineering of Consensus, Stanford (CA), USA, Aug. 2022.
- "Blockchain consensus protocols." **Keynote talk**, 4th Blockchain Technology Symposium (BTS 2022), Virtual, June 2022.

Ignacio Amores Sesar

- "A Security Analysis of Avalanche." Presented at FOCODILE 2022, the 3rd International Workshop on Foundations of Consensus and Distributed Ledgers, Lucca, Italy, June 2022.

Editorial Boards

Christian Cachin

- Associate editor for Distributed Computing, 2015–, Springer.

Societies and Steering Committees

Christian Cachin

- Member of Steering Committee for ACM Conference on Advances in Financial Technologies (AFT), 2019–.
- Member of Steering Committee for ACM Symposium on Principles of Distributed Computing (PODC), 2019–2022.

Conference Program Committees

Christian Cachin

- Member of Program Committee for ConsensusDay 22 workshop, at ACM CCS 2022, Los Angeles (CA), USA.
- Member of Program Committee for 36th Symposium on Distributed Computing (DISC 2022), Augusta (GA), USA.
- Member of Program Committee for 4th ACM Conference on Advances in Financial Technologies (AFT 2022), Boston (MA), USA.
- Member of Program Committee for 5th Science of Blockchain Conference (SBC 2022), Stanford (CA), USA.
- Member of Program Committee for 43rd IEEE Symposium on Security and Privacy (IEEE S&P 2022), San Jose (CA), USA.
- Member of Program Committee for Financial Cryptography and Data Security (FC'22), 2022, Grenada.

Duc V. Le

- Member of Poster Jury for 43rd IEEE Symposium on Security and Privacy (IEEE S&P 2022), San Jose (CA), USA.
- Member of Program Committee for ConsensusDay 22 workshop, at ACM CCS 2022, Los Angeles (CA), USA.
- Member of Program Committee for ACM Symposium on Access Control Models and Technologies (ACM SACMAT 2022), 2022, Online Conference.

7.8 Publications

Conference Papers

- I. Amores-Sesar, C. Cachin, and A. Parker, “Generalizing weighted trees: A bridge from Bitcoin to GHOST,” in *Proc. 3rd ACM Conference on Advances in Financial Technologies (AFT)* (F. Baldimtsi and T. Roughgarden, eds.), pp. 156–169, Sept. 2021.

- O. Alpos, C. Cachin, and L. Zanolini, “How to trust strangers: Composition of Byzantine quorum systems,” in *Proc. 40th Symposium on Reliable Distributed Systems (SRDS)*, pp. 120–131, Sept. 2021.

- O. Alpos, C. Cachin, G. A. Marson, and L. Zanolini, “On the synchronization power of token smart contracts,” in *Proc. 41st International Conference on Distributed Computing Systems (ICDCS)*, pp. 640–651, 2021.

- C. Cachin and L. Zanolini, “Brief announcement: Revisiting signature-free asynchronous byzantine consensus,” in *Proc. 35th International Symposium on Distributed Computing (DISC)* (S. Gilbert, ed.), vol. 209 of *LIPIcs*, pp. 51:1–51:4, Schloss Dagstuhl - Leibniz-Zentrum für Informatik, Oct. 2021.

- C. Cachin and L. Zanolini, “Asymmetric asynchronous byzantine consensus,” in *Proc. ESORICS Workshops on Data Privacy Management (DPM), Cryptocurrencies and Blockchain Technology (CBT)* (J. García-Alfaro, J. L. Muñoz-Tapia, G. Navarro-Arribas, and M. Soriano, eds.), vol. 13140 of *Lecture Notes in Computer Science*, pp. 192–207, Springer, 2021.

Preprints and Other Publications

- C. Cachin, J. Mićić, and N. Steinhauer, “Quick order fairness.” e-print, arXiv:2112.06615 [cs.DC]; to appear in the proceedings of Financial Cryptography ’22, 2021.

8 Logic and Theory Group

8.1 Personnel

Head:	Prof. Dr. T. Studer	Tel.: +41 31 684 39 84 email: thomas.studer@unibe.ch
Office Manager:	B. Choffat	Tel.: +41 31 684 84 26 email:bettina.choffat@unibe.ch
Scientific Staff:	Dr. J. Luo	email: Jieting.luo@unibe.ch (as of 01.02.2022)
	Dr. F. Faroldi	email: federico.faroldi@unibe.ch (as of 01.11.2021)
	M. Baur	email: michael.baur@unibe.ch
	A. Rohani	email: atefeh.rohani@unibe.ch
	L. Zenger	email: lukas.zenger@unibe.ch

8.2 Overview

The LTG research group (logic and theory group) focuses on theoretical computer science and mathematical logic, especially proof theory, computational logics and theory of computation. We have been dealing for many years with formal methods, analysis of deductions, general computations and, in particular, applications of mathematical logic to computer science. During the previous year the main subject areas have been the following:

Computational Logic: Logical formalisms are perfectly suited to the specification of complex systems, the representation of knowledge and information, the description of processes (e.g. in distributed multi-agent systems) and for providing formal proofs of important system properties such as, for example, correctness and fairness. The research group has long been interested in the deductive, procedural and dynamic aspects of the corresponding formalisms and in the design of modern deductive systems. New approaches are being developed for information update purposes. In addition, the way in which simple, logical formalisms can be extended to become genuine multi-user systems taking into account the dynamic aspects of ontologies in the data mining context and in connection with the semantic web is being investigated.

Proof Theory: This research topic focuses on the development and analysis of formal systems of first and second order arithmetic, set theory and of what are known as logical frameworks (type and set theoretical, explicit, constructive, extensional, intentional). Our interests range from feasible subsystems of arithmetic to highly impredicative set and type theories and deals with the interplay between constructive, recursive and operational approaches. In addition, abstract computations and computable knowledge are being investigated.

8.3 Research Projects

Modalities in Substructural Logics: Theory, Methods and Applications

Modal logics are a family of formal systems based on classical logic which aim at improving the expressive power of the classical calculus allowing to reason about “modes of truth”. The aim of the present proposal is to put forward a systematic study of substructural modal logics, understood as those modal logics in which the modal operators are based upon the general ground of substructural logics, weaker deductive systems than classical logic. Our aim is also to explore the applications of substructural modal logics outside the bounds of mathematical logic and, in particular, in the areas of knowledge representation; legal reasoning; data privacy and security; logical analysis of natural language.

Research staff: All members of the research group

Financial support: Horizon 2020, MSCA-RISE

Explicit Reasons

This project is concerned with reasons why one believes something, reasons why one knows something, and reasons why one ought to do something. We develop formal languages in which reasons can be represented explicitly and investigate the logical properties of explicit reasons. To achieve this, we rely on the framework of justification logic. In particular, we present non-normal deontic logics with justifications. Further, we develop a semiring framework for justifications, and we engineer a possible world semantics for justifications that supports additional structure like

graded justifications or probability distributions on justifications. Moreover, we add justifications and belief dynamics to Artemov's new foundations for epistemic logic.

Research staff: M. Baur, A. Rohani, T. Studer

Financial support: Swiss National Science Foundation (No. 184625)

Proof and Model Theory of Intuitionistic Temporal Logic

Intuitionistic logic enjoys a myriad of interpretations based on computation, information or topology, making it a natural framework to reason about dynamic processes in which these phenomena play a crucial role. Yet there is a large gap to be filled regarding our understanding of the computational behaviour of intuitionistic temporal logics. The aim of this project is to cement our understanding of intuitionistic temporal logics by developing their model theory based on dynamic topological systems, and their proof theory based on prominent paradigms such as Gentzen-style calculi as well as cyclic proofs.

