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Institut für Informatik
Universität Bern

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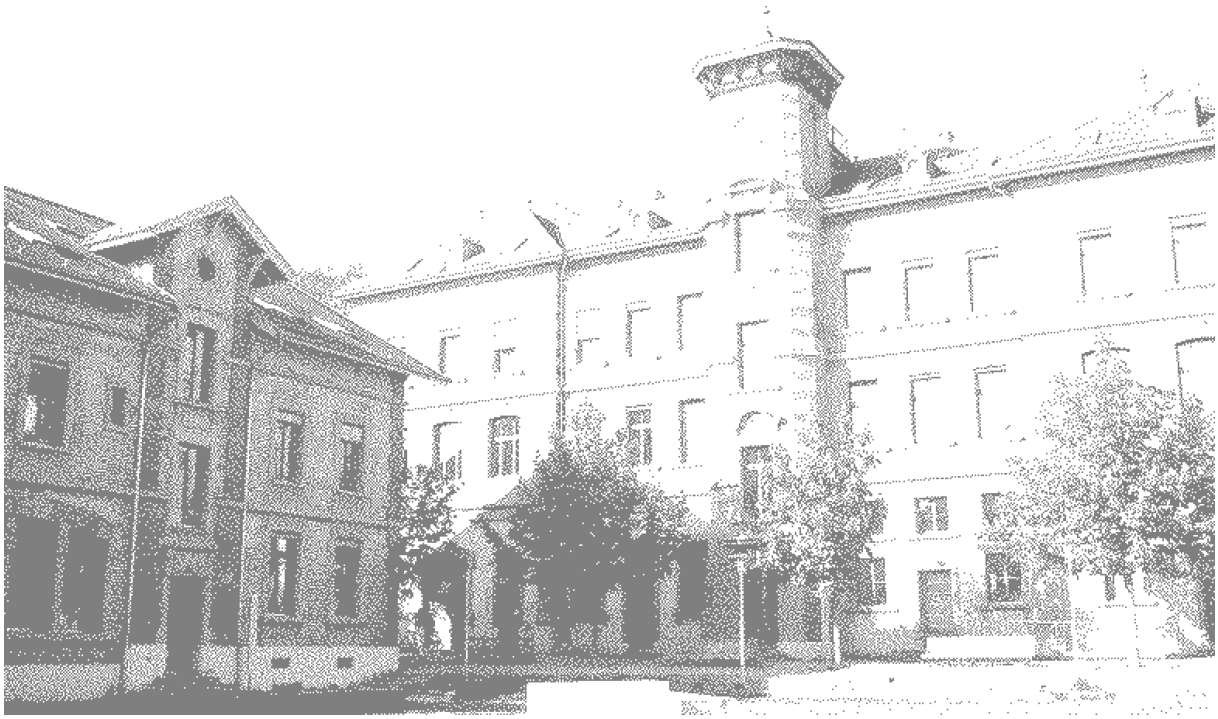
INF Annual Report 2022/23



INF Annual Report

Academic Year 2022/2023

September 21, 2023

Contents

1 Institute of Computer Science (INF)

1.1 Address

Neubrückstrasse 10, 3012 Bern, Switzerland
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http://www.inf.unibe.ch

1.2 Personnel

Members

Florence Aellen, Jesutofunmi Ajayi, Sigurd Alnes, Orestis Alpos, Dr. Jayamine Alupotha, Ignacio Amores Sesar, Mariarosaria Barbaraci, Michael Baur, Dr. Pierre-Alexandre Beaufort, Michal Bechny, Alexander Boll, Prof. Dr. David Bommes, Dr. Peppo Brambilla, Prof. Dr. Torsten Braun, Prof. Dr. Christian Cachin, Llukman Cerkezi, Hamadi Chihaoui, Bettina Choffat, Riccardo Cusinato, Aram Davtyan, Yihan Deng, Lucas De Sousa Pacheco, Dr. Antonio Di Maio, Negar Emami, Dr. Federico Faroldi, Prof. Dr. Paolo Favaro, Mathias Fuchs, Chuyang Gao, Dr. Sebati Ghosh, Anthony Gillioz, Pinar Göktepe, Dr. Sandra Greiner, Priska Grunder, Dragana Heinzen, Martin Heistermann, Dr. Benedikt Hitz-Gamper, Mária Hrabošovà, Dr. Linlin Jia, 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, Hugo Melo dos Santos, Dr. Camille Mignardot, Jovana Mićić, Alejandro Nardo, Valentin Nigolian, Joël Niklaus, Natalia Norori, Dr. Manuel Ohrndorf, Diego Oliveira Rodrigues, Simone Raimondi, Pooja Rani, PD Dr. Kaspar Riesen, Atefeh Rohani, Dr. Thomas Rusterholz, Sepehr Sameni, Eric Samikwa, Alp Eren Sari, Dr. Philippe Schneider, Michael Senn, Viktor Shipitsin, Dr. Thomas Studer, PD Dr. Matthias Stürmer, Radoslava Svihrova, Dr. Aylin Tastan, Dr. Ruxandra Tivadar, Dr. Christos Tsigkanos, Prof. Dr. Athina Tzovara, Pablo Valenzuela Toledo, François-Xavier Wicht, Dimitrios Xenakis, Hexu Xing, Luca Zanolini, Lukas Zenger

Administration

Bettina Choffat, Priska Grunder, Dragana Heinzen

Technical staff

Orestis Alpos, Dr. Peppo Brambilla, Martin Heistermann

2 Teaching Activities

2.1 Courses for Major and Minor in Computer Science

Autumn Semester 2022

Bachelor 1st Semester

Diskrete Mathematik (C. Cachin, 5 ECTS)

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

Programmierung 1 (K. Riesen, 5 ECTS)

Bachelor 3rd Semester

Computernetze (T. Braun, 5 ECTS)

Einführung in Software Engineering (T. Kehrer, 5 ECTS)

Digitale Nachhaltigkeit (M. Stürmer, 5 ECTS)

Bachelor 5th Semester

Computergrafik (D. Bommes, 5 ECTS)

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

Machine Learning (P. Favaro, 5 ECTS)

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

Master Courses

Software Product Lines (T. Kehrer, 5 ECTS)

Advanced Networking and Future Internet (T. Braun, 5 ECTS)

Justification Logic (T. Studer, 5 ECTS)

Computer Vision (P. Favaro, 5 ECTS)

Applied Optimization (D. Bommes, 5 ECTS)
Cryptography (C. Cachin, 5 ECTS)

Seminars (each 5 ECTS)

Seminar: Software Engineering (T. Kehrer)
Seminar: Communication and Distributed Systems (T. Braun)
Seminar: Logic and Theoretical Computer Science (T. Studer)
Seminar: Machine Learning and Artificial Intelligence (P. Favaro)
Seminar: Computer Graphics & Geometry Processing (D. Bommes)
Seminar: Cryptology and Data Security (C. Cachin, P. Liniger)
Seminar: Pattern Recognition (K. Riesen)

Service Courses (each 3 ECTS)

Programmieren für Naturwissenschaften (K. Riesen)
Programmieren für Naturwissenschaften (Biologie) (P. Liniger)
Grundkurs Programmieren (B. Hitz-Gamper, M. Stürmer)

Spring Semester 2023

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

Internet of Things (T. Braun, 5 ECTS)

Deep Learning (P. Favaro, 5 ECTS)

Cryptography Protocols (C. Cachin, 5 ECTS)

Graph-Based Pattern Recognition (K. Riesen, 5 ECTS)

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

Compiler Construction (T. Kehrer, 5 ECTS)

Seminars (each 5 ECTS)

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

Seminar: Communication and Distributed Systems (T. Braun)

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

Seminar: Applied Optimization (D. Bommes)

Seminar: Cryptology and Data Security (C. Cachin)

Seminar: Privaterecht und Informatik: Distributed Trust and Blockchain (C. Cachin, M. Eggen)

Seminar: Software Engineering (T. Kehrer)

Seminar: Quantum Mobile Networks (A. Di Maio)

Seminar: Pattern Recognition (K. Riesen)

Service Courses (each 3 ECTS)

Programmieren für Naturwissenschaften (K. Riesen)

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

2.2 Students

Major Subject Students: AS 2022: 310 SS 2022: 282

Minor Subject Students: AS 2022: 184 SS 2023: 169

Ph.D. Candidates: AS 2022: 57 SS 2023: 60

2.3 Degrees and Examinations

PhD: 6

Master: 23

Bachelor: 19

Completion of Minor Studies: 31 (90E:0, 60E:8, 30E:12, 15E:6, 930 ECTS)

Semester Examinations AS 2022: 1117 (3953 ECTS)

Bachelor's/Master's Theses AS 2022: 17 (230 ECTS)

Semester Examinations FS 2023: 673 (2502 ECTS)

Bachelor's/Masters Theses FS 2023: 15 (230 ECTS)

2.4 Activities

Contribution to the "Studies Orientation Day", Bern, September 16, 2022

Contribution to the "National Future Day for Girls and Boys", Bern, November 10, 2022

Contribution to the "Bachelor Infotage", December 6+7, 2022 (semihybrid)

Contribution to the "MINT-Day" for Middle school students, Bern, March, 7, 2023

Contribution to the “Master Infotage”, March 22 + 23, 2023

Finals of the Swiss Olympiad in Informatics, May 26 + 27, 2023

3 Cognitive Computational Neuroscience Group

3.1 Personnel

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	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 techniques to record neural activity in humans, in combination with machine learning

techniques, to study neural functions of the human brain in health and disease. The main areas of focus include: (a) machine learning algorithms for analysing neurological data, and (b) studying the neural correlates of sensory processing and predictions.

3.3 Research Projects

Deep learning techniques for predicting the chances of a coma patient to regain consciousness

Coma after cardiac arrest is one of the most common causes of admission to the intensive care units. Measuring the integrity of neural functions in coma remains to date an open challenge. The integrity of the auditory processing network has been shown to be informative of a patient's chances of awakening. In our work, we are evaluating auditory processing in coma after cardiac arrest. We are analysing electroencephalography (EEG) responses to auditory stimuli, presented in acute coma patients. In particular, we are developing novel algorithms to analyse these signals, with the use of convolutional neural networks (CNNs).
In our recent work, we focused on EEG responses to standardized auditory stimulation from a multicentre and multiprotocol patient cohort of coma patient. These were used to train CNNs to classify whether a given EEG response was recorded in a survivor or not survivor. Patients outcome was assessed three months after cardiac arrest and the EEG recordings. CNNs achieved a positive predictive power for predicting awakening of 0.83 ± 0.04 and 0.81 ± 0.06, for patients undergoing therapeutic hypothermia and normothermia treatments, respectively. A high predictive power for awakening also persisted for patients in clinical 'grey zone', for whom existing tests do not provide a conclusive outcome. Last, we evaluated that the neural network's output was strongly correlated to the neural synchrony and complexity of EEG responses to sounds, which have been previously shown to relate to patients' outcome. This work suggests that CNNs have a strong potential to be used in a clincial routine, and assist in clinical decision-making.

Research staff: Florence Aellen, Sigurd Alnes, Thomas Rusterholz, Athina Tzovara

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

Intrinsic brain dynamics and auditory processing

The human brain exhibits a rich repertoire of intrinsic brain dynamics, which manifest at multiple timescales. Neural timescales quantify the speed of fluctuations in neural signals, and manifest as patterns of oscillatory and non oscillatory activity. Neural timescales are organized along sensory processing hierarchies, as an intrinsic property of brain circuits. These are thought to facilitate processing of external stimuli at multiple stages, but there is limited direct evidence for their role in auditory processing. In our work, we investigated intrinsic neural dynamics and their interactions with processing of sounds using intracranial electroencephalography, measured in patients with epilepsy. Patients were presented with pure tones and were asked to relax.
We measured intrinsic timescales during a baseline period, before the occurence of the sounds, by quantifying the rate of decay of the temporal autocorrelation function. Our results showed that intrinsic neural timescales progressively increase, moving away from primary auditory areas, and exhibit a spatial gradient that follows the temporal lobe anatomy. Moreover, intrinsic timescales at baseline explained the latency of auditory responses. Single-electrode response onsets and peak latencies could be explained by baseline timescales, using a linear model. Our findings show that the human auditory network exhibits a repertoire of intrinsic neural dynamics. These are orgeanized in cortical gradients, which exhibit a millimeter resolution explain the timing of auditory responses.

Research staff: Riccardo Cusinato, Sigurd Alnes, Ruxandra Tivadar, Pinar Göktepe-Kavis, Camille Mignardot, Athina Tzovara

Financial support: Swiss National Science Foundation (320030_188737)

Data-driven phenotyping of sleep disorders

Diagnosing many sleep wake disorders is a major challenge due to the lack of specific disease markers and frequently co-occurring sleep disorders and other comorbidities. In our work, we aimed at assessing a cohort of well-characterized patients with sleep wake disorders. We studies whether an unsupervised learning clustering algorithm could provide a data-driven identification of patient sub-groups.
We analysed more than 6000 patients from the Bernese Sleep Registry. We analysed about 300 biomarkers from this database, which included

questionnaires, results of polysomnography and vigilance tests, and also the patients' clinical diagnosis. We developed a data processing pipeline, to extract and cluster the available clinical biomarkers. We first focused on a cohort of patients with central disorders of hypersomnolence, and identified four patient clusters: two clusters for narcolepsy type 1 (NT1) but not narcolepsy type 2 or idiopathic hypersomnia. This result reflects the clinical practice, where NT1 is more easily dissociated compared to NT2 or idiopathic hypersomnia. We then advanced to the full cohort of sleep wake disorders, where we found nine clusters: four contained patients with obstructive and central sleep apnea syndrome, one with primarily NT1 patients, and four with intermixed disorders. In an smaller, and cleaner cohort of patients without coexisting sleep wake disorders, we additionally identified one cluster of patients with chronic insomnia disorder. This project confirms the existence of clear clusters for patients with NT1, and shows that there are intermixed groups in the full spectrum of sleep wake disorders. These results suggest that new biomarkers are needed for improving characterisation and diagnosis of sleep wake disorders.

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. On a daily basis, we 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 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) and 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 usually missing. However, disease classification is urgently needed for identification of new digital biomarkers from raw signals of electrophysiological assessments as well as markers derived from biological samples.
Here, we aimed at automatically generating ICSD-III codes, based on patient clinical records. To this aim, we have developed a prototype for a text processing pipeline. This pipeline is founded upon text embedding techniques and a neural network-driven classifier, utilizing both a Multiclass CNN and a Hierarchical Attentive Network. To discern the most appropriate classification representation, we systematically applied algorithms such as FastText, Word2Vec, and GLOB across various combinations of textual sources. Through the utilization of institutional internal category text, we have achieved a notable accuracy rate averaging 85%. The interpretability of our models has been assessed employing the SHAP and LIME libraries, along with maximal decomposition techniques. Moreover, an investigation of semantic shifts among distinct text corpora has been conducted via classification tasks, elucidating both semantic and chronological patterns of drift. In the future, we intend to amalgamate the outcomes of the automatic ICSD-III code generation with the underpinning model interpretability. Furthermore, we will undertake a comprehensive exploration of sleep quality facets within the textual data. These insights

will enable us to harness sleep quality attributes for reinforcing the diagnostic and therapeutic processes.

Research staff: Yihan Deng

Personalized disease monitoring and support

Computational algorithms, including deep learning, are increasingly adopted in the medical field for their ability in identifying complex patterns within extensive datasets. However, in scenarios where explainability and control are crucial, probabilistic modeling approaches might be more desirable. As the medical domain seeks tools for both universal and personalized patient care, in our project we are combining deep learning with advanced statistical models. We are focusing on developing tailored disease monitoring systems, encompassing real-time tracking, lifestyle support, and exploration of novel biomarkers. We are aiming to design systems that harness a diverse set of data, including demographics, clinical information, objective metrics, subjective feedback, and biosignals like electrocardiography or electroencephalography.
In a first study, we are focusing on studying a cardiac monitoring and alert system. The aim is to develop an algorithm able to identify in real-time possible arrhythmias in patients affected by Inherited Arrhythmogenic Diseases. Given the rarity of this condition, advanced data augmentation techniques like Deep Generative Models have been explored and applied to overcome the problem of data scarcity and class unbalancing.
Another direction is applying personalized algorithms for digital nudging in cardiac rehabilitation. A personalized behavioral change system combining reinforcement learning algorithms and behavioral psychology aims to increase the adherence to cardiovascular rehabilitation. Data collected through continuous monitoring with wearable devices and digital diaries support the subsequent causal inference and analysis aiming to evaluate the effectiveness of these digital interventions. The third part of our study focuses on quantifying effects associated with breathing-related sleep disorders, which are often accompanied by other sleep comorbidities. The manifestation of sleep has a wide variability even in healthy individuals and is subject to age-related development. In addition, the prevalence of sleep disorders may in turn be confounded by demographic factors or the clinical profile of the individual. Given these considerations, our research focuses on advanced statistical modeling with elements of causal inference to create personalized digital biomarkers that can expand the understanding of

sleep and lead to a more accurate diagnostic screening.

Research staff: Giuliana Monachino, Radoslava Svihrova, Michal Bechny

3.4 Master's Thesis

- Julian Weyermann, "Analysis of simultaneously acquired invasive electroencephalography data for studying interpersonal communication", February 2023
- Jakub Tłuczek, "Personalized goal recommendation framework for habit creation", July 2023

3.5 PhD Thesis

- Florence Aellen, "Artificial Intelligence techniques for studying neural functions in coma and sleep disorders", March 2023

3.6 Awards

- Publication award, Swiss Society for Neuroscience, to Florence Aellen for: "Auditory stimulation and deep learning predict awakening from coma after cardiac arrest" (Aellen et al., 2023)
- Poster award, Swiss Society for Neuroscience, to Florence Aellen for: "Progression of auditory processing in acute coma: changes in neural synchrony and complexity"

3.7 Further Activities

Presentations

Athina Tzovara

- How can we assess subjective experiences and internal representations in the brain? Symposium organizer and presenter, Organization for Human Brain Mapping, Montreal, Canada, July 2023

- Decoding the auditory brain in post-anoxic coma, Invited talk, Neurosciences in intensive care international symposium, Institut Pasteur, Paris, France, June 2023

- Studying the auditory brain in coma and wakefulness, Invited talk, University of Leeds, UK, March 2023

- Addressing bias in big data and AI for healthcare: a call for open science, Invited talk, Ethos + Tekhne: Spring School for AI Researchers, Pisa, Italy, March 2023

- Timing in the auditory predictive brain: electrophysiological correlates and prediction of coma outcome, session organizer and presenter, Benefri Neuroscience Workshop, Bern, Switzerland, February 2023

- Auditory processing and deviance detection as markers of coma outcome. Invited talk, Freie Universitaet Berlin, Germany, December 2022.

- Gender bias in academia: a problem that needs solutions. Invited talk, University of Oslo, Norway

- Deep learning for EEG analysis in the ICU. Symposium talk, Swiss Federation of Clinical Neuro-Societies Congress, Basel, Switzerland, September 2022.

- Improving diversity and equity in academia: lessons from the Organization for Human Brain Mapping. Symposium talk, Neuroinformatics Assembly: International Neuroinformatics Coordinating Facility, September 2022

- Studying the auditory brain in coma and wakefulness with computational techniques, Invited talk, University of Newcastle, UK, September 2022

Florence Aellen

- Progression of auditory processing in acute coma: changes in neural synchrony and complexity, poster presentation, Organisation of Human Brain Mapping, Montreal, Canada, July 2023

- Disentangling the complex landscape of sleep-wake disorders with data-driven phenotyping: A study of the Bernese center, e-presentation (short oral presentation), European Academy of Neurology, Budapest, Hungary, July 2023
- Progression of auditory processing in acute coma: changes in neural synchrony and complexity, e-presentation (short oral presentation), European Academy of Neurology, Budapest, Hungary, July 2023
- Progression of auditory processing in acute coma: changes in neural synchrony and complexity, poster presentation, Swiss Society of Neuroscience Annual Meeting, Lugano, Switzerland, June 2023
- AI for sleep scoring: moving towards integration in the clinic, oral presentation, Bern Data Science Day, May 2023
- AI for studying sleep disorders and coma, talk, Sleep-Wake Epilepsy Days, Bern, November 2022

Ruxandra Tivadar

- Predictive Sensing in Wakefulness and Sleep, Invited talk, symposium “Multisensory processes and rehabilitation”, Instituto Italiano di Tecnologia Genova, Italy, October 2022

Sigurd Alnes

- Neural complexity and the spectral slope characterize auditory EEG responses in sleep and wake, Poster presentation, Organization for Human Brain Mapping, Montreal, Canada, July 2023

Pinar Göktepe-Kavis

- Neural representation of future outcomes is affected by decision context, Poster presentation, 11th Symposium on Biology of Decision-Making, Paris, June 2023.

Riccardo Cusinato

- Intrinsic Neural Timescales in the Temporal Lobe Support an Auditory Processing Hierarchy, Poster presentation, Organization for Human Brain Mapping, Montreal, Canada, July 2023

Michal Bechny

- Do state-of-the-art sleep-scoring algorithms preserve clinical information? Poster presentation, World Sleep Congress 2023, Rio de Janeiro, Brazil, October 2023.
- Quantifying dynamics of sleep in subjects with sleep-disordered breathing: towards new biomarkers. Poster presentation, World Sleep Congress 2023, Rio de Janeiro, Brazil, October 2023.

Giuliana Monachino

- Automatic sleep scoring: the relationship between age and sleep. Oral presentation, 11th Research and Innovation Day in Human Medicine of Southern Switzerland. June 2022.
- Automatic sleep scoring: the relationship between age and sleep. Poster presentation, Sleep Europe 2022 – The 26th Congress of the European Sleep Research Society. September 2022

Yihan Deng

- Analysis of Semantic Drifting in Diagnostic Texts for Sleep Disorders. Presentation, CBMS 2023 IEEE 36th International Symposium on Computer-Based Medical Systems (CBMS), L'Aquila, Italy, June 2023.

Conference and Scientific Committees

Athina Tzovara

- Committee on Best Practice in Data Analysis and Sharing (COBIDAS) for magnetic resonance imaging (MRI) data, member, 2022-2023
- Organization for Human Brain Mapping (OHBM), member of Diversity and Inclusivity Committee, 2022-2023

Journal Committees

Athina Tzovara

- Guest Editor for European Journal of Neuroscience

Reviewing Activities

Journal Reviews
Athina Tzovara

- Communications Biology
- IEEE Journal of Biomedical and Health Informatics
- Neuroimage
- PLOS Digital Health
- Science Advances
- Transactions on Neural Systems & Rehabilitation Engineering

Yihan Deng

- Journal of Biomedical and Health Informatics
- Journal of Biomedical Informatics

Conference Abstracts
Athina Tzovara

- Organization for Human Brain Mapping

Yihan Deng

- IEEE CBMS 2023

Grant reviews
Athina Tzovara

- UK Research and Innovation (UKRI) grant reviewer

Master thesis evaluation committee memberships

Ruxandra Tivadar

- Master of Science (MSc) in Neuroscience, University of New England, AUS, external jury member, topic expert. “Individual Responses to Organisational Change: An Interoceptive Predictive Processing Account”, Ms Julia Page, June 2023
- Master of Science (MSc) in Neuroscience, University of New England, AUS, external jury member, topic expert. “The Neuroscience of Moral Choice: An EEG study of affective and cognitive processes during moral decision making”, Mr Sadr Ali, August 2023

3.8 Publications

Journal Publications

- Aellen F.M., Alnes S.L Loosli F. Rossetti A.O., Zubler F., De Lucia M., Tzovara A. (2023) Auditory stimulation and deep learning predict awakening from coma after cardiac arrest. Brain, https://doi.org/10.1093/brain/awac340

- Cusinato R. *, Alnes S.L. *, van Maren E., Boccalaro I., Ledergerber D., Adamantidis A., Imbach L.L., Schindler K., Baud M.O. Tzovara A.. (2023) Intrinsic neural timescales in the temporal lobe support an auditory processing hierarchy. Journal of Neuroscience, https://doi.org/10.1523/JNEUROSCI.1941-22.2023 * equal contribution

- Fiorillo L. *, Monachino G. *, van der Meer J., Pesce M, Warncke J.D., Schmidt M.H., Bassetti C.L.A., Tzovara A., Favaro P., Faraci F.D. U-Sleep's resilience to AASM guidelines. npj Digital Medicine, https://doi.org/10.1038/s41746-023-00784-0 * equal contribution

- Zubler F., Tzovara A., Deep learning for EEG-based prognostication after cardiac arrest: from current research to future clinical applications. Frontiers Neurology, https://doi.org/10.3389/fneur.2023.1183810

- Aellen F., van der Meer J., Dietmann A., Schmidt M., Bassetti C.L.A.*, Tzovara A.*, Disentangling the complex landscape of sleep-wake disorders with data-driven phenotyping: A study of the Bernese center. European Journal of Neurology, Accepted, * Co-senior authors, http://doi.org/10.1111/ene.16026

Conference Abstracts

- Deng Y., van der Meer J., Tzovara A., Schmidt M., Bassetti C.L.A., Denecke K. (2023) Analysis of Semantic Drifting in Diagnostic Texts for Sleep Disorders. IEEE 36th International Symposium on Computer-Based Medical Systems (CBMS),https://doi.org/10.1109/CBMS58004.2023.00308

3.9 Organization of Science Outreach Activities

- Master InfoTag, Florence Aellen and Pinar Goektepe-Kavis, March 2023
- MINT Tag, Florence Aellen and Pinar Goektepe-Kavis, March 2023

4 Communication and Distributed Systems Group

4.1 Personnel

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	D. Xenakis*	Tel.: +41 31 511 7631 email: dimitrios.xenakis@unibe.ch
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	Y. Farhat	email: yamshid.farhat@bkw.ch

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D. Oliviera Rodrigues email: diego.oliveira@unibe.ch
(until 30.6.2023)

*With financial support from a third-party credit

4.2 Overview

The research group “Communication and Distributed Systems” has been investigating how mobile communication systems and networks can support multimedia and mixed reality applications and cloud computing services with high quality, reliability, and energy efficiency demands. Moreover, we are investigating localization mechanisms for wireless devices and new Future Internet paradigms such as Information-Centric Networking (ICN) and 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

Efficient Distributed and Federated Machine Learning for Internet of Things

Internet of Things (IoT) systems generate large volumes of data from user devices. The raw data generated by IoT devices are often private or sensitive and can be too large to transmit over the networks. This data is essential for ML models to deliver personalized and intelligent IoT services. Running ML models entirely on the cloud shows 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. Secondly, sensitive raw user data may be exposed during transmission, remote processing, and storage. Thirdly, transferring the

raw sensor data from IoT devices increases the ingress throughput on the backhaul network.