Research staff: L. Zenger, T. Studer

Financial support: Swiss National Science Foundation (No. 196176)

A Formal Approach to the Structure of Reasons

The general aim of this project is to investigate the structure of practical reasons, with the objective of giving a unified formal account of the aggregation and subtraction of reason content, and of partial reasons. This account will serve as the semantic backbone to construct logical systems to reason with reasons.

Research staff: F. Faroldi

Financial support: SNSF Ambizione Project (No. 201906)

Fair Blockchain

This project is concerned with developing a reliable, scalable, and secure system to eliminate opportunism in online transactions using blockchain technologies without relying on intermediaries.

Research staff: J. Luo

Financial support: UniBe Seal of Excellence (No. 2020-02)

8.4 Master's Theses

- D. Lehnherr: A Logic of Interactive Proofs
- V. Schmidt: Hyperreal Probabilistic Computational Tree Search

8.5 Bachelor's Theses

- A. Kiener: Multiversion Concurrency Control inn PostgreSQL
- S. Krättli: Ontology Mediated Query Answering
- N. Marty: CTL Model Checking – An Overview
- O. Stähli: Deep Learning in the Wild – Entwicklung eines AI-basierten, bioakustischen Wolf-Monitoring-Systems

8.6 Further Activities

Editorial Boards

Gerhard Jäger

- Member of the Editorial Board of Archive for Mathematical Logic
- Member of the Editorial Board of Logica Universalis

Thomas Studer

- Member of the Editorial Board of Springer book series on Progress in Computer Science and Applied Logic

Invited Talks

Federico Faroldi

- All-Things-Considered Ought via Reasons in Justification Logic, NMCPL, Bochum, Germany, November 2021
- Generic Reasoning, Logic(s) in Defective Science, UNILOG congress, Crete, Greece, 6-11 April, 2022

Gerhard Jäger

- An applicative perspective:universes and identities, Conference on the occasion of Pierluigi Minari's 65th birthday, Firenze, October 2021
- Gentzen in the 3- and 4-valued jungle, Proof and Computation 2022, Schlehdorf, May 2022
- The admissible extension of subsystems of second order arithmetic, logic Colloquium 2022, Reykjavik, June 2022

Thomas Studer

- A Logic of Interactive Proofs, 9th International Conference on Research and Education in Mathematics, University Putra Malaysia, online, August 2021
- Justification Logic – Introduction and Recent Developments, Tsinghua Logic Salon, online, November 2021
- A Logic of Interactive Proofs, Conference on the occasion of Pierluigi Minari's 65th birthday, Florence, October 2021
- Justification Logic – Introduction and Recent Developments, Carl Friedrich von Weizsäcker Kolloquium, Tübingen, Juni 2022

Technical and Research Committees

Federico Faroldi

- Research Ethics Board, Member, Università degli Studi dell'Insubria, Italy

Gerhard Jäger

- Member of the Scientific Council of the European Association for Computer Science Logic

Thomas Studer

- Swiss Delegate to the International Federation for Information Processing Technical Committee 1 (Foundations of Computer Science)
- Swiss Delegate to the International Union of History and Philosophy of Science and Technology
- Presidium Member of the Platform Mathematics, Astronomy and Physics of the Swiss Academy of Sciences
- Board member of the Swiss Society for Logic and Philosophy of Science
- Member of the Jury for Bernays Award
- Member of the Committee for the Promotion of Young Talents (Kommission Nachwuchsförderung) of ScNat
- Member of the Kantonale Maturitätskommission, Hauptexperte Informatik

Atefeh Rohani

- Board Member of the Swiss Graduate Society for Logic and Philosophy of Science

Organized Events

Thomas Studer

- Logic and Application, Inter University Centre Dubrovnik, 20-24 September 2021

8.7 Publications

- Michael Baur and Thomas Studer, Semirings of Evidence, Journal of Logic and Computation, 31(8):2084-2106, 2021
- Dragan Doder, Zoran Ognjanovic, Nenad Savic, and Thomas Studer, Incomplete Information and Justifications, in A. Özgün, Y. Zinova, editors, Logic, Language and Computation TbiLLC 2019, volume 13206 of LNCS, pages 258-278. Springer, 2022.
- Federico Faroldi, Meghdad Ghari, Eveline Lehmann and Thomas Studer, Consistency and Permission in Deontic JustificationLogic, Journal of Logic and Computation, in press, 2022
- Federico Faroldi, Common Law Precedent in the Logic of Reasons. In: Shahid Rahman, Matthias Armgardt, Hans Christian Nordtveit Kvernenes (eds.), New Systematic and Historic Studies in Legal Reasoning and Logic, Springer, 2022
- Federico Faroldi, Towards a Logic of Value and Disagreement via Imprecise Measures, Bulletin of the Section of Logic, 2021.
- Federico Faroldi, General AI and Transparency in the EU AI Act, i-lex, 2021
- Federico Faroldi, Mind the Gap. A Note on Expressivist Semantics. In: V. Kopsaj, Problemi di filosofia pratica 2021, Printservice Editore, Libreria CLU, Pavia, 2021
- Gerhard Jäger, Stage comparison, fixed points, and least fixed points in Kripke-Platek environments, to appear in: Notre Dame Journal of Formal Logic
- David Lehnherr, Thomas Studer, and Zoran Ognjanovic, A Logic of Interactive Proofs, in S. Artemov, A. Nerode, editors, Proceedings of Logical Foundations of Computer Science LFCS'22, volume 13137 of LNCS, pages 143-155. Springer, 2022.
- Olivier Stähli, Thomas Ost, and Thomas Studer, Development of an AI-based bioacoustic wolf monitoring system, in Proceedings of FLAIRS-35, 2022.
- Thomas Studer, The impossibility of keeping secrets, Malaysian Journal of Mathematical Sciences, 15(S):91-104, 2021

- Chao Xu, Thomas Studer, and Yanjing Wang, A Logic of Knowing Why, Synthese 198:1259-1285, 2021

9 Pattern Recognition Group

9.1 Personnel

Head:	PD Dr. K. Riesen	Tel.: +41 31 684 4998 email: kaspar.riesen@unibe.ch
Office Manager:	B. Choffat	Tel.: +41 31 631 8426 email: bettina.choffat@unibe.ch
Scientific Staff:	M. Fuchs	email: mathias.fuchs@unibe.ch
	A. Gillioz	email: anthony.gillioz@unibe.ch

9.2 Overview

The Pattern Recognition Group has been established in 2020 by Kaspar Riesen at the University of Bern. We broadly investigate algorithms and complex data structures in the field of pattern recognition and data science. In particular, the group has a strong expertise in graph based representation in intelligent information processing.
Due to fast developments in both storage media and data acquisition, we observe rapidly increasing amounts of data available in diverse areas in both science and industry. Simultaneously, we observe that in many applications the underlying data is inherently complex, making graphs the most useful and adequate data structure available to date. These two developments evoke the need for ongoing research of robust and efficient methods that assist humans in understanding and handling their pools of big sets of complex data.
The group's research is devoted to the development of novel graph based algorithms for pattern recognition and data science that actually provide feasible and robust solutions for this need.