Because of their proximity to the data, conventional consumer-level devices, such as IoT devices, are great candidates 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. Recent studies have proposed moving ML toward the IoT edge through distributed ML to address these challenges.

This research aims to determine how to efficiently distribute ML tasks across different elements in IoT systems, taking into account computation and communication constraints [Samikwa et al., 2022b]. Previously, we proposed Early Exit of Computation, a scheme for low-latency and energy-efficient distributed DNN inference over IoT networks. In this approach, the computation of inference tasks on the resource-constrained IoT devices is exited early through a dynamically selected partition point.

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., 2022a]. 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 to mitigate tradeoffs between minimizing the training time and the energy consumption on IoT devices.

To enable flexible, decentralized, and parallel execution of neural network models over several resource-constrained IoT devices, we introduce distributed micro-split deep learning (DISNET) [Samikwa et al., 2023a]. To achieve this, we model the problem of flexible fine-grained neural network splitting and device allocation, comprising arbitrary-sized DNN partitions and dynamic mesh networks with heterogeneous resources, and formulate its relaxation. We then devise an efficient heuristic based on the relaxed problem that iteratively combines vertical and horizontal DNN partitioning for distributed execution of neural networks in dynamic IoT with diverse computing and network capabilities without compromising accuracy.

Navigating data and resource heterogeneity in edge IoT environments is another challenge for distributed ML in IoT. Our recent work, Dynamic Federated Learning, aims to confront the dual problem of data and resource heterogeneity for distributed training in edge IoT through a fusion of resource-aware split computing for deep neural networks and a similarity-based dynamic clustering mechanism [Samikwa et al., 2023b].

Lastly, we study an approach for edge-based ML energy optimization in smart city IoT temperature sensors [Samikwa et al., 2023c]. In this work, we utilize various DNNs suitable for low-power IoT sensor devices to pre-

dict temperature using multivariate time series from different sensors and compare their accuracy. Furthermore, we highlight the tradeoff between prediction accuracy, which is correlated to the length of the observed input sequence, and energy consumption dependent on ventilation time.

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 minimize latency and energy consumption [Medeiros et al., 2023] jointly. 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.

Research staff: A. Medeiros, T. Braun.

Network Function Virtualization and Fog Service Support in 5G Networks

Next-Generation Mobile Networks must provide connectivity for a wide range of services with heterogeneous performance requirements. Network support for services requiring low latency and high reliability is antici-

pated to be the most challenging based on current deployments, which often rely on centralized processing (i.e. cloud data centres) on specialized hardware. Following this, a departure from the current hardware-centric network architecture and a greater focus on network virtualization has been proposed 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.
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. Then, we proposed a novel solution for the online admission of Network Slice Requests in softwarized mobile networks [Ajayi et al., 2023], where the goal is to maximize the utility received from the admitted requests while improving the efficiency of utilized network resources. Our current work looks at the adaptive selection of slice admission control policies for network slice provisioning by leveraging online learning.

Research staff: J. Ajayi, T. Braun.

Intelligent Mobility Services

Nowadays, huge amounts of data regarding human mobility traces are available from diverse location-based services (e.g., GPS or cellular base stations). 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. 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 unavailable, are more challenging. Therefore, fusing different signal sources is critical for achieving accurate positioning indoors.
Following the above, we introduced Anchor-free Ranging-Likelihood-based Cooperative Localization (ARLCL) [Xenakis et al., 2023]; a novel anchor-free and technology-agnostic localization algorithm that utilizes inter-exchanged ranging signals from sensors to enable their simultaneous positioning. Ranging technologies with easy-to-model propagation properties, such as UWB or LiDAR are among the first beneficiaries that ARLCL is targeting. To examine its applicability, even to noisier signals and often unsuitable for ranging signals, we assessed ARLCL with real-world BLE RSS measurements. At the same time, we considered deployments that typically induce flip-ambiguity, being a major problem in cooperative localization.
Comparison against the most widely adopted optimization method (Mass-Spring) and the recent likelihood-based approach (Maximum Likelihood - Particle Swarm Optimization) showed that ARLCL outperformed the baselines in almost all scenarios. Our gain in positioning accuracy is also positively correlated to both the swarm's size and the signal's quality, reaching an improvement of 40%.

Mobility & Trajectory Prediction

Accurate analysis, modelling, and prediction of mobile users' mobility patterns are essential for improving the quality of service in modern wireless networks, such as proactive handover management, service migration, load balancing, autonomous driving vehicles, and traffic management. In this direction, this sub-project aims to create advanced machine-learning models that precisely and optimally anticipate the future locations and trajectories of pedestrians and vehicles in dynamic urban scenarios.
As our initial continuation, we proposed a reinforcement learning (RL)-designed LSTM mobility predictor. Evaluations showed that RL-LSTM outperforms other state-of-the-art machine learning predictors and neural architecture search mechanisms (such as Grid Search and AutoML) by increasing the prediction accuracy up to 10%. Subsequently, we evaluated the impact and robustness of our suggested trajectory predictor on the performance of actual network applications, such as service migration and handover management.
In our second contribution, we introduced a framework, termed RC-TL, to address expansive networks' scalability challenges.RC-TL clusters similar trajectory users, training a single RL-designed CNN model per cluster based on a subset of users' data, and transferring the pre-trained model to

other members within the cluster to decrease the computational resource consumption. Evaluations showed that RC-TL reduces 66% of the time required for the neural architecture search regarding RL-LSTM, while reaching a similar prediction accuracy. RC-TL also can save up to 90% of the computational resources.

For our third contribution, we extended our endeavours to the domain of social-aware multi-agent trajectory prediction, wherein the spatio-temporal interdependencies among neighbouring users or group users can enhance the accuracy of trajectory forecasts. In this direction, we introduced an innovative system named INTRAFORCE [Emami et al., 2022], which employs RL to construct a Social-Transformer architecture based on intra-cluster user mobility features. The results of INTRAFORCE showed that RL-transformer 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. INTRAFORCE reaches the minimum average displacement error equivalent to 0.22m compared to several state-of-the-art social and individual trajectory predictors.

As our fourth contribution, we introduced FedForce [Emami et al., 2023a] mobility prediction system, which broadens the scope of reinforced social multi-agent trajectory prediction to encompass privacy-preserving and distributed machine learning through the federated learning (FL) paradigm. FedForce integrates a multi-objective cost function within its RL optimizer for neural architecture search. This function considers factors like network throughput availability, dataset characteristics, and local devices' computational resource availability for training simultaneously. The results of FedForce showed that it converges to the same accuracy as the centralized training model with minimal delay, and it enhances accuracy compared to classical FL (up to 10%). Additionally, FedForce reduces training and transmission time (down to 50% compared to classical federated learning models). Moreover, FedForce has the potential to conserve up to 80% of computational resources and reduce communication overhead by 96%. It also decreases the average displacement error down to 0.20m.

Finally, as our fifth contribution, we proposed the GTP-Force [Emami et al., 2023b] mobility prediction system, which considers the non-cooperative user interactions through a game theoretic (GT) approach. GTP-Force engages multiple contesting RL agents to personalize their neural architectures within a game. The results of GTP-Force showed that it achieves higher average accuracy (up to 15% improvement) than existing GT-based mobility predictors. It also decreases the average displacement error down to 0.19m.

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

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

Software-Defined Service-Centric Networking in Urban Environments

Disruptive applications for mobile devices that Edge Computing facilities can enhance are emerging, such as the Internet of Things, Immersive Media, and Connected and Autonomous Vehicles. These applications have strict requirements to work properly that are difficult to fulfil with the cloud's current computing paradigm. In this context, Edge Computing is an architecture expected to meet the requirements imposed on these applications. This architecture introduces 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 the positioning of stateful data in edge networks [O. Rodrigues et al., 2023b], and produced a survey on emerging applications enabled by Edge Computing [O. Rodrigues et al., 2023a].

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 typical and individually deployed setups for a single user with support for multi-users [Santos et al., 2023]. The Context Awareness Engine project funded by Orange SA explores network context information to discover, reason, and predict network and subscriber situations using appropriate computation and information modelling based on collected network data from various sources (network nodes, devices, applications). We researched to develop a Reinforcement Learning and Transfer Learning mobility predictor with the Orange dataset. 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.

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 in bringing intelligent devices and network management capabilities. 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 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 positioning devices and services.

MEC will train object detection and classification, driving assistance, and other crucial tasks in vehicular networks and connected vehicles. 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 training 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. We propose the Neural-based Federated User SIMilarity (NSIM), a neural network-based predictor trained to estimate the similarity of datasets used to train neural networks pairwise. NSIM can 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 significantly improving model convergence time and accuracy.

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 with the network infrastructure and neighbouring vehicles upon contact, increasing the number of successful model transfers. DOTFL also uses 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, verifying the authenticity of exchanged data when the IoT is growing becomes more challenging. 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 solution to 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. Furthermore, we have built a real-world IoT testbed to validate Veritaa's applicability for the IoT.

Metrological traceability is used to trace back measurement values to international standards and assess a given measurement's accuracy. 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 certificates and measurement value signatures on the Graph of Trust [Schaerer et al., 2022].

In the Internet of Things, the integrity of a system often depends on the specific location of the sensors. Therefore, the position of the sensors should also be auditable. We proposed the Auditable Positioning System (APS) to make the locations measured by indoor positioning systems auditable [Schaerer et al., 2023]. As proof of concept, we have implemented

the APS in our existing Veritaa testbed using an indoor positioning system based on the Angle of Arrival and Bluetooth Low Energy. Positioning systems based on the Angle of Arrival have flaws in the physical layer that make them vulnerable to replay attacks manipulating a position. Since this attack is on the physical layer, it is hard to secure by cryptographic functions. We proposed an evaluated SecureAoX, a Location Verification System that uses the Angle of Departure as independent location information to detect manipulated positions [Schaerer et al., 2022]. With these two systems combined, we provide an immutable audit trail that enables third-party auditors to verify if a particular asset was in a claimed position.

Research staff: J. Schärer, T. Braun.

Innovative Electric Network Planning with Advanced Machine Learning Algorithms

To reach the energy strategy goals for 2050, a massive penetration of distributed energy sources (i.e. solar panels) and a new type of consumers (i.e. 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 will 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.
This project aims to evaluate new methods for optimally planning 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 behaviour 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, [Farhat et al., 2022].
We continue this research in [Farhat et al., 2023], where we aim to evaluate the potential impact of grid tariffs on local energy systems' optimal design. We introduce an initial stage of our research endeavour by formulating a linear optimization algorithm that minimizes local energy costs. We conducted a case study in a Swiss municipality wherein 85 buildings were subjected to different grid tariff schemes (including volumetric, power

peak-based, and seasonal). Our algorithm was employed to identify the optimal designs and evaluate the impact at the municipality level. Based on our findings, it can be inferred that the chosen grid tariff scheme heavily influences factors such as solar panels & Energy Storage Systems size and type selection, profitability rates and allocation of costs related to the power grid. We discuss the implications of these findings for network operators and policymakers and provide some recommendations for designing grid tariffs that can promote the achievement of the Swiss Energy Strategy goals and ensure the reliability and cost efficiency of the energy system.

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

Collection of Psychological Measurements via a Smartphone

In this project, we developed a smartphone application for Android and iOS platforms to collect data on the user's smartphone usage and physical sensors. For example, the user's smartphone usage regarding screen time, call duration, and app usage data is monitored. 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 project's final goal is to find correlations between the psychological profile of the participants and the measurements collected from our application to gain new insights into subjects' physical and behavioural features with certain psychological features. While the project is ongoing, we conducted an initial correlation analysis and described how the dataset was collected from the smartphone sensors [Xenakis et al., 2023].

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

Financial support: Faculty of Sciences, University of Bern

Networking for Immersive Communications (NICO)

The growing need for immersive communications for virtual and augmented reality applications comes with extreme bandwidth, reliability, and latency requirements. NICO addresses these extreme challenges and requirements through 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 must 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 to improve users' Quality-of-Experience (QoE),
2. disruptive methods to identify QoE parameters in immersive communications combining system measurements and psychological behaviours,
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 to support low latency and high throughput,
4. novel mechanisms to minimize latency 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.

Regarding viewport prediction in Virtual Reality (VR) video streaming, our foremost objective is to provide a comprehensive framework for real-time 360-degree video streaming. Our focus encompasses the optimization of video compression, caching, and transmission processes. We have developed and rigorously assessed a novel algorithm for Multi-Object-Tracking (MOT), which mimics the natural behaviour of the human visual system in tracking moving entities in a VR environment. This algorithm leverages the Transformer architecture and incorporates attention mechanisms to evaluate object similarities, generating corresponding object-tracking paths. The experimental outcomes achieve state-of-the-art performance and obviate the need for training on object motion patterns. This task poses considerable challenges in VR environments. Moreover, we have re-engineered the overarching infrastructure for 360-degree video streaming, which includes server-side content analysis solutions, viewer-side viewport prediction algorithms, and content caching strategies. This trailblazing endeavour aims to deliver a pragmatic framework for real-time 360-degree video streaming.

We propose an edge caching approach for latency minimization by extended caching mechanisms. It combines optimization techniques with a data-driven AI algorithm using real user viewports request trajectory datasets. This approach enables real-time decision-making with reduced computational complexity compared to offline algorithms. It supports partial caching, enabling more effective utilization of cached content among multiple users and enhancing multi-user video caching. Our method directly predicts the optimal caching strategy, eliminating the need for content popularity comparisons and considering network bandwidth and storage capacity constraints for content replacement. We propose an L2 edge caching architecture for 360-degree video, trade-off time and space for significantly reduced latency. Experimental validation demonstrates the approach's effectiveness in computational efficiency, reducing latency and improving caching efficiency through partial caching.

Research staff: H. Xing, C. Gao, M. Hrabasova, 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 also have a dedicated NVMe SSD server with 96 parallel threads (48 cores), storage of 21T, and 250 GB of RAM. We operate two external Dell PowerVault MD3800i that provide us with 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

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

The CDS group has its own testbed for Distributed and Federated Learning in IoT that consists of:

- 8 NVIDIA Jetson nano consisting of:
  - NVIDIA JetPack and Developer Kit
  - NVIDIA Maxwell 128 NVIDIA CUDA nano cores
  - ARM Cortex-A57 MPCore processor
  - Intel Dual Band Wireless-AC 8265 - WiFi/BLE
- 10 Raspberry Pi A+/3B+/Zero consisting of:
  - 1.2GHz Broadcom BCM2837/A57 MPCore processor
  - BCM43438 wireless LAN and BLE on board
  - EMU Check power monitor device with USB data logger
- Lenovo ThinkCentre M90t (edge server) consisting of:
  - NVIDIA GeForce RTX 2060
  - Intel Core i9-10900
  - Wi-Fi 6 / 802.11ax Bluetooth i 5.1

4.4 Ph.D. Theses

- Schaerer, J. ”A Distributed Audit Trail for the Internet of Things”, June, 2023. URL: https://boristheses.unibe.ch/4443/

- Oliveira Rodrigues, D. ”Mobility-aware Software-Defined Service-Centric Networking for Service Provisioning in Urban Environments”, June, 2023. URL: https://boristheses.unibe.ch/4327/

- Melo dos Santos, H. L. ”Multimedia Service Orchestration in Multi-tier Edge Computing Environments”, May, 2023.

4.5 Awards

- Best paper award candidate in the *24th International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM23, Boston)* for the paper ”ARLCL: Anchor-free Ranging-Likelihood-based Cooperative Localization.” (Dimitris Xenakis et al.).

- Recognition of Outstanding Teaching Achievements for the online ”Quantum Mobile Networks” Virtual Exchange Seminars in Spring Semester 2023, among the top 11 courses offered by the Faculty of Sciences at the University of Bern. (Antonio Di Maio)

- Recognition of Outstanding Teaching Achievements for the seminar ”Communication and Distributed Systems” in Autumn Semester 2022, among the top 6 courses offered by the Faculty of Sciences at the University of Bern. (Torsten Braun)

4.6 Further Activities

Invited Talks

Disclaimer: The invited talks list only includes invited talks not considering conference paper presentations.

Torsten Braun

- ”Networking for Immersive Communications”, Focus Group XR, University of Bern, March 20, 2023

- ”A Low-Cost LoRaWAN Sensor Network for Analyzing Urban Heat Islands, Keynote, 21st Mediterranean Communication and Computer Networking Conference (MedHocNet 2023), Ponza Island, June 14, 2023
- ”Operating Systems for the Internet of Things”, Presentation at Technical University of Panama (UTP), July 5, 2023, Panama City
- ”Cellular Networks”, Presentation at Technical University of Panama (UTP), July 5, 2023, Panama City
- ”Computer Network Research at University of Bern”, Presentation at Technical University of Panama (UTP), July 25/27, 2023, Panama City

Eric Samikwa

- ”Dynamic Federated Learning for Heterogeneous Learning Environments”, Presentation at Bern Data Science Day, University of Bern, May 5, 2023

Memberships

Torsten Braun

- Erweitertes Leitungsgremium Fachgruppe “Kommunikation und Verteilte Systeme”, Gesellschaft für Informatik
- Kuratorium Fritz-Kutter-Fonds
- Expert for Bachelor Theses at Fachhochschule Bern

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
- PiscoMed Journal ”Energy Modelling and Prediction”

Conference Technical Program Committees

Torsten Braun

- International Conference on Intelligence in Things, Hanoi, 2023
- International Conference on Next Generation Wired/Wireless Networks and Systems (NEW2AN), Tashkent, Uzbekistan, December 15 - 16, 2022
- International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), October 11-13, 2022, Valencia, Spain
- International Teletraffic Congress CONGRESS (ITC 34), September 14-16, Shenzhen, China
- IEEE International Conference on Mobile Ad-Hoc and Smart Systems (MASS), October 20 - 22, 2022, Denver, Colorado
- IFIP Wireless and Mobile Networking Conference (IFIP WMNC), October 17-19, 2022, Sousse, Tunisia
- IEEE Global Communications Conference (Globecom), Rio de Janeiro, Brazil, December 4-8. 2022
- IEEE Consumer Communications and Networking Conference (CCNC), January 8-11, 2023, Las Vegas, USA
- Wireless On-demand Network systems and Services Conference (WONS), January 31- February 1, 2023, Madonna di Campiglio, Italy
- ACM Symposium on Applied Computing (SAC 2023), March 27–April 2, 2023, Tallinn, Estonia
- IEEE International Conference on Communications (ICC), May 28 - June 1, 2023, Rome, Italy
- IFIP Networking 2022 Conference, June 12-15, 2023, Barcelona, Spain
- IEEE/ACM International Symposium on Quality of Service (IWQoS), 19–21 June 2023, Orlando, FL, USA
- International Workshop on Urban Computing, August 15, 2022, Washington, DC, USA

- IEEE International Conference on Mobile Ad-Hoc and Smart Systems (MASS 2022), October 20-22, 2022, Denver, Colorado

Antonio Di Maio

- The 20th IEEE Autonomous and Trusted Vehicles Conference (ATC) 2023 (28-31.8.23, Portsmouth, UK)
- IEEE Symposium on Computers and Communications (ISCC) 2023, MoCS, 9-12.7.23, Tunis, Tunisia
- The ACM Internet Measurement Conference (IMC) 2022, October 25-27 2022, Nice, France.
- THE ACM MobiHoc'22 Workshop: Smart Living and Communications the next Generations Networks (SLICO), October 17-20 2022, Seoul, South Korea.
- The 1st ESORICS Workshop on Security and Privacy of Mobile IoT (SP-MIoT 2022), 30 September 2022, Copenhagen, Denmark.
- IEEE Symposium on Computers and Communications (ISCC) 2022, MoCS, Rhodes Island, Greece

Project and Person Reviewing Activities

Torsten Braun

- Research Council of Norway
- Luxembourg National Research Fund (CORE Panel chair)
- Independent Research Fund Denmark (DFF, 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
- Dutch Research Council
- Member of Accreditation Committee at German University of Oman

Journal Article Reviewing Activities

Torsten Braun

- IEEE Communications Standards
- IEEE Transactions on Service Management
- IEEE/ACM Transactions on Networking
- IEEE Transactions on Machine Learning in Communications and Networking
- IEEE Internet of Things Journal
- IEEE Wireless Communications Magazine
- Proceedings of the IEEE
- IEEE Network Magazine
- ACM Computer Communications Review

Antonio Di Maio

- IEEE Systems Journal
- IEEE Transactions on Vehicular Technologies
- IEEE Transactions on Intelligent Transportation Systems
- IEEE Transactions on Network and Service Management
- IEEE Transactions on Emerging Topics in Computational Intelligence
- Elsevier Computer Communications
- Elsevier Information Sciences
- Elsevier Computer Networks
- Elsevier Vehicular Communications
- Wiley Concurrency and Computation: Practice and Experience
- Wiley Transactions on Emerging Telecommunications Technologies (ETT)

- Wiley International Journal of Network Management (NEM)
- MDPI Sensors
- MDPI Sustainability
- MDPI Applied Science
- MDPI Electronics
- MDPI Information Journal
- MDPI Future Internet
- MDPI Entropy
- MDPI Drones
- MDPI Mathematics
- MDPI Computers
- Journal of Internet Technology
- PeerJ Computer Science

Ph.D. Committee Memberships

Torsten Braun

- Sara Farrag Mohamed, German Univesity of Cairo, Egypt, June 6, 2023
- Marwa Hisham Loutfy Zamzam, German Univesity of Cairo, Egypt, September 15, 2022
- Frank Engelhardt, Universität Magdeburg, Germany, October 15, 2022

4.7 Publications

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

Book Chapters

- Hammler, Patric; Riesterer, Nicolas; Mu, Gang; Braun, Torsten (2022). Multi-Echelon Inventory Optimization Using Deep Reinforcement Learning. In *Quantitative Models in Life Science Business*, pp. 73-93, November 2022, Springer (10.1007/978-3-031-11814-2_5).

Journal Papers

- Samikwa, Eric; Di Maio, Antonio; Braun, Torsten (2022). ARES: Adaptive Resource-Aware Split Learning for Internet of Things. In *Computer Networks*, September 2022, Elsevier (10.1016/j.comnet.2022.109380).
- Li, Zan; Zhao, Xiaohui; Zhao, Zhongliang; Braun, Torsten (2023). CrowdFusion: Multi-Signal Fusion SLAM Positioning Leveraging Visible Light. In *IEEE internet of things journal*, vol. 10, issue 14, pp. 13065-13076, March 2023, IEEE (10.1109/JIOT.2023.3260205).
- Samikwa, Eric; Di Maio, Antonio; Braun, Torsten (2023). DISNET: Distributed Micro-Split Deep Learning in Heterogeneous Dynamic IoT. In *IEEE internet of things journal*, September 2023, IEEE (10.1109/JIOT.2023.3313514).
- O. Rodrigues, Diego; M. de Souza, Allan; Braun, Torsten; Maia, Guilherme; A. F. Loureiro, Antonio; A. Villas, Leandro (2023). Service Provisioning in Edge-Cloud Continuum Emerging Applications for Mobile Devices. In *Journal of internet services and applications*, in press, Springer.
- Medeiros, Alisson; Di Maio, Antonio; Braun, Torsten; Neto, Augusto (2023). TENET: Adaptive Service Chain Orchestrator for MEC-enabled Low-latency 6DoF Virtual Reality. In *IEEE Transactions on Network and Service Management*, vol. 20, issue 3, submitted, IEEE.

Conference Papers

- Ajayi, Jesutofunmi; Di Maio, Antonio; Braun, Torsten; Xenakis, Dimitrios (2023). An Online Multi-dimensional Knapsack Approach for Slice Admission Control. In the *20th Consumer Communications &*

Networking Conference (CCNC23, Las Vegas), pp. 152-157, March 2023, IEEE (10.1109/CCNC51644.2023.10060460).

- Farhat, Yamshid; M. Lipsa, Gabriel; Braun, Torsten (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 *PES Innovative Smart Grid Technologies Europe Conference (ISGT-Europe22, Novi Sad)*, November 2022, IEEE (10.1109/ISGT-Europe54678.2022.9960540).