9.3 Research Projects

Novel State-of-the-Art Graph Matching Algorithms

A large amount of graph based methods for pattern recognition and related fields have been proposed. One of these methods is *graph edit distance* – a powerful and flexible graph dissimilarity measure and actually one of the main subjects of this project. Regarding graph edit distance (or more generally graph matching) we observe two substantial gaps in research

that we aim to research and bridge. Formally, within the present project we research. . .

1. . . . encodings of matching information in a novel data structure to formalize the stable cores of specific classes by means of graphs. The rationale of this matching-graph representation is that it can be beneficial to focus on stable/important parts of graphs during algorithmic comparisons (rather than on complete graphs).

2. . . . hierarchical graph representations in conjunction with linear time graph embedding. This procedure is motivated by the fact that hierarchical representations (including fast and expressive graph embeddings) can be exploited in *filter-and-verify* strategies in order to substantially speed up and improve the matching processes.

By verifying both hypotheses we plan to make significant advances in the field of structural pattern recognition and establishing novel paradigms that go beyond the current understanding. In particular, the overall objective is the development and research of novel, robust graph edit distance methods that outperform the current state-of-the-art in graph matching on existing and novel data sets stemming from different real world scenarios. Hence, the proposed project involves both research on fundamental algorithms and solving concrete problems in applications.

Financial support: Swiss National Science Foundation Project No. 188496

Research staff: M. Fuchs, A. Gillioz, B. Fankhauser, K. Riesen

Spatio-temporal graph convolutional networks - a novel deep learning approach to forecasting river temperatures

The Federal Office for the Environment (FOEN) analyses several environmental aspects of Switzerland. The monitoring of water temperatures over long time periods belongs to one of the most important tasks of the Hydrology Division of FOEN. At the moment, the Hydrology Division maintains approximately 80 metering stations. Stations measure various parameters such as water temperature, discharge, water level etc. The sampling frequency is in most cases consistently regulated at a ten minutes interval. Although the initiation date of monitoring varies between 1971 and 2015 as more stations were installed over time, concise water data is available

over several decades. Besides the federal metering stations, the cantons of Switzerland maintain more than 700 additional stations. As is often the case in Switzerland, measurement policies vary in the different cantons. Ongoing climatic change and thereby resulting adverse effects to all lifeforms and society are a major concern in almost all countries. Since several years rising river water temperatures are being observed. Hence, several studies have been conducted to model and forecast the river temperatures. As far as we could identify none of the current studies focus on the connectivity of rivers or try to model a large part if not the entire Swiss river (water) network as a collective. We propose a novel deep learning approach to modelling the Swiss river network with a spatio-temporal graph. Spatio- temporal graphs are graph structures where the node and/or edge features are allowed to change over time. Using the temporal information of the spatial graph, temperature for a future time step can be forecasted. The key idea of graph spatial-temporal networks is to consider spatial dependency and temporal dependency simultaneously. In this project we develop novel and robust methods, algorithms, data structures, and heuristics that go beyond current understanding in graph-based machine learning on a concrete physical system that is fundamentally important to our society.

Financial support: Swiss National Science Foundation (Practice-to-Science project in collaboration with Bern University of Applied Sciences)

Research staff: B. Fankhauser, K. Riesen

9.4 Further Activities

Editorial Boards

Kaspar Riesen

- Associate editor for Pattern Recognition, 2015–, Elsevier.

Conference Program Committees

Kaspar Riesen

- Member of Program Committee for 16th International Conference on Document Analysis and Recognition ICDAR 2021

Invited Talks

Mathias Fuchs

- Augment Small Training Sets Using Matching-Graphs at ICPRAI 2022
- Graph Embedding in Vector Spaces Using Matching-Graphs at SISAP 2021

Anthony Gillioz

- Graph Reduction Neural Networks for Structural Pattern Recognition at S+SSPR 2022
- Improving Graph Classification by Means of Linear Combinations of Reduced Graphs at ICPRAM 2022
- Speeding up Graph Matching by Means of Systematic Graph Reductions Using Centrality Measures at ICPRS 2022

9.5 Publications

Journal Publications

- Mathias Fuchs, Kaspar Riesen: A novel way to formalize stable graph cores by using matching-graphs. Pattern Recognit. 131: 108846 (2022)

Refereed Conferences

- Anthony Gillioz, Kaspar Riesen: Graph Reduction Neural Networks for Structural Pattern Recognition. S+SSPR 2022
- Anthony Gillioz, Kaspar Riesen: Speeding up Graph Matching by Means of Systematic Graph Reductions Using Centrality Measures. ICPRS 2022
- Mathias Fuchs, Kaspar Riesen: Augment Small Training Sets Using Matching-Graphs. ICPRAI (2) 2022: 343-354

- Anthony Gillioz, Kaspar Riesen: Improving Graph Classification by Means of Linear Combinations of Reduced Graphs. ICPRAM 2022: 17-23
- Mathias Fuchs, Kaspar Riesen: Graph Embedding in Vector Spaces Using Matching-Graphs. SISAP 2021: 352-363
- Hans Friedrich Witschel, Kaspar Riesen, Loris Grether: Natural Language-based User Guidance for Knowledge Graph Exploration: A User Study. KDIR 2021: 95-102

10 Research Center for Digital Sustainability Group

10.1 Personnel

Head:	PD Dr. M. Stürmer*	Tel.: +41 31 684 3809 email: matthias.stuermer@unibe.ch
Office Managers:	N. Brugger*	Tel.: 41 31 684 4771 email: nathalie.brugger@inf.unibe.ch
Scientific Staff:	J. Niklaus*	email: joel.niklaus@unibe.ch
Developers:	P. Brunner*	patrick.brunner@inf.unibe.ch
	M. Buchholz*	marco.buchholz@inf.unibe.ch
	Y. Dällenbach*	yannik.daellenbach@inf.unibe.ch
	R. Gruber*	roman.gruber@inf.unibe.ch
	O. Meier*	oscar.meier@inf.unibe.ch
	A. Nardo*	alejandro.nardo@inf.unibe.ch
	M. Piu*	maurizio.piu@inf.unibe.ch
	A. Schürmann*	alec.schuermann@inf.unibe.ch
	D. Schweizer*	dominic.schweizer@inf.unibe.ch
	K. Stauffer*	kerrie.stauffer@inf.unibe.ch
	N. Thalheim*	noe.thalheim@inf.unibe.ch
	R. Widmer* *	roland.widmer@inf.unibe.ch
Other Staff:	L. Biehl*	email: lara.biehl@inf.unibe.ch
	M. Fanger*	email: maria.fanger@inf.unibe.ch
	Dr. B. Hitz-Gamper*	Tel.: +41 31 684 4712: email: benedikt.hitz@inf.unibe.ch
	A. Jörg*	email: adrian.joerg@inf.unibe.ch

10.2 Overview

Since July 1st, 2021 PD Dr. Matthias Stürmer is the head of the Institute of Public Sector Transformation in the Business School at the Bern University of Applied Sciences (BFH). He stays at the Institute for Computer Science of the University of Bern for the lecture “Digital Sustainability” and he is teaching the “Open Data” lecture of the Institute of Information Systems.

Also, the NRP77 project ”Open Justice vs. Privacy” remains at the Institute for Computer Science with the doctoral student Joel Niklaus. And Dr. Benedikt Hitz is still in charge of the programming course for non-computer science students.

10.3 Research Projects

NRP77 - Open Justice vs. Privacy

Justice should be open and transparent to ensure the public understanding of court decisions. On the other hand, each person should have the right to privacy and in particular the right to be forgotten. With this work we try to find a balance in this antagonism. The literature for anonymization of unstructured text documents is thin and for court decisions virtually nonexistent. We plan to implement an end-to-end system for anonymization and re-identification of Swiss court decisions. This system will serve as a proof of concept that both the re-identification of a large part of manually anonymized court decisions is possible and that re-identification can be made significantly harder with the automated anonymization of our system. Our system will relieve legal experts of the burdensome task of manually anonymizing court decisions. Additionally, we hope to advance the knowledge in the field of text anonymization in general which will also serve many other fields.

Research staff: J. Niklaus, M. Stürmer.

Financial support: National Research Project NRP 77 Digital Transformation, SNSF project No. 407740-187477

10.4 Further Activities

Memberships

Joel Niklaus

- Member of SwissNLP

Matthias Stürmer

- President of the Digital Impact Network

- President of CH Open
- Board Member of Opendata.ch
- Member of Smart Capital Region
- Managing Director of Parldigi (Parlamentarische Gruppe Digitale Nachhaltigkeit)

Conference and workshop organization

Matthias Stürmer

- IT-Beschaffungskonferenz 2021, conference on IT procurement, Bern, Switzerland, August 26, 2021
- DINAcon 2021, conference on digital sustainability, Bern, Switzerland, October 29, 2021

Invited Talks

Joel Niklaus

- ”Swiss-Judgment-Prediction: A Multilingual Legal Judgment Prediction Benchmark.” at the Natural Legal Language Processing Workshop 2021, Punta Cana, Dominican Republic. Association for Computational Linguistics.

Matthias Stürmer

- “Digitale Nachhaltigkeit vs. nachhaltigeDigitalisierung” 6 July 2022 within the University of Bern CAS Nachhaltige Entwicklung, module “Digitalisierung –Chancen und Risiken für eine nachhaltige Gesellschaftsentwicklung”
- “Atelier Digitalisierungspotential Programmvereinbarungen” 19 May 2022 at the “Kantonsveranstaltung Programmvereinbarungen im Umweltbereich”, Bern
- “Begriffsklärung ‘Smart City’ in Burgdorf” 16 May 2022 for the Burgdorf public administration, Burgdorf
- “Potential der Digitalisierung für die Destination Bern” 10 May 2022 at Tourism Destination Council Bern, Schwarzenburg

- “Open Source Studie Schweiz 2021” 9 May 2022 virtual presentation at BITKOM Arbeitskreis Open Source
- ”Technologische Bausteine der digitalen Transformation” 5-7 May 2022 as Module 2 within the CAS Digitale Transformation at the University of Bern
- “Künstliche Intelligenz mit der menschlichen Sprache: Möglichkeiten und Grenzen moderner Natural Language Processing (NLP) Technologien” 27 April 2022 TechTalk at the ICT Warrior Academy, Bern
- “Daten sind mehr als das neue Öl!” 7 April 2022 at the “Daten-Dialog Vol. II” forum of the Statistisches Amt Kanton Basel-Stadt, Basel
- “Grundlagen des Data Managements” and “Grundlagen von Open (Government) Data” 20 January 2022 in the module “Open Government Data Management” at University of Bern, Bern
- “Machine Learning (ML), Chatbots, Natural Language Processing (NLP) and Ethics in Artificial Intelligence” 11 December 2021 in “Emerging Technology” module of the Master in Digital Business Administration at Bern University of Applied Sciences
- “Sustainable Digitalization and the Concept of Digital Sustainability” 18 November 2021 Omics lecture “From Genomes to Metabolomes” at University of Bern
- “Digitalisierung im Bildungsbereich: Nutzen und Gefahren als Tool, Object und Subject” 13 November 2021 at “Nationales VPOD Bildungsforum”, Bern
- “History of Hackathons, Blick zurück und nach vorne” 13 November 2021 at Open Data Hackathon of Canton of Bern, Bern
- “Digitalisierungs-Strategien und Open Government Data” 11 November 2021 virtual presentation at Europa Seminar on “E-Government und Datenschutz”, University of Zürich
- “Sustainability and Digitalization: The Concept of Digital Sustainability” 5 November 2021 at Bern Sustainability Day 2021, Bern
- “Nachhaltigkeit und Digitalisierung: Zwei Trends mit Zukunft” 5 November 2021 at “Garaio REM Brainfood”, Bern

- “Nachhaltigkeit und Digitalisierung: Zwei Trends mit Zukunft” 4 November 2021 at “Kirche im Dialog”, Bern
- “Cloud Computing, Mobile Apps und Open Source Software” 28 October 2021 in “Emerging Technology” module of the Master in Digital Business Administration at Bern University of Applied Sciences
- “Open Source Software, Open Data and Digital Sustainability” 21-22 October 2021 Module “Digital Sustainability” in the Master of Science in Bioinformatics and Computational Biology at University of Bern
- “Grundlagen des Data Managements” and “Grundlagen von Open (Government) Data” 21 October 2021 in the module “Open Government Data Management” at University of Bern, Bern
- “Technische und rechtliche Grundlagen zur Digitalisierung” 14-16 October 2021 Module 2 within CAS Tourismus und Digitalisierung of University of Bern
- “Tech-Trends, Herausforderungen und Lösungsansätze” 9 September 2021 at Rochester-Bern Executive Programs “Wirksames KMU-Management”, Bern
- “Digital Sustainability” 7 September 2021 virtual presentation at Swiss Triple Impact and CH Open workshop
- “Digital Snack –Open Source” 7 September 2021 virtual presentation at BFH Wirtschaft
- “Der öffentliche Sektor und das Institut Public Sector Transformation im Wandel” 1 September 2021 at the eGov Lunch of the Institute for Public Sector Transformtation of Bern University of Applied Sciences, Bern
- “Open Government Data: Was ist OGD und was bringt‘s?” 18 August 2021 at the Open Government Data Forum Kanton Thurgau, Frauenfeld

10.5 Publications

Disclaimer: The publication list only includes publications published during the academic year, but does not include submitted and not yet published papers.

Conference Papers

- Joel Niklaus, Ilias Chalkidis, and Matthias Stürmer. 2021. Swiss-Judgment-Prediction: A Multilingual Legal Judgment Prediction Benchmark. In Proceedings of the Natural Legal Language Processing Workshop 2021, pages 19–35, Punta Cana, Dominican Republic. Association for Computational Linguistics. https://aclanthology.org/2021.nllp-1.3

- Tobias Welz, Matthias Stuermer 2021 “Monitoring Sustainable Public Procurement Behaviour – Demand-side Analysis of public tenders in Switzerland” Proceedings of the 20th European Roundtable on Sustainable Consumption and Production (erscp 2021), Graz, September 8 – 10, 2021 https://doi.org/10.3217/978-3-85125-842-4-20

11 Software Composition Group

11.1 Personnel

Head:	Prof. Dr. O. Nierstrasz	Tel: +41 31 631 46 18 email: oscar.nierstrasz@unibe.ch (until 31.12.2021)
Office Managers:	B. Choffat	Tel: +41 31 631 46 92 email: bettina.choffat@unibe.ch
Scientific Staff:	P. Gadient	email: pascal.gadient@unibe.ch (until 31.12.2021)
	M. Hazhirpasand*	email:mohammadreza.hazhirpasand @unibe.ch (until 31.12.2021)
	N. Patkar*	email: nitish.patkar@unibe.ch (until 28.02.2022)
	P. Rani*	email: pooja.rani@unibe.ch (until 31.12.2021)
	Dr. N. Stulova	email: nataliia.stulova@unibe.ch (until 31.12.2021)

11.2 Overview

Software systems that are used in practice must evolve over time to maintain their relevance, yet as systems evolve, they become more complex and harder to maintain. The Software Composition Group carries out research into tools, techniques and programming language mechanisms to enable the graceful evolution of complex software systems.
The research group concluded its official activities at the end of 2021 with the retirement of Prof. Nierstrasz.