- Santos, Hugo; Rosário, Denis; Cerqueira, Eduardo; Braun, Torsten (2023). Multi-criteria Service Function Chaining Orchestration for Multi-user Virtual Reality Services. In the *Global Communications Conference (GLOBECOM22, Rio de Janeiro)*, January 2023, IEEE (10.1109/GLOBECOM48099.2022.10000827).

- Medeiros, Alisson; Di Maio, Antonio; Braun, Torsten; Neto, Augusto (2023). Service Chaining Graph: Latency- and Energy-aware Mobile VR Deployment over MEC Infrastructures. In the *Global Communications Conference (GLOBECOM22, Rio de Janeiro)*, January 2023, IEEE (10.1109/GLOBECOM48099.2022.10001403).

- Xenakis, Dimitrios; Di Maio, Antonio; Braun, Torsten (2023). ARLCL: Anchor-free Ranging-Likelihood-based Cooperative Localization. In the *24th International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM23, Boston)*, pp. 36-45, August 2023, IEEE (10.1109/WoWMoM57956.2023.00018).

- Xenakis, Dimitrios; Samikwa, Eric; Ajayi, Jesutofunmi; Di Maio, Antonio; Braun, Torsten; Schlegel, Katja (2023). Towards Personality Detection and Prediction using Smartphone Sensor Data. In the *21st Mediterranean Communication and Computer Networking Conference (MedComNet23, Island of Ponza)*, July 2023, IEEE (10.1109/MedComNet58619.2023.10168869).

- O. Rodrigues, Diego; Braun, Torsten; Guilherme, Maia; Leandro, Villas (2022). Mobility-aware Software-Defined Service-Centric Networking. In the *31st International Conference on Computer Communications and Networks (ICCCN22, Honolulu)*, pp. 1-10, September 2022, IEEE (10.1109/ICCCN54977.2022.9868869).

- O. Rodrigues, Diego; Braun, Torsten; Maia, Guilherme; Villas, Leandro (2023). Mobility-aware Latency-constrained Data Placement in

SDN-enabled Edge Networks. In the *IEEE/IFIP Network Operations and Management Symposium (NOMS23, Miami)*, June 2023, IEEE (10.1109/NOMS56928.2023.10154445).

- Pacheco, Lucas; Braun, Torsten (2022). Distributed Optimal-Transport Clustering for Malicious User Rejection in Federated-Learning VANETs. In the *3rd KuVS Fachgespräch "Machine Learning & Networking" (Malene22, Griebnitzsee)*, October 2022, Hasso-Plattner-Institut.

- Pacheco, Lucas; Braun, Torsten (2023). Asynchronous Federated Learning for Personalized Healthcare: Enhancing Privacy and Efficiency through Machine Learning and Computer Networking Integration. In *Bern Data Science Day (Bern)*, May 2023, Unibe Data Science Lab.

- Samikwa, Eric; Braun, Torsten (2022). Resource-Aware Distributed Machine Learning on Heterogeneous IoT Devices. In the *3rd KuVS Fachgespräch "Machine Learning & Networking" (Malene22, Griebnitzsee)*, October 2022, Hasso-Plattner-Institut (10.48350/175295).

- Samikwa, Eric; Braun, Torsten (2023). Dynamic Federated Learning for Heterogeneous Learning Environments. In *Bern Data Science Day (Bern)*, May 2023, Unibe Data Science Lab (10.48350/182489).

- Samikwa, Eric; Schärer, Jakob; Braun, Torsten; Di Maio, Antonio (2023). Machine Learning-based Energy Optimisation in Smart City Internet of Things. In the *24th International Symposium on Theory, Algorithmic Foundations, and Protocol Design for Mobile Networks and Mobile Computing (MobiHoc23 Workshops, Washington)*, in press, ACM (10.1145/3565287.3616527).

- Di Maio, Antonio, Aghaei Dinani, Mina, and Rizzo, Gianluca (2023). The Upsides of Turbulence: Baselining Gossip Learning in Dynamic Settings. In the *24th International Symposium on Theory, Algorithmic Foundations, and Protocol Design for Mobile Networks and Mobile Computing (MobiHoc23 Workshops, Washington)*, in press, ACM (10.1145/3565287.3616530)

- Schaerer, Jakob; Braun, Torsten (2022). A Distributed Calibration Certificate Infrastructure. In the *4th Conference on Blockchain Research & Applications for Innovative Networks and Services (BRAINS22, Paris)*, October 2022, IEEE (10.1109/BRAINS55737.2022.9909437).

- Schaerer, Jakob; Di Maio, Antonio; Braun, Torsten (2022). SecureAoX: A Location Verification System. In the *14th IFIP Wireless and Mobile Networking Conference (WMNC22, Sousse)*, pp. 38-45, November 2022, IEEE (10.23919/WMNC56391.2022.9954303).

- Schaerer, Jakob; Di Maio, Antonio; Braun, Torsten (2023). APS: An Auditable Positioning System Based on Angle-of-Arrival Proof of Location and Graph of Trust. In the *International Conference on Pervasive Computing and Communications Workshops and other Affiliated Events (PerCom23 Workshops, Atlanta)*, pp. 446-452, June 2023, IEEE (10.1109/PerComWorkshops56833.2023.10150318).

- Emami, Negar; Di Maio, Antonio; Braun, Torsten (2022). INTRAFORCE: Intra-Cluster Reinforced Social Transformer for Trajectory Prediction. In the *18th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob22, Thessaloniki)*, November 2022, IEEE. (10.1109/WiMob55322.2022.9941547).

- Emami, Negar; Di Maio, Antonio; Braun, Torsten (2023). FedForce: Network-adaptive Federated Learning for Reinforced Mobility Prediction. In the *48th Conference on Local Computer Networks (LCN23, Florida)*, in press, IEEE (10.1109/LCN58197.2023.10223407).

- Emami, Negar; Di Maio, Antonio; Braun, Torsten (2023). GTP-Force: Game-Theoretic Trajectory Prediction through Distributed Reinforcement Learning. In the *20th International Conference on Mobile Ad-Hoc and Smart Systems (MASS23, Toronto)*, in press, IEEE (10.48350/182255).

- Farhat, Yamshid; M. Lipsa, Gabriel; Braun, Torsten (2023). How Network Tariffs Impact the Optimal Design of Local Energy Systems: A Swiss Case Study In the *PES Innovative Smart Grid Technologies Europe Conference (ISGT-Europe23, Grenoble)*, in press, IEEE

5 Computer Graphics Group

5.1 Personnel

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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

Locally Meshable Frame Fields

The main robustness issue of state-of-the-art frame field based hexahedral mesh generation algorithms originates from non-meshable topological configurations, which do not admit the construction of an integer-grid map but frequently occur in smooth frame fields. In this project, we investigate the topology of frame fields and derive conditions on their meshability, which are the basis for a novel algorithm to automatically turn a given non-meshable frame field into a similar but locally meshable one. Despite local meshability is only a necessary but not sufficient condition for the stronger requirement of meshability, our algorithm increases the 2% success rate of generating valid integer-grid maps with state-of-the-art methods to 58%, when compared on the challenging HexMe dataset. The source code of our implementation and the data of our experiments are available at `https://lib.algohex.eu`.

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

T-Mesh Quantization using Flows in Bi-Directed Networks

We study the T-mesh quantization problem, a core component of state-of-the-art quadrangular (re-)meshing methods. Its goal is to assign integer lengths to a polygonal surface decomposition subject to linear constraints that guarantee the meshability of the individual patches. The objective is an application-dependent per-variable separable convex function. State-of-the-art algorithmic pipelines typically solve quantization problems using commercial general-purpose branch-and-cut solvers, greedy heuristics, or a combination of the two. These approaches either do not scale well with input complexity or deliver suboptimal result quality. We investigate how this and other integer optimization problems can be expressed by generalizing minimum-cost flow problems. Classic flow problems have been intensely studied for decades in computer science and can be solved efficiently and always have integer optimal solutions. However, they are too limited to model the constraints of quantization problems. We introduce the Minimum-Deviation-Flow Problem in bi-directed networks (Bi-MDF) and demonstrate its use in modeling and efficiently solving different kinds of T-Mesh quantization problems. In bi-directed networks, edges can have two heads or two tails, greatly expanding modeling capabilities. While not all desirable properties of classic flow problems are preserved, its constraints still contain useful structure compared to general linear integer constraints. This structure enabled our development of efficient algorithms for approximating and exactly solving Bi-MDF problems. We extended QuadWild (a SOTA quad meshing tool) with our solver and compared quantization quality and runtime with their original implementation. On the authors' 300 dataset, our exact solver finishes after only 0.49Additionally, we developed a novel half-arc-based T-Mesh quantization formulation that extends the feasible quantization solution space to include previously unattainable quad meshes. The Bi-MDF problem is more general than our application in layout quantization, potentially enabling similar speedups for other optimization problems that fit into the scheme.

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

Expansion Cones: A Progressive Volumetric Mapping Framework

Volumetric mapping is a ubiquitous and difficult problem in Geometry Processing and has been the subject of research in numerous and various directions. While several methods show encouraging results, the field still lacks a general approach with guarantees regarding map bijectivity. Through this work, we aim at opening the door to a new family of methods by providing a novel framework based on the concept of progressive expansion. Starting from an initial map of a tetrahedral mesh whose image may contain degeneracies but no inversions, we incrementally adjust vertex images to expand degenerate elements. By restricting movement to so-called expansion cones, the number of degenerate elements decreases in a strictly monotonic manner, without ever introducing any inversion. Adaptive local refinement of the mesh is performed to facilitate this process. We developed a prototype algorithm in the realm of this framework for the computation of maps from ball-topology tetrahedral meshes to convex or star-shaped domains. This algorithm was evaluated and compared to state-of-the-art methods, demonstrating its benefits in terms of bijectivity. We also benchmarked the associated cost in terms of sometimes significant mesh refinement to obtain the necessary degrees of freedom required for establishing a valid mapping. This work was published in ACM's Transactions On Graphics journal (TOG) and presented at the SIGGRAPH '23 conference.

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

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

Frame-fields in 2D and 3D have become an important ingredient of computer graphics and geometry processing algorithms, e.g. mesh genera-

tion, architectural geometry, or sketch vectorization. The prototypical task of a frame-field generator consists of finding the smoothest field that obeys problem-specific alignment constraints. Available methods typically discretize the frame field on the same mesh that is used to discretize the underlying domain and its boundary constraints. This is problematic since the required resolution to faithfully capture the local field rotation is not known apriori. In practice, this dilemma usually results in either suboptimal runtime caused by a conservative choice of mesh resolution everywhere, or alternatively, low accuracy resulting from meshes that are solely optimized to faithfully represent the domain itself but do not provide sufficient degrees of freedom for accurately representing a smooth frame-field. Following on our previous successful work on 2D adaptive cross-field generation, we have extended our method to work in three dimensions. Because our method does not work on a fixed discretization, we have also extensively investigated how to compare two frame fields generated on different samplings of the domain. This is not a trivial task since the way the smoothness of the field is measured depends significantly on the sampling we do. In the last part, we have focused particularly on improving the performance of our method: specifically, we have developed an approach that allows for refining almost fully in parallel for our octree (or quadtree) while providing an optimal memory layout of our data without any additional step. Compared to established frame-field optimizers on tetrahedral meshes, which in contrast to our approach require the solution of large linear systems, the runtime to obtain a field of similar accuracy is reduced by several orders of magnitude. Another benefit of our adaptive technique is that it solely requires a specification of alignment conditions as input, and therefore easily supports a wide range of different applications.

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

Globally Meshable Frame Fields

It is a common practice in engineering modelling to first do numerical experiments to find out the best design that fits the requirements, and only

after the numerical investigation is complete, the first prototypes are being assembled in form. During the modelling stage, the biggest time sink is the geometrical design, as Danielle Panozzo pointed out in one of his recent reviews. This is because the industry standard way of modelling shapes is by going from CAD-model to underlying hex-mesh, and given that to this day there is no fully automated hex-mesh pipeline that can generate a satisfactory (meaning different criteria imposed on the mesh quality by the FEM software, etc) mesh automatically, this process is done semi-manually. One can imagine very difficult geometries of the engine parts, that are meshed in that fashion and the human effort that is invested into this suddenly becomes clear. With that in mind, search for an automated hex-meshing pipeline is a lucrative task. Among different approaches to hex-meshing, Frame-Field based one seems most attractive because it promises to deliver boundary aligned and reasonably low distorted hex-meshes automatically, that are ready to use with the FEM software. This method, however, still suffers from robustness issues. The goal of this project is to mitigate a core robustness issue - Global Meshability. As discussed in the Doctoral Thesis of our colleague, Heng Liu, an arbitrary smooth Frame-Field for a given mesh, has more degrees of freedom that globally meshable one. Mathematically, this is sound since the space of smooth vector fields over the smooth manifold is itself not a free module, i.e. a global basis cannot be assumed. Global hex-meshability of the Frame-Field as a property is by itself very close to parallelizability (at least component-wise), which is for smooth manifolds essentially equal to a space if vector fields to have a global basis. In fact, for hex-meshable frame field it is possible to provide a volume decomposition such that each individual region of the field is singularity-free (and thus parallelizable). Following this, the current approach to the problem is to start with a smooth Frame-Field that is generated for an input tet-mesh by state-of- the-art algorithms, convert it to a locally meshable one, and then convert it to a globally meshable one. The idea is to find an input manifold decomposition into the locally parallelizable subdomains, and then accurately stitch these regions together. To do so, we start with a locally meshable Frame-Field and compute a singular graph first. Having that, for each network of connected singular arcs we spawn a set of separating surfaces and grow them until we reach the boundary. Next, using the surfaces and the singularity graph, we find inconsistencies in the structure and correct them such that each of the individual volumes becomes locally meshable. During the course of the year, the surface integrator has been developed. The development of the mechanism for detection/correction of the inconsistencies of the different kind is in its initial stages.