11.3 Research Projects

Agile Software Assistance

Research staff: All members of the research group.
Duration: Feb 1, 2019 – Apr. 30, 2022
Financial support: SNSF project #200020-181973

- **Speculative software analysis.** Developers use code comments to understand and maintain programs. Given the unstructured nature of comments and the existence of multiple standards, developers become confused about which conventions to follow while writing comments. They therefore post questions related to comment conventions on Q&A platforms such as Stack Overflow, or Quora. We investigated these sources to gain insight into the challenges developers face. We formed a taxonomy of challenges they face and also collected the recommendations experts provided to resolve the challenges. The taxonomy can help tool developers and researchers to identify the gaps in the current tools, and help them design future tools to satisfy developer information needs. Knowing that developers become confused about comment conventions, we dived deeper into developer commenting practices regarding comment conventions. In our subsequent work, we explored the adherence of Smalltalk comments to the commenting conventions. We extended the study to Java and Python. In particular, we analyzed numerous coding style guidelines and open-source projects to see the extent to which developers follow these guidelines in writing code comments. As a result, we highlighted the aspects of comments that are not well covered by the style guidelines. With this mismatch between style guidelines and commenting practices of developers, it is important to check existing quality tools to verify the mismatch. We extracted popular linters of Java and Python. We then ran on 100 projects of both languages to see how they are used in practice. Based on the achieved results, we are experimenting on extending linters for unsupported comment conventions.

- **Executable domain models.** To facilitate non-technical stakeholder participation in software engineering activities, such as requirements engineering and software modeling, an appropriate methodology and corresponding tools must be developed. A traditional round-trip engineering approach based on model transformations does not scale well to modern agile development environments where numerous artifacts are produced using a range of heterogeneous tools and technologies. To boost artifact connectivity and maintain their consistency, we proposed to create and manage software-related artifacts as first-class entities directly in an integrated development environment (IDE). We exemplified our approach in the Glamorous Toolkit IDE, and discussed the results of a semi-structured pilot survey we conducted with practitioners and researchers to evaluate its useful-

ness in practice.

With behavior-driven development (BDD), domain experts describe system behavior and desired outcomes through natural language-like sentences, *e.g.*, using the Gherkin language. There is no empirical evidence about the actual usage of these Gherkin features. To fill this gap, we analyzed the content of 1,572 spec files extracted from 23 open-source projects. Our results shed some light on the discrepancies between the recommendations for defining Gherkin specifications and their actual adoption in practice.

To further improve the existing BDD support, we proposed an alternative approach to specify and verify application behavior visually, interactively, and collaboratively within an IDE. Instead of writing textual scenarios, non-technical stakeholders compose, edit, and save scenarios by using tailored graphical interfaces that allow them to manipulate involved domain objects.

- **Domain-specific software quality.** We advanced the understanding of *Security Smells* in mobile apps, *i.e.*, we completed the empirical study by investigating the prevalence of security smells in servers used by Android mobile apps and in the HTTP headers of their web communication. That is, we analyzed the prevalence of six security smells in app servers and investigated the consequence of these smells from a security perspective. We used an existing dataset that includes 9 714 distinct URLs that were used in 3 376 Android mobile apps. We exercised the URLs twice over fourteen months, and stored the HTTP headers and bodies. We realized that the top three smells exist in more than 69% of all tested apps, and that unprotected communication and server misconfigurations are very common. Particularly alarming is the finding that apps using JSON app servers suffer 1.5 times more from app server security smells than non-JSON apps, and even worse, closed-source applications suffer 1.6 times more compared to open-source applications. Moreover, source-code and version leaks, or the lack of update policies foster future attacks against these data centric systems. We found that app server security smells are omnipresent and they indicate poor app server maintenance. Moreover, we discovered that, on average, 93% of the security-related headers are not used in server responses, indicating great potential for future improvements. We also found that unlike major web browsers, the support for such fields in HTTP client libraries is very limited, and that server responses for mobile apps

frequently lack them. We encourage a more comprehensive use of existing HTTP headers and timely development of relevant web browser security features in HTTP client libraries.

We further started to explore the creation of phishing websites since some security smells can enable phishing attacks where an adversary spoofs a website to gain personal data from a victim. Such sites often require expensive manual work even with the help of tools, and therefore scammers are primarily attracted by major international websites with a large reach. In consequence, IT professionals do not have access to an effective tool to raise the awareness of phishing in their companies, and moreover, people seem to underestimate the potential phishing threat from local sites. To address this problem, we developed a prototype that can dynamically mimic websites by using enriched screenshots, which requires no additional programming experience and is simple to set up. We found that 98% of the hyperlinks in mimicked websites are functional with our tool, compared to 43% with the best competitor. Moreover, only 29% of the page visits from fourteen participants were considered as suspicious, and only two participants suspected phishing attempts at the time they were performing their tasks. We believe that our open-sourced tool has value for different stakeholders, and that this threat requires more attention, especially when considering the emerging ultra-broadband network technologies, *i.e.*, fiber landline and 5G cellular networks.

In other work, we developed an automated pipeline, FuzzingDriver, to create efficient, noise-free dictionaries for coverage-based greybox fuzzers (CGF). FuzzingDriver does not augment any overhead to the fuzzing job as it is run beforehand. Fuzzing six open-source targets, our findings showed that using FuzzingDriver's dictionaries can outperform Google dictionaries.

Analyzing 150 security-related posts, we aimed for an investigation on API-level to further clarify developers' obstacles in using Java symmetric-related APIs. The results revealed that the generation of parameters (e.g., keys) or instantiating a Cipher object (e.g., specifying encryption mode) are the main two issues faced by developers. The identified risks in using such APIs were mainly related to the use of unsafe encryption modes and constant/static values as a key or initialization vector.

We analyzed crypto-related vulnerability reports on the HackerOne platform to discover what types of crypto flaws exist in practice. We

extracted eight themes in the reports and suggested the proper mitigation strategies. The SSL-related attacks theme had the highest number of reports among the themes.

We surveyed the top 1% of crypto responders on Stack Overflow. The participants were asked to provide us with why inexperienced developers fail using cryptography correctly, and what resources might help such developers or crypto designers. These developers mentioned 36 crypto hurdles, e.g., validating certificate chains, and the root causes, e.g., outdated tutorials, indicating why cryptography is difficult for developers. Furthermore, they recommended 29 ways in which cryptography can be facilitated for developers as well as crypto designers, such as employing misuse-resistant crypto libraries.