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

Metric-Based 3D Frame-Field Generation

Frame-field-based approaches are one of the most promising in the current hex meshing research. So far, those mostly utilize orthonormal frame fields that are represented as sets of six cubic-symmetrical unit vectors. As an advantage, such frame fields are relatively straightforward in implementation and usage; however, they are deficient when it comes to non-orthogonal, highly nonuniform hexahedral meshes, which are the most common types of meshes in the industry. This project explores the metric-based method of generating non-orthogonal frame fields, which was previously described in Fang et al. The metric-based approach proved to be quite effective in quad meshing, however, the 3D models received rather limited attention so far. The idea of this approach is to extend the notion of orthonormal frame fields to a g-orthonormal one, where a frame is represented by its metric part g and a cross-field, i.e. $F = g^{-\frac{1}{2}}R$. Intuitively, one can get the idea that we can simply use existing methods designed for orthonormal methods on the orthonormal part, but that would not yield the result we are after. The metric part is supposed to guide the frame field computation so that the resulting frame field topology is more expressively adapted to certain features (encoded within metric) of the model, which should allow the local adaptivity for the resulting hex mesh. For orthonormal frame fields, the smoothness measure is the norm of the gradient. For the non-orthonormal ones described above this measure can be extended to the norm of the covariant derivative under the connection induced by the metric, which makes the smoothness measure and the parameterization metric-aware. Boundary alignment constraints are reformulated as well to take the metric into account. It is important to note that the method needs a tetrahedral mesh as an input. We solve the optimization problem on energies using the spherical harmonics representation of the frame fields. The optimization is performed in two stages, where the initial step's solution is then used as an initial guess for the second optimization on Euler angles. Current work is focused on generating satisfactory frame fields and selecting the most suitable metric for particular models.

Research staff: Liubov Kamaldinova, 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 Ph.D. Theses

- Heng Liu, "Frame Fields for Hexahedral Mesh Generation", April 2023.

5.5 Master's Theses

- Dave Meier, "3D building planimetry from unaligned point clouds", July 2022.

5.6 Bachelor's Theses

- Luca Schaller, "Up to 58 Tets/Hex to untangle Hex meshes", November 2022.
- Julius Oeftiger, "Rust-V Physically Based Spectral Rendering", July 2022.

5.7 Awards

- Honorable Mention at ACM SIGGRAPH 2023, Martin Heistermann, Jethro Warnett, David Bommes: *M*in-Deviation-Flow in Bi-directed Graphs for T-Mesh Quantization.
- Seminal Graphics Papers, 50th anniversary ACM SIGGRAPH, David Bommes, Henrik Zimmer, Leif Kobbelt: *M*ixed-Integer Quadrangulation.
- Recognition of Outstanding Teaching Achievements for the lecture "Computer Graphics" in Autumn Semester 2022, among the top 6 (out of 179) courses offered by the Faculty of Sciences at the University of Bern, David Bommes, Simone Raimondi.

5.8 Further Activities

Invited Talks

David Bommes

- “Locally Meshable Frame Fields”. Geometry Workshop, Innsbruck, Austria, August 2023.
- “Singularity Optimization for High-Quality Integer-Grid Maps”. FRAMES 2023, Nancy, France, August 2023.
- “Hexahedral Mesh Generation with Integer-Grid Maps”. SSD Seminar Series, RWTH Aachen University, Germany, December 2022.

Presentations

Martin Heistermann

- “Min-Deviation-Flow in Bi-Directed Graphs for T-Mesh Quantization”. ACM SIGGRAPH, Los Angeles, August 2023.

Heng Liu

- “Locally Meshable Frame Fields”. ACM SIGGRAPH, Los Angeles, August 2023.
- “Locally Meshable Frame Fields”. FRAMES, Nancy, August 2023.

Valentin Zénon Nigolian

- “Expansion Cones: A Progressive Volumetric Mapping Framework”. ACM SIGGRAPH, Los Angeles, August 2023.
- “Expansion Cones: A Progressive Volumetric Mapping Framework”. FRAMES, Nancy, August 2023.

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 2023, Conference Co-Chair, August 24-25, 2023, Nancy, France

Conference Program Committees

David Bommes

- ACM SIGGRAPH 2023
- EUROGRAPHICS (EG) 2022
- EUROGRAPHICS STARs (EG STARs) 2023
- Symposium on Geometry Processing (SGP) 2022 & 2023
- Geometric Modeling and Processing (GMP) 2022
- Solid and Physical Modeling (SPM) 2022 & 2023
- Vision, Modeling and Visualization (VMV) 2022 & 2023

Reviewing Activities

David Bommes

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

PhD Committee Memberships

David Bommes

- Aeyyedmohammad Moulaeifard (PhD Jury), RWTH Aachen University, December 12, 2022

5.9 Publications

Journal Publications

- Heng Liu, David Bommes: “Locally Meshable Frame Fields”, ACM Transactions on Graphics, Volume 42(4), (Proc. **ACM SIGGRAPH**), 2023.
- Martin Heistermann, Jethro Warnett, David Bommes: “Min-Deviation-Flow in Bi-Directed Graphs for T-Mesh Quantization”, ACM Transactions on Graphics, Volume 42(4), (Proc. **ACM SIGGRAPH**), 2023, **Honorable Mention**.
- Valentin Zénon Nigolian, Marcel Campen, David Bommes: “Expansion Cones: A Progressive Volumetric Mapping Framework”, ACM Transactions on Graphics, Volume 42(4), (Proc. **ACM SIGGRAPH**), 2023.
- Maxence Reberol, Kilian Verhetsel, François Henrotte, David Bommes, Jean-François Remacle: “Robust Topological Construction of All-Hexahedral Boundary Layer Meshes”, ACM Transactions on Mathematical Software, Volume 49(1), 2023.
- Mohammad Moulaeifard, Florian Wellmann, Simon Bernard, Miguel de la Varga, David Bommes: “Subdivide and Conquer: Adapting Non-Manifold Subdivision Surfaces to Surface-Based Representation and Reconstruction of Complex Geological Structures”, Mathematical Geosciences, Volume 55, 2022.

6 Computer Vision Group

6.1 Personnel

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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 deconvolution, 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

Spatio-Temporal Crop Aggregation for Video Representation Learning

We propose Spatio-temporal Crop Aggregation for video representation LEarning (SCALE), a novel method that enjoys high scalability at both training and inference time. Our model builds long-range video features by learning from sets of video clip-level features extracted with a pre-trained backbone. To train the model, we propose a self-supervised objective consisting of masked clip feature predictions. We apply sparsity to both the input, by extracting a random set of video clips, and to the loss function, by only reconstructing the sparse inputs. Moreover, we use dimensionality reduction by working in the latent space of a pre-trained backbone applied to single video clips. These techniques make our method not only extremely efficient to train but also highly effective in transfer learning. We demonstrate that our video representation yields state-of-the-art performance with linear, nonlinear, and k-NN probing on common action classification and video understanding datasets.

Research staff: Sepehr Sameni, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690, and an Adobe Reward.

Semi-supervised Learning

We introduce a new distribution-aware label refinement strategy where the predictions of the model are derived from the labels posterior distribution. Unlike other buffer-based semi-supervised methods such as CoMatch and SimMatch, our method explicitly addresses imbalances in the global data distribution while maintaining local sensitivity. This explicit control allows

us to be more robust w.r.t confirmation bias, especially under class imbalance. We show that we improves performance when paired with different Semi-Supervised methods such as FixMatch, ReMixMatch, SimMatch and FreeMatch and different pre-training strategies. We achieve state-of-the-art results under different degrees of class imbalance on standard CIFAR10-LT/CIFAR100-LT especially in the low data regime and improve prove performance compared to a new competitive baseline on the more challenging benchmarks SemiAves, SemiCUB, SemiFungi and Semi-iNat.

Research staff: Abdelhak Lemkhenter, Paolo Favaro

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. One problem with the current image representations is they are computed using every pixel in the image. This may cause problems if the image contains irrelevant content such as other objects in the background. Our current intuition to tackle this problem is to perform unsupervised semantic segmentation so that the scene would be divided into objects. Thus, it would be possible to compute image representations only based on relevant image pixels. To achieve an unsu-

pervised semantic segmentation, we utilize an inpainting paradigm. The assumption is it would not be possible to inpaint the image if the object is completely removed. Although there are some methods in the literature applying this principle successfully to perform semantic segmentation, we aim to perform the same thing in the feature space of a well-known self-supervised method for getting image representation. Therefore, we aim to reduce some issues encountered in the pixel space (e.g. same color on the object and the background).

Research staff: Alp Eren Sari, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

Sparse 3D Reconstruction via Object-Centric Ray Sampling

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 Novel View Generation with Generative Model

In this project, we aim to generate novel views of an object given only a single view of that object. We train our model on a collection of images in the wild of the same category but without information about the pose of the main object in the view and without multiple views of the same object instance. More specifically, our model is a pose-conditioned generative model. To obtain the pose encodings we leverage the emerging properties of recent self-supervised image representations, namely DINOv2. First, we center and rescale the objects in the images given the segmentation masks obtained by finding the main direction of variance in the DINOv2 feature space. We then cluster the dataset based on the Euclidean distance in the space spanned by the first 3 PCA components of the DINOv2 patch embeddings.
Finally, a conditional diffusion model is trained to generate images given the pose. At the inference time, we generate consistent novel views for all pose labels by adjusting self-attention values in the diffusion model.

Research staff: Llukman Cerkezi, Aram Davtyan, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

Zero-shot Image Restoration via Diffusion Inversion

In this project, we present a novel zero-shot framework for solving Image Restoration (IR) tasks, including but not limited to image super-resolution, inpainting, compressed sensing, and blind deconvolution. Our method uses a pre-trained off-the-shelf diffusion model as an unbiased generative prior of the restored image, without requiring any extra training or network modifications.In contrast to prior work, we parameterize restored images as a deterministic function of the input noise in the diffusion model. To mitigate the substantial computational cost associated with inverting a fully unrolled diffusion model, we leverage the inherent capability of these models to skip ahead in the forward diffusion process by arbitrary time steps.

Research staff: Hamadi Chihaoui, Abdelhak lemkhenter, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

When Self-Supervised Pre-training Meets Single Image Denoising

In this project, we present a self-supervised pre-training scheme for single image denoising based on a novel pretext task. Our work is inspired by the success of self-supervised learning (SSL) methods in transfer learning. These methods have been shown to be extremely effective when used to pretrain a model that is then fine-tuned on small datasets. As pretext task, we propose to train a denoising network on patches of the downsampled input image, which we treat as pseudo-clean image patches, and an adaptive noise estimator to learn the specific noise distribution of the input image. By carrying out the pre-training on the single input image, rather than on a separate dataset, we avoid the well-known noise distribution gap between images in the training dataset and the single input image used at test time.

Research staff: Hamadi Chihaoui, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

Efficient Video Prediction via Conditional Flow Matching

Building a precise and reliable predictive model of the environment from a video dataset is the first step towards designing controllable generative models and serves as a necessary building block to do planning to solve downstream tasks. Prior work in video generation suffers from the high computational costs of modeling the past during training and inference. We propose to solve this issue by introducing RIVER, a model that uses flow matching as a backbone and conditions only on a small random set of past frames at each integration step of the image generation process. Moreover, to enable the generation of high-resolution videos and to speed up the training, we work in the latent space of a pretrained VQGAN. We show that RIVER achieves superior or on par performance compared to prior work on common video prediction benchmarks, while requiring an order of magnitude fewer computational resources.

Research staff: Aram Davtyan, Sepehr Sameni, 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. 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. 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 and the actions assigned to the agents. To this end, we propose YODA, a novel unsupervised method to autoregressively generate videos from a single frame and a sparse motion input. Our trained model can generate realistic object-to-object interactions and separate the dynamics and the extents of multiple objects despite only observing them under correlated motion activities. We show both qualitatively and quantitatively that YODA accurately follows the user control, while yielding a video quality that is on par with or better than state-of-the-art video generation prior work on several datasets.