We analyzed 500 posts from 20 crypto libraries on Stack Overflow. We found various complicated areas that are shared among the crypto libraries, such as sign/verification, working with modes of encryption, IV, and salt. The majority of posts (112) were about encryption/decryption problems and 111 were about installation/compilation issues of crypto libraries.

For further details, please consult:
`http://scg.unibe.ch/asa3`

11.4 Ph.D. Theses

- Pascal Gadient. *The Dilemma of Security Smells and How to Escape It*. PhD thesis, University of Bern, May 2022. URL: `http://scg.unibe.ch/archive/phd/Gadi22a.pdf`.
- Mohammadreza Hazhirpasand. *The Bumpy Relationship of Developers and Cryptography*. PhD thesis, University of Bern, May 2022. URL: `http://scg.unibe.ch/archive/phd/Hazh22a.pdf`.
- Nitish Patkar. *Supporting Multiple Stakeholders in Agile Development*. PhD thesis, University of Bern, March 2022. URL: `http://scg.unibe.ch/archive/phd/patkar-phd.pdf`.
- Pooja Rani. *Assessing Comment Quality in Object-Oriented Languages*. PhD thesis, University of Bern, January 2022. URL: `http://scg.unibe.ch/archive/phd/rani-phd.pdf`.

11.5 Master's Theses

- Christian Zürcher. BString: A string-based framework to improve application security. Masters thesis, University of Bern, February 2022. URL: http://scg.unibe.ch/archive/masters/Zuer22a-BString.pdf.

11.6 Bachelor's Theses and Computer Science Projects

- Suada Abukar. Adherence of class comments to style guidelines. Bachelor's thesis, University of Bern, August 2021. URL: http://scg.unibe.ch/archive/projects/Abuk21a.pdf.

- Pascal André. WebAssembly security – what security-related questions do developers discuss about WebAssembly? Bachelor's thesis, University of Bern, December 2021. URL: http://scg.unibe.ch/archive/projects-LOCAL/Andr21a.pdf.

- Dominik Briner. Developer tool support for security code smells. Bachelor's thesis, University of Bern, August 2021. URL: http://scg.unibe.ch/archive/projects/Brin21a.pdf.

- Sophie Gabriela Pfister. Jenny in wonderland — exploring the difficulties of symmetric encryption. Bachelor's thesis, University of Bern, December 2021. URL: http://scg.unibe.ch/archive/projects-LOCAL/Pfis21a.pdf.

- Cyrill J. Rohrbach. Implementing Mondrian in Glamorous Toolkit. Bachelor's thesis, University of Bern, September 2021. URL: http://scg.unibe.ch/archive/projects/Rohr21a.pdf.

- Artthik Sellathurai. Increasing stakeholder engagement with object cards. Bachelor's thesis, University of Bern, March 2022. URL: http://scg.unibe.ch/archive/projects/Sell22a.pdf.

11.7 Awards

- Faculty Prize for Patrick Frischknecht's MSc thesis, Detection of Cybersquatted Domains

11.8 Further Activities

Editorial Boards and Steering Committees

Oscar Nierstrasz

- AITO — Association Internationale pour les Technologies Objets (Member)
- JOT — Journal of Object Technology (Steering Committee Member)

Reviewing Activities

Oscar Nierstrasz

- Information and Software Technology
- Software Quality Journal

Pascal Gadient

- PeerJ Journal

Pooja Rani

- Information and Software Technology
- ACM TOSEM

11.9 Publications

Journal Papers

- Arianna Blasi, Nataliia Stulova, Alessandra Gorla, and Oscar Nierstrasz. RepliComment: identifying clones in code comments. *Journal of Systems & Software*, page 111069, 2021. URL: `http://scg.unibe.ch/archive/papers/Blas21a-RepliComment.pdf`, `doi:10.1016/j.jss.2021.111069`.

Conference Papers

- Arash Ale Ebrahim, Mohammadreza Hazhirpasand, Oscar Nierstrasz, and Mohammad Ghafari. FuzzingDriver: the missing dictionary to increase code coverage in fuzzers. In *29th edition of the IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER)*, March 2022. URL: `http://scg.unibe.ch/archive/papers/Ebra22a.pdf`, `doi:10.1109/SANER53432.2022.00042`.

- Pascal Gadient, Pascal Gerig, Oscar Nierstrasz, and Mohammad Ghafari. Phish what you wish. In *21st IEEE International Conference on Software Quality, Reliability, and Security (QRS)*, December 2021. URL: `http://scg.unibe.ch/archive/papers/Gadi21b.pdf`, `doi:10.1109/QRS54544.2021.00113`.

- Pascal Gadient, Oscar Nierstrasz, and Mohammad Ghafari. Security header fields in HTTP clients. In *21st IEEE International Conference on Software Quality, Reliability, and Security (QRS)*, December 2021. URL: `http://scg.unibe.ch/archive/papers/Gadi21c.pdf`, `doi:10.1109/QRS54544.2021.00020`.

- Pascal Gadient, Marc-Andrea Tarnutzer, Oscar Nierstrasz, and Mohammad Ghafari. Security smells pervade mobile app servers. In *ACM / IEEE International Symposium on Empirical Software Engineering and Measurement (ESEM)*, October 2021. URL: `http://scg.unibe.ch/archive/papers/Gadi21a.pdf`, `doi:10.1145/3475716.3475780`.

- Mohammadreza Hazhirpasand and Mohammad Ghafari. Cryptography vulnerabilities on HackerOne. In *21st IEEE International Conference on Software Quality, Reliability, and Security (QRS)*, pages 18–27, December 2021. URL: `http://scg.unibe.ch/archive/papers/Hazh21f.pdf`, `doi:10.1109/QRS54544.2021.00013`.

- Mohammadreza Hazhirpasand, Mohammad Ghafari, and Oscar Nierstrasz. Crypto experts advise what they adopt. In *2021 36th IEEE/ACM International Conference on Automated Software Engineering Workshops (ASEW)*, pages 179–184, 2021. URL: `http://scg.unibe.ch/archive/papers/Hazh21e.pdf`, `doi:10.1109/ASEW52652.2021.00044`.

- Mohammadreza Hazhirpasand, Mohammad Ghafari, and Oscar Nierstrasz. Worrisome patterns in developers: A survey in cryptography. In *2021 36th IEEE/ACM International Conference on Automated Software Engineering Workshops (ASEW)*, pages 185–190, 2021. URL: http://scg.unibe.ch/archive/papers/Hazh21d.pdf, doi:10.1109/ASEW52652.2021.00045.

- Mohammadreza Hazhirpasand, Oscar Nierstrasz, and Mohammad Ghafari. Dazed and confused: What's wrong with crypto libraries? In *2021 18th International Conference on Privacy, Security and Trust (PST)*, pages 1–6, 2021. URL: http://scg.unibe.ch/archive/papers/Hazh21b.pdf, doi:10.1109/PST52912.2021.9647786.

- Mohammadreza Hazhirpasand, Oscar Nierstrasz, Mohammadhossein Shabani, and Mohammad Ghafari. Hurdles for developers in cryptography. In *2021 IEEE International Conference on Software Maintenance and Evolution (ICSME)*, pages 659–663, 2021. URL: http://scg.unibe.ch/archive/papers/Hazh21c.pdf, doi:10.1109/ICSME52107.2021.00076.