Research staff: Aram Davtyan, Paolo Favaro

Financial support: Swiss National Science Foundation Project No. 188690

E-COVER: Events-Conditioned Video Reconstruction via Flow Matching

Event-based vision is a novel approach to Computer Vision using a non-traditional type of sensor. This field is not mature (no more than 15 years of research have passed since the appearance of the first commercially available event sensor). The main difference lies in the way the scene is recorded: with the help of an event camera, we can only register the

difference in the logarithms of the intensities (illuminations) of each pixel independently. This gives us the ability to record with extremely high dynamic range and frame rate. With qualitative image intensity reconstruction as a preprocessing step, we can use current state-of-the-art algorithms working with conventional images as input and improve the quality of the entire system while maintaining the benefits of event sensors. We propose a novel approach to reconstruct image intensities (in the form of a video sequence) from only event streams. Reconstructing images from events is challenging because multiple image sequences could yield the same sequence of events. We handle the inherent ambiguity of this task by using a diffusion model that learns to generate a distribution of images corresponding to the same events. Another challenge in addressing this task is that events are generated only when objects move or, if they emit light, change their color. Thus, to still take into account such non-moving structures, existing methods use auto-regressive models to accumulate the events history into a single current frame and predict the next frame based on the current frame and the arrival of new events. However, because diffusion models are slow at generating frames, they are not suitable for training in an auto-regressive manner. As a solution, we propose a much simpler, yet effective, diffusion feed-forward model where the history of the events is directly handled by accumulating a fixed number of events, regardless of when they were generated in the past. We call our method **E**vents-**co**nditioned **V**id**e**o **R**econstruction via Flow Matching, or, in short, E-COVER. In order to validate the effectiveness of E-COVER, we conduct extensive experiments on multiple datasets, designed specifically for event-based vision. We demonstrate that E-COVER achieves on-par or even superior results compared to prior work, despite using a simple feed-forward model.

Research staff: Viktor Shipitsin, Paolo Favaro

Financial support: CVG

6.4 Ph.D. Theses

- Abdelhak Lemkhenter, “Novel Techniques for Robust and Generalizable Machine Learning.”, August 2023.
- Luigi Fiorillo, “Automated Sleep Scoring, Deep Learning and Physician Supervision”, October 2022

6.5 Master's Theses

- Seyedeh Sharareh Mirzargar, "Machine Learning Based Prediction of Mental Health Using Wearable-measured Time Series", July 2022
- Ariane Hanbi Lee, "A multivariate time series prediction using statistical models and artificial neural networks", November 2022
- Tony Licata, "Assessment of movement and pose in a hospital bed by ambient and wearable sensor technology in healthy subjects", September 2022

6.6 Bachelor's Theses

- Timo Blattner, "New Variables of Brain Morphometry: the Potential and Limitations of CNN Regression", August 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 2022

Invited Talks

Paolo Favaro

- "Unsupervised Segmentation Learning with MOVE", Google Computational Imaging Workshop, August 2022

- “Towards Self-Learning”, GCPR 2022 Keynote.
- “Towards Scalable Learning”, Swiss Faculty Retreat, March 2022.

Presentations

Aram Davtyan

- “Efficient Video Prediction via Sparsely Conditioned Flow Matching”, Oral, GCPR, September 2023.
- “Controllable Video Generation through Local and Global Motion Dynamics”, Poster, GCPR, September 2023.
- “KOALA: A Kalman Optimization Algorithm with Loss Adaptivity”, Poster, GCPR, September 2023.
- “Learn the Force We Can: Multi-Object Video Generation from Pixel-Level Interactions”, Poster, International Computer Vision Summer School, July 2023.

Sepehr Sameni

- “Efficient Video Prediction via Sparsely Conditioned Flow Matching”, Oral, GCPR, September 2023.
- “Spatio-Temporal Crop Aggregation for Video Representation Learning”, Poster, GCPR, September 2023.
- “Representation Learning by Detecting Incorrect Location Embeddings”, Poster, GCPR, September 2023.
- “KOALA: A Kalman Optimization Algorithm with Loss Adaptivity”, Poster, GCPR, September 2023.

Seminars Given by External Speakers

- Timo Blattner, “New Variables of Brain Morphometry: the Potential and Limitations of CNN Regression”, September 23, 2022.
- Yuki Asano, “Self-supervised Learning from Images, and Augmentations”, December 9, 2022.
- Karsten Kreis, “Advanced Diffusion Models: Accelerated Sampling, Smooth Diffusion, and 3D Shape Generation”, December 22, 2022.

- Tengda Han, “Understanding Long Videos with Minimal Supervision”, March 17, 2023.
- Guillermo Gallego, “Event-based optical flow and stereo depth estimation using contrast maximization”, April 17, 2023.

Conference Program Committees and Reviews

Paolo Favaro

- CVPR 2022 and 2023 Area Chair

Abdelhak Lemkhenter

- ICCV 2023 Reviewer

Journal Committees

Paolo Favaro

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

Aram Davtyan

- ACM Transactions on Graphics Reviewer

Refereed Conference Proceedings

- A. Davtyan, S. Sameni, P. Favaro, “Efficient Video Prediction via Sparsely Conditioned Flow Matching”, in International Conference on Computer Vision (ICCV), 2023.
- S. Sameni, S. Jenni, P. Favaro, “Spatio-Temporal Crop Aggregation for Video Representation Learning”, in International Conference on Computer Vision (ICCV), 2023.
- S. Sameni, S. Jenni, P. Favaro, “Representation Learning by Detecting Incorrect Location Embeddings”, in AAAI Conference on Artificial Intelligence, 2023.
- L. Fiorillo, D. Pedroncelli, V. Agostini, P. Favaro and F. D. Faraci, “Multi-Scored Sleep Databases: How to Exploit the Multiple-Labels in Automated Sleep Scoring”, in Sleep Journal, 2023.

- L. Fiorillo, G. Monachino, J. Meer, M. Pesce, J. Warncke, M. H. Schmidt, C. L.A. Bassetti, A. Tzovara, P. Favaro and F. D. Faraci, “U-Sleep: resilient to AASM guidelines”, in npj Digital Medicine, 2023.
- A. Bielski, P. Favaro, “MOVE: Unsupervised Movable Object Segmentation and Detection”, in Conference on Neural Information Processing Systems (NeurIPS), 2022.
- Yanbei Chen, Manchen Wang, Abhay Mittal, Zhenlin Xu, Paolo Favaro, Joe Tighe, Davide Modolo, “ScaleDet: A scalable multi-dataset object detector”, in the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2023.
- Achin Jain, Gurumurthy Swaminathan, Paolo Favaro, Hao Yang, Avinash Ravichandran, Hrayr Harutyunyan, Alessandro Achille, Onkar Dabeer, Bernt Schiele, Ashwin Swaminathan, Stefano Soatto, “A Meta-Learning Approach to Predicting Performance and Data Requirements”, in the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2023.
- Zhaowei Cai, Avinash Ravichandran, Paolo Favaro, Manchen Wang, Davide Modolo, Rahul Bhotika, Zhuowen Tu and Stefano Soatto, “Semi-supervised Vision Transformers at Scale”, in 36th Conference on Neural Information Processing Systems (NeurIPS), 2022.

7 Cryptology and Data Security Group

7.1 Personnel

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	F.-X. Wicht	email: francois-xavier.wicht@unibe.ch (as of 01.03.2023)
	L. Zanolini	email: luca.zanolini@unibe.ch (until 31.01.2023)

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, Michael Senn, 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. We are also 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.
Moreover, we have used methods from epistemic logic to analyze *group knowledge*, the knowledge that multiple parties in a group obtain when they share their local knowledge. The traditional interpretation does not account for relations between the parties. We have formulated the notion of *synergistic knowledge* that allows to model those relationships. As examples, we have considered investigate the use of consensus objects and the problem of the dining cryptographers.

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

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

Analysis of existing consensus protocols

Avalanche is a blockchain consensus protocol with exceptionally low latency and high throughput and stands behind the AVAX cryptocurrency. The protocol uses random sampling of peer nodes, forms a directed acyclic graph (DAG) instead of a chain, and does not totally order all transactions. We have provided the first abstract specification and a matching formal analysis of Avalanche consensus. It shows that the protocol fulfills the notion of generic broadcast, which only orders related transac- tions. The work also describes a vulnerability that affects the liveness of the protocol and proposes a possible fix for the problem.

Research staff: Ignacio Amores-Sesar, Christian Cachin, Philipp Schneider.

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: Jayamine Alupotha, Christian Cachin, Duc V. Le, Luca Zanolini.

Financial support: Protocol Labs (`https://protocol.ai`), 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, Orestis Alpos, Mariarosaria Barbaraci, Noah Schmid, Michael Senn.

Financial support: Ripple University Blockchain Research Initiative (UBRI) and Ripple Impact Fund, donation.

Digital currencies for central banks

Cryptocurrencies have shown how to realize a secure equivalent of money in a purely digital way. They challenge the role of traditional currencies, which are issued by central banks. Central banks have therefore started to investigate digital currencies, and many are exploring how to issue a central-bank digital currency (CBDC) to consumers for this purpose. By making such Retail CBDCs accessible to households, the existing relationships between central banks, commercial banks, and people will undergo fundamental changes.

This interdisciplinary research project addresses the topic from two perspectives: law and computer science. Key questions concern the legal and technical requirements for cash-like CBDCs, the fundamental normative principles that should apply, and the algorithmic approaches that are available. In particular, there is a strong tension between privacy and data-protection demands, which exist for traditional cash in certain forms, and the objectives of various societal norms that aim to prevent tax evpasion, money laundering, and so on.
This project is in collaboration with Mirjam Eggen and team at the Institute for Civil Law.

Research staff: Christian Cachin, François-Xavier Wicht.

Financial support: Office for Digitalization (Digitalisierungskommission, DigiK), University of Bern.

7.4 Ph.D. Theses

- "Asymmetric Trust in Distributed Systems." Luca Zanolini, July 2023.

7.5 Master's Theses

- "Solana Consensus Protocol." Elias Wipfli, Spring 2023.
- "Balance attack on a forkable blockchain'." Marcel Zauder, Spring 2023.
- "Exploring threshold cryptosystems." Michael Senn, Spring 2023.
- "Blockchain privacy notions using the transaction graph model." François-Xavier Wicht, Fall 2022.
- "Concurrent distributed storage protocols." Marco Cacciatore, Fall 2022.

7.6 Bachelor's Theses

- "Implementing and evaluating protocol $\Pi 3$ in BlockSim." Lawrence Chiang, Spring 2023.

- "E-Voting verifier for the Swiss Post voting system." Marc Günter, Fall 2022.
- Marko Cirkovic, "Cryptographic primitives for on-chain tumbler designs", Spring 2022.
- "Security in the NFT world." Noé Bayard, Fall 2022.
- "Benchmarking threshold signatures for consensus protocols." Julien Brunner, Fall 2022.

7.7 Further Activities

Talks

Christian Cachin

- "Consensus in blockchains: Overview and recent results." **Invited talk**, University of St. Gallen, Switzerland, June 2023.
- "Consensus in blockchains: Overview and recent results." **Distinguished Lecture**, Vienna Cybersecurity and Privacy Research Cluster, Technische Universität Wien, Austria, June 2023.
- "Asymmetric Byzantine consensus ." Initiative for Cryptocurrencies and Smart Contracts (IC3), retreat, Les Diablerets, Switzerland, January 2023.

Orestis Alpos

- Member of panel "The Future of Cryptography – Challenges and Key Technologies." Cyber-Defence Campus Conference, Bern, October 2022.

Mariarosaria Barbaraci

- "Thetacrypt: A Distributed Service for Threshold Cryptography on Chain." DEBS Conference, Doctoral Symposium, Neuchatel, June 2023.

Jovana Mićić

- "Quick Order Fairness." IOHK seminar, online, March 2023.

- “Quick Order Fairness.” Initiative for Cryptocurrencies and Smart Contracts (IC3), retreat, Les Diablerets, Switzerland, January 2023.
- “Quick Order Fairness.” Presentation to Chainlink, Lausanne, Switzerland, June 2023.

François-Xavier Wicht

- "A Formal Evaluation of Privacy in Monero." Monero Konferenco – Technical Conference in Privacy and Financial Technology, Prague, June 2023.
- "A Transaction-Level Model for Blockchain Privacy." DEBS Conference, Doctoral Symposium, Neuchatel, June 2023.

Luca Zanolini

- "Quorum Systems in Permissionless Networks." ConsensusDay 2022 Workshop, Los Angeles, November 2022.
- "Quorum Systems in Permissionless Networks." Presented at IC3 Winter Retreat, Les Diablerets, January 2023.

Editorial Boards

Christian Cachin

- Associate editor for Distributed Computing, 2015–2023, Springer.