- Nitish Patkar, Andrei Chis, Nataliia Stulova, and Oscar Nierstrasz. Interactive behavior-driven development: a low-code perspective. In *Proceedings of the 24rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings*. ACM, 2021. URL: http://scg.unibe.ch/archive/papers/Patk21a.pdf, doi:10.1109/MODELS-C53483.2021.00024.

- Nitish Patkar, Andrei Chis, Nataliia Stulova, and Oscar Nierstrasz. First-class artifacts as building blocks for live in-IDE documentation. In *2022 IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER)*. IEEE, 2022. URL: http://scg.unibe.ch/archive/papers/Patk22a.pdf, doi:10.1109/SANER53432.2022.00016.

- Pooja Rani, Suada Abukar, Nataliia Stulova, Alexander Bergel, and Oscar Nierstrasz. Do comments follow commenting conventions? A case study in Java and Python. In *2021 IEEE 21st International Working Conference on Source Code Analysis and Manipulation (SCAM)*, 2021. URL: http://scg.unibe.ch/archive/papers/Rani21f.pdf, arXiv:2108.10766, doi:10.1109/SCAM52516.2021.00028.

- Pooja Rani, Mathias Birrer, Sebastiano Panichella, Mohammad Ghafari, and Oscar Nierstrasz. What do developers discuss about code comments? In *2021 IEEE 21st International Working Conference on Source Code Analysis and Manipulation (SCAM)*, 2021. URL: http://scg.unibe.ch/archive/papers/Rani21e.pdf, arXiv:2108.07648, doi:10.1109/SCAM52516.2021.00027.

Workshop Papers

- Adwait Chandorkar, Nitish Patkar, Andrea Di Sorbo, and Oscar Nierstrasz. An exploratory study on the usage of Gherkin features in open-source projects. In *5th Workshop on Validation, Analysis and Evolution of Software Tests (VST 2022, co-located with SANER 2022)*. IEEE, March 2022. URL: http://scg.unibe.ch/archive/papers/Patk22b.pdf, doi:10.1109/SANER53432.2022.00134.

- Pooja Rani, Alexandre Bergel, Lino Hess, Timo Kehrer, and Oscar Nierstrasz. Can we automatically generate class comments in Pharo? In *IWST'22: Proceedings of International Workshop on Smalltalk Technologies*, 2022. URL: http://scg.unibe.ch/archive/papers/Rani22b.pdf.

12 Software Engineering Group

12.1 Personnel

Head:	Prof. Dr. T. Kehrer	Tel:	+41 31 684 4618
		email:	timo.kehrer@unibe.ch (as of 01.01.2022)
Office Managers:	B. Choffat	Tel:	+41 31 684 8426
		email:	bettina.choffat@unibe.ch
Scientific Staff:	Dr. P. Rani	email:	pooja.rani@unibe.ch (as of 01.02.2022)
	Dr. PD C. Tsigkanos	email:	christos.tsigkanos@unibe.ch (as of 15.01.2022)
	A. Boll	Tel:	+41 77 485 3930
		email:	alexander.boll@unibe.ch (as of 01.01.2022)
	M. Ohrndorf	email:	mohrndorf@informatik.uni-siegen.de (as of 01.07.2022)
	P. V. Toledo	email:	Pablo.valenzuela@unibe.ch (as of 01.07.2022)

12.2 Overview

Modern societies, economies, industries and sciences generate an ever-increasing demand for software. This software shall be of high quality, long-living and flexible, while software development itself is faced with frequently changing requirements and limited resources.

The mission of the Software Engineering Group is to tackle these major challenges through research and teaching in software engineering, the discipline that fosters the application of systematic engineering principles to the development, operation and maintenance of software. We aim at understanding the problems and challenges that software developers are faced with in oftentimes highly interdisciplinary environments, and at devising novel software engineering methods, techniques and tools addressing their needs.

The group has been established in January 2022 and dedicates itself to contribute its research results to the scientific discourse on software engineering, to transfer its knowledge to practitioners and computational scientists, and to contribute to the education of the next generation of software

engineers for the future.

12.3 Research Projects

VariantSync: Automating the Synchronisation of Software Variants

Research staff: Alexander Schultheiß, Timo Kehrer
Duration: 2019 – 2023
Financial support: DFG project KE 2267/1-1

Today's software is often released in multiple variants to meet all customer requirements. Software product lines have the potential to decrease development costs and time-to-market, and have been actively researched for more than two decades. Nevertheless, practitioners frequently rely on ad-hoc reuse based on a principle which is known as clone-and-own, where new variants of a software family are created by copying and adapting an existing variant. However, if a critical number of variants is reached, their maintenance and evolution becomes impractical, if not impossible, and the migration to a product line is often infeasible.
With the research conducted in *VariantSync*, we aim to enable a fundamentally new development approach which bridges the gap between clone-and-own and product lines, combining the minimal overhead of clone-and-own with the systematic handling of variability of software product lines in a highly flexible methodology. The key idea is to transparently integrate the central product-line concept of a feature with variant management facilities known from version control systems in order to automatically synchronize a set of evolving variants. Lifting the underlying techniques employed by version control systems to the abstraction level of features which are shared among variants is an open problem and the main research challenge addressed in *VariantSync*. We believe that our research results have the potential to effectively change the way how practitioners will develop multi-variant software systems for which it is hard to foresee which variants will be added or released in the future.

FONDA: Foundations of Workflows for Large-Scale Scientific Data Analysis

Research staff: Anh Duc Vu*, Christos Tsigkanos, Timo Kehrer

Duration: 2020 – 2024
Financial support: DFG Collaborative Research Center 1404

Essentially all scientific disciplines are generating an ever-increasing amount of data. To derive scientific discoveries, these data sets are analyzed by complex data analysis workflows (DAWs), which are series of discrete analysis programs arranged in (often non-linear) pipelines. Because they usually deal with very large data sets, DAWs must be executed on distributed and/or parallel computational infrastructures. Traditionally, DAWs are optimized for speed, which leads to solutions that are hard to reproduce and share and that are tightly bound to exactly one type of input. However, as stated as summary in a recent NSF/DOE workshop that brought together the workflow and the HPC communities, "... human productivity arguably still is the most expensive resource, trumping power, performance, and other factors ...".
The Collaborative Research Center FONDA takes up this observation and investigate methods for increasing productivity in the development, execution, and maintenance of DAWs for large scientific data sets. Our long-term goal is to develop methods and tools that achieve substantial reductions in development time and development cost of DAWs. We will approach these questions from a fundamental perspective, i.e., we aim at finding new abstractions, models, and algorithms that can eventually form the basis of a new class of future DAW infrastructures. Toward these goals, FONDA in its first focuses on three critical properties of DAWs and of DAW engines, namely portability, adaptability, and dependability (PAD). We want to investigate answers to questions such as: How can we build DAWs and DAW engines that enable portability of analysis across different infrastructures? How must DAWs be designed to adapt to changing input data or slightly changing requirements? How can we build dependable DAW systems that are aware of and control their own limitations and preconditions?

12.4 Activities

Scientific Boards and Steering Committees

Timo Kehrer

- GReTA — International Seminar Series on Graph Transformation Theory and Applications

- VariVolution — International Workshop on Variability and Evolution of Software-Intensive Systems

Pooja Rani

- Board Member of CHOOSE (Swiss Group for Software Engineering, special interest group of the Swiss Informatics Society

Program Committees

Timo Kehrer

- 44th IEEE/ACM International Conference on Software Engineering (ICSE), New Ideas and Emerging Results, 2022
- 25th ACM / IEEE International Conference on Model Driven Engineering Languages and Systems (MODELS), 2022
- 15th International Conference on Graph Transformation (ICGT), 2022
- 22nd IEEE International Working Conference on Source Code Analysis and Manipulation (SCAM), 2022
- International Workshop on Software Engineering for eScience (SE4eScience), 2022
- International Workshop on Software Engineering for Computational Science (SE4Science), 2022

Pooja Rani

- International Workshop on Natural Language Based Software Engineering (NLBSE) 2022

Christos Tsigkanos

- IEEE International Conference on Web Services (ICWS) 2022
- European Conference on Software Architecture (ECSA) Tools 2022
- Foundations of Software Engineering (ESEC/FSE) 2022 Tutorials
- International Symposium on Software Engineering for Adaptive and Self-Managing Systems (SEAMS) 2022
- European Conference and Service-Oriented and Cloud Computing (ESOCC) 2022

Reviewing Activities

Timo Kehrer

- Transactions on Software Engineering
- Journal of Systems and Software
- Science of Computer Programming
- Information and Software Technology
- Software and Systems Modeling
- Journal of Software: Evolution and Process

Pooja Rani

- Transactions on Software Engineering and Methodology (TOSEM)
- Information and Software Technology (IST)
- International Conference on Computational Science (ICCS) 2022

Christos Tsigkanos

- Transactions on Software Engineering (TSE)
- Transactions on Autonomous and Adaptive Systems
- Science of Computer Programming

Other Memberships

Pooja Rani

- Mentor in Womentoring program of SUB (Studierendenschaft der Universität Bern)

Presentations

Pooja Rani

- Poster Presentation ”What do class comment tells us? An investigation of comment evolution and practices in Pharo Smalltalk”, ICSE: International Conference on Software Engineering 2022, Pittsburgh, United States, 2022.
- Invited talk, ”Decoding developer commenting practices,” University of Zurich, Switzerland, 2022.

Awards

- Best research paper award at the International Workshop on Smalltalk Technologies, Novi Sad, Serbia, for the paper *Pooja Rani, Alexandre Bergel, Lino Hess, Timo Kehrer and Oscar Nierstrasz: Can We Automatically Generate Class Comments in Pharo?*

12.5 Publications

Edited Volumes

- Fabio Gadducci, Timo Kehrer. Special issue on Theoretical Topics in Graph Transformation. Theoretical Computer Science 931: 155-156, 2022.

Journal Papers

- L. Beurer-Kellner, J. v. Pilgrim, C. Tsigkanos, T. Kehrer. A Transformational Approach to Managing Data Model Evolution of Web Services. IEEE Transactions on Services Computing, 2022.

- Sofia Ananieva, Sandra Greiner, Timo Kehrer, Jacob Krüger, Thomas Kühn, Lukas Linsbauer, Sten Grüner, Anne Koziolek, Henrik Lönn, S. Ramesh, Ralf H. Reussner. A conceptual model for unifying variability in space and time: Rationale, validation, and illustrative applications. Empirical Software Engineering 27(5): 101, 2022.

- Laura Wartschinski, Yannic Noller, Thomas Vogel, Timo Kehrer, Lars Grunske. VUDENC: Vulnerability Detection with Deep Learning on a Natural Codebase for Python. Information and Software Technology 144: 106809, 2022.

- Stefan Höppner, Timo Kehrer, Matthias Tichy. Contrasting dedicated model transformation languages versus general purpose languages: a historical perspective on ATL versus Java based on complexity and size. Software and Systems Modeling 21(2): 805-837, 2022.

- A. Boll, N. Vieregg, T. Kehrer. Replicability of experimental tool evaluations in model-based software and systems engineering with MATLAB/Simulink. Innovations in Systems and Software Engineering, 1-16, 2022.

Conference Papers

- A. Vu, T. Kehrer and C. Tsigkanos. Outcome-Preserving Input Reduction for Scientific Data Analysis Workflows. Automated Software Engineering (ASE) New Ideas and Emerging Results, 2022.
- E. Visconti, C. Tsigkanos, and L. Nenzi. WebMonitor. Verification of Web User Interfaces. Automated Software Engineering (ASE) Demo Track, 2022.
- Alexander Schultheiß, Paul Maximilian Bittner, Sascha El-Sharkawy, Thomas Thüm, Timo Kehrer. Simulating the Evolution of Clone-and-Own Projects with VEVOS. International Conference on Evaluation and Assessment in Software Engineering (EASE), 2022.
- Sofia Ananieva, Sandra Greiner, Jacob Krüger, Lukas Linsbauer, Sten Grüner, Timo Kehrer, Thomas Kühn, Christoph Seidl, Ralf H. Reussner. Unified Operations for Variability in Space and Time. International Working Conference on Variability Modelling of Software-Intensive Systems (VaMoS), 2022.
- Paul Maximilian Bittner, Alexander Schultheiß, Thomas Thüm, Timo Kehrer, Jeffrey M. Young, Lukas Linsbauer. Feature Trace Recording - Summary. Software Engineering (SE), 2022.
- Stefan Höppner, Timo Kehrer, Matthias Tichy. Contrasting Dedicated Model Transformation Languages vs. General Purpose Languages: A Historical Perspective on ATL vs. Java based on Complexity and Size - Extended Abstract. Software Engineering (SE), 2022.
- Alexander Schultheiß, Paul Maximilian Bittner, Thomas Thüm, Timo Kehrer. Scalable N-Way Model Matching Using Multi-Dimensional Search Trees - Summary. Software Engineering (SE), 2022.

Workshop Papers

- Pooja Rani, Alexandre Bergel, Lino Hess, Timo Kehrer, and Oscar Nierstrasz. Can we automatically generate class comments in Pharo? In *IWST'22: Proceedings of International Workshop on Smalltalk Technologies*, 2022.

13 Administration

University:

D. Bommes:	Member of the Research Commission (Forschungskommission)
T. Studer:	Member of *Kantonale Maturitätskommission*

Faculty:

D. Bommes:	Joint Master in Computer Science of the Universities of Bern, Fribourg and Neuchâtel: President of the Branch Committee (as of October 2021) Member of the Strategy Board Faculty delegate (as of October 2021)
P. Favaro:	Member of the BeDSI (Bern Data Science Initiative) Member of the SciIT in Data Science (CAS Program Management)
T. Kehrer:	Member of the Strategy Board Deputy Faculty delegate (as of April 2022)
O. Nierstrasz:	Member Digitalization Strategy Working Group (until September 2021) Faculty contact person for digitalization (until September 2021)
T. Studer:	Member of the Strategy Board Representative of high Mittelbau in faculty meetings

Institute:

D. Bommes:	Director of Studies
C. Cachin:	Deputy Director of Studies Member of Library Committee on behalf of INF Representative to CUSO Doctoral School in Computer Science Managing Director of INF (01.02. – 31.07.2022) Member of Hauskommission Engehalde (as of January 2022)
P. Favaro:	Managing Director of INF (until 31.01.2022 and as of 01.08.2022)

O. Nierstrasz:	Deputy Director of INF (until December 2021) Member of Hauskommission Engehalde (until December 2021)
T. Studer:	Member of Hauskommission Exakte Wissenschaften