Societies and Steering Committees

Christian Cachin

- Member of Steering Committee for ACM Conference on Advances in Financial Technologies (AFT), 2019–.

Conference Program Committees

Christian Cachin

- Member of Program Committee for 42nd Symposium on Principles of Distributed Computing (PODC 2023), Orlando (FL), USA.
- **Program Co-Chair** for Financial Cryptography and Data Security conference (FC'23), 2023.

Duc V. Le

- Member of Program Committee for Financial Cryptography and Data Security conference (FC'23), 2023.
- Member of Program Committee for ACM Symposium on Access Control Models and Technologies (SACMAT), 2023.

7.8 Publications

Journal Papers

- D. Lehnherr, Z. Ognjanovic, and T. Studer, “A logic of interactive proofs,” *Journal of Logic and Computation*, vol. 32, no. 8, pp. 1645–1658, 2022.

Conference Papers

- S. Azouvi, C. Cachin, D. V. Le, M. Vukolic, and L. Zanolini, “Modeling resources in permissionless longest-chain total-order broadcast,” in *Proc. 26th International Conference on Principles of Distributed Systems (OPODIS)* (E. Hillel, R. Palmieri, and E. Rivière, eds.), vol. 253 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pp. 19:1–19:23, Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2022.

- C. Cachin, G. Losa, and L. Zanolini, “Quorum systems in permissionless networks,” in *Proc. 26th International Conference on Principles of Distributed Systems (OPODIS)* (E. Hillel, R. Palmieri, and E. Rivière, eds.), vol. 253 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pp. 17:1–17:22, Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2022.

- I. Amores-Sesar, C. Cachin, and E. Tedeschi, “When is spring coming? A security analysis of Avalanche consensus,” in *Proc. 26th International Conference on Principles of Distributed Systems (OPODIS)* (E. Hillel, R. Palmieri, and E. Rivière, eds.), vol. 253 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pp. 10:1–10:22, Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2022.

- C. Cachin, J. Mićić, N. Steinhauer, and L. Zanolini, “Quick order fairness,” in *Proc. Financial Cryptography and Data Security (FC)* (I. Eyal and J. A. Garay, eds.), vol. 13411 of *Lecture Notes in Computer Science*, pp. 316–333, Springer, 2022.

Preprints and Other Publications

- Z. Wang, M. Cirkovic, D. V. Le, W. Knottenbelt, and C. Cachin, “Pay less for your privacy: Towards cost-effective on-chain mixers.” Cryptology ePrint Archive, Paper 2023/1222, Aug. 2023.

- O. Alpos, C. Cachin, S. Holmgaard Kamp, and J. Buus Nielsen, “Practical large-scale proof-of-stake asynchronous total-order broadcast.” Cryptology ePrint Archive, Paper 2023/1103, July 2023.
- O. Alpos, I. Amores-Sesar, C. Cachin, and M. Yeo, “Eating sandwiches: Modular and lightweight elimination of transaction reordering attacks.” e-print, arxiv:2307.02954 [cs.DC], 2023.
- O. Alpos and C. Cachin, “Do not trust in numbers: Practical distributed cryptography with general trust.” Cryptology ePrint Archive, Paper 2022/1767, Dec. 2022.

8 Logic and Theory Group

8.1 Personnel

Head:	Prof. Dr. T. Studer	Tel.: +41 31 684 39 84 email: thomas.studer@unibe.ch
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	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. Egger: Dynamic Logic for Verifiable Data Collection Processes

8.5 Bachelor's Theses

- J. Kunz: Shor's Algorithm
- D. Marti: Die Komplexitätsklasse BQP

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

Gerhard Jäger

- Explicit Mathematics Reloaded, The Proof Society: 4th International Workshop on Proof Theory, Utrecht, November 2022.

Thomas Studer

- Cut-elimination for Modal Logics with Fixed Points, Logic Seminar, Gothenburg, October 2022
- Cyclic Proofs, Computational Logic Seminar CUNY, New York City (online), November 2022
- Synergistic Knowledge, Epistemic and Topological Reasoning in Distributed Systems, Dagstuhl, July 2023

Atefeh Rohani

- Conditional Obligations in Justification Logic, Swiss Logic Gathering, Schwarzsee, March 2023

Lukas Zenger

- Cut-elimination for Non-wellfounded Proofs, Logic Seminar, Gothenburg, November 2022
- An Ill-founded Proof System for Intuitionistic Temporal Logic, Swiss Logic Gathering, Schwarzsee, March 2023

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, 26-30 September 2022
- Swiss Logic Gathering, Schwarzsee, 9-11 March 2023

8.7 Publications

- Gerhard Jäger, Simplified cut elimination for Kripke-Platek set theory, in: F. Ferreira, R. Kahle, G. Sommaruga (eds), Axiomatic Thinking II, Springer; 2022.
- Jan Rooduijn and Lukas Zenger, An analytic proof system for common knowledge logic over S5, in D. Fernández-Duque, A. Palmigiano, S.Pinchinat, editors, Proceedings of Advances in Modal Logic, pages 659 - 680, 2022

- David Lehnherr, Zoran Ognjanovic and Thomas Studer, A Logic of Interactive Proofs, Journal of Logic and Computation, 2022
- Thomas Studer and Atefeh Rohani, Explicit non-normal modal logic, Journal of Logic and Computation, in press, 2023
- Federico Faroldi, Thomas Studer and Atefeh Rohani, Conditional Obligations in Justification Logic, to appear in: Proceedings of Logic, Language, Information, and Computation - WoLLIC, 2023
- Mehdi Dastani, Beishui Liao, Jieting Luo and Thomas Studer, What Do You Care About: Inferring Values from Emotions (extended abstract), in A. Ricci, W. Yeoh, N. Agmon, B. An, editors, Proceedings of the 22nd International Conference on Autonomous Agents and Multiagent Systems, pages 2289-2291. IFAMAS, 2023
- Gerhard Jäger, Identity, Equality, and Extensionality in Explicit Mathematics, in: D. Bridges, H. Ishihara, M. Rathjen, H. Schwichtenberg (eds.), Handbook of Constructive Mathematics, Encyclopedia of Mathematics and Its Applications 185, Cambridge University Press, 2023

9 Pattern Recognition Group

9.1 Personnel

Head:	PD Dr. K. Riesen	Tel.: +41 31 684 4998 email: kaspar.riesen@unibe.ch
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	M. Fuchs	email: mathias.fuchs@unibe.ch
	A. Gillioz	email: anthony.gillioz@unibe.ch
	B. Fankhauser	email: benjamin.fankhauser@unibe.ch (as of 01.09.2022, externally financed)
	C. Masanti	email: corina.masanti@unibe.ch (as of 01.10.2022, externally financed)

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, L. Jia, 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

A PROSE - Advanced PROofreading SErvices

Current solutions for fully automated proofreading do not meet the requirements of many business customers of Rotstift, an SME that is offering proof-reading services in the three official Swiss languages (German, French, Italian) and English. Rotstift is currently focused on orthography,

grammar, punctuation, and typography. In these areas, unresolved challenges for automated proofreading exist, comprising detection of so-called real-word errors, compliance with specific typesetting rules and company-specific spelling guidelines, and ensuring the use of gender-neutral language. Further tasks that currently require better solutions are the automatic detection of subjective language and incorrect information (e.g. dates, addresses) in customer documents. The major challenge results from linguistic problems (e.g. ambiguities) combined with a specific lack of training data, which have hindered scientific progress and maturity of software solutions. Therefore, the aim of this project is to research and solve the identified scientific obstacles and build a reliable and advanced (semi-)automated proofreading and editing solution, which will be integrated into the proofreading process at Rotstift so that human effort is substantially reduced and Rotstift can scale up its services to a still growing demand, offering its services at a cheaper price to new customer segments. Since 2019 Rotstift has been collecting manually corrected documents digitally. Hence, there is now a large and unique collection of around 80'000 documents available that can be used to train and evaluate machine learning algorithms. This will be accompanied by an active learning approach where human proofreaders are involved proactively when the solution lacks confidence regarding its error detection. We aim at a solution that is able to recognize 80% of relevant errors with a precision of at least 70%, which we assume will be sufficient to significantly reduce the workload of human proofreaders.

Financial support: Innosuisse Project No. 101.128 IP-ICT

Research staff: C. Masanti, K. Riesen

Novel Paradigms for Machine Learning in Medicine

The overarching goal of the planned project1 is to research novel state-of-the-art algorithms in digital medicine using techniques from artificial intelligence and machine learning. In particular, we plan to develop algorithmic solutions and computational frameworks that can help practitioners analyze medical data from multiple sources to identify diseases, decide on the next step of treatment, determine potential problems, and improve the overall efficiency of care. Actually, hospitals all over the world started collecting large amounts of data. This data typically com- prise patient, laboratory, pathological, epidemiological, or medication data as well as

medical imaging and unstructured text data (e.g. diagnostic, transfer, or discharge reports). With its Insel Data Science Center (IDSC) the Inselspital Bern has also established a central hub for all data science related tasks – including the Insel Data Platform (IDP) as a data collection, preprocessing, and delivery platform.
Based on IDP, we plan to explore an integrated algorithmic framework capable of automatically learning possible diagnoses for multiple diseases and co-morbidities at once. Moreover, we aim at building and researching novel frameworks that allow practitioners to interact, challenge, and query the learned models in an adequate manner. The overall goal of this interaction is to cement the trust in the use of machine learning algorithms as well as to improve the precision of the derived diagnoses. It is our main hypothesis that this might readily lead to new gold-standards and novel perspectives on machine learning in digital medicine with the potential to initiate the next era in supporting systems for clinical decisions.
The planned principal project is both ambitious and interdisciplinary as it brings together computer science (especially artificial intelligence and machine learning) and medicine (especially clinical diagnostics). Therefore, one group leader from the Institute of Computer Science from the University of Bern and a Professor from the Inselspital Bern have joined forces to define and submit a solid principal application. The main objective of the present application is to grant a preparatory project for building the basis for the planned principal project and comprises the following three major tasks. Implementing a structural pilot with well-defined pipelines and procedures to share both data and infrastructure between the University and the Inselspital. Building the foundation of a general framework for machine learning tools such that they become directly applicable to the respective datasets (and conduct preliminary empirical evaluations). Preparing a principal application for the Sinergia funding scheme of the SNSF.

Financial support: UniBE ID Grant

Research staff: A. Tastan, K. Riesen

9.4 Bachelor's Theses

- M. Schüpbach: Echtzeitbenachrichtigung von persönlichem Stromverbrauch

- R. de Gottardi: Matching Graphs with Enriched Node Labels using Weisfeiler-Lehmann Hashes

- J. Studer: Leveraging Graph Structure for Graph Classification: An Examination of Graph Neural Networks

- T. Özsoy: Uncovering Gulf of Execution and Gulf of Evaluation in User-Computer Interactions

- J. Gaumez: Evaluating Human-Computer Interaction Theories through Practical Experiments

- D. Fischli: Interactive Graph Drawing A Drawing Software

- K. Bardheci: Visualization of Matching-Graphs — An Approach with Multidimensional Scaling

- R. Gibson: Graph Representation Through Topological Descriptors

- F. Gribi: Binary Classification of Blood Values

- J. Zurbrügg: Clustering of Hydrological Stations

9.5 Awards

- Recognition of Outstanding Teaching Achievements for the lecture ”Graph Based Pattern Recognition” in Spring Semester 2023, among the top 11 courses offered by the Faculty of Sciences at the University of Bern. (Kaspar Riesen)

- Recognition of Outstanding Teaching Achievements for the seminar ”Pattern Recognition” in Spring Semester 2023, among the top 11 courses offered by the Faculty of Sciences at the University of Bern. (Kaspar Riesen)

- Recognition of Outstanding Teaching Achievements for the lecture ”Programmierung 1” in Autumn Semester 2022, among the top 6 courses offered by the Faculty of Sciences at the University of Bern. (Kaspar Riesen)

9.6 Further Activities

Editorial Boards

Kaspar Riesen

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

Conference Program Committees

Kaspar Riesen

- Member of Program Committee for the 17th International Conference on Document Analysis and Recognition 2023
- Member of Program Committee for the 13th IAPR-TC-15 International Workshop on Graph-Based Representations in Pattern Recognition 2023

Invited Talks

Mathias Fuchs

- Graph Augmentation for Neural Networks Using Matching-Graphs at ANNPR 2022
- Matching-Graphs for Building Classification Ensembles at GbRPR 2023

Anthony Gillioz

- Two-Step Graph Classification on the Basis of Hierarchical Graphs at ICPRAM 2023
- Graph-Based vs. Vector-Based Classification: A Fair Comparison at GbRPR 2023

Corina Masanti

- Novel Benchmark Data Set for Automatic Error Detection and Correction at NLDB 2023

Benjamin Fankhauser

- Graph-Based Deep Learning on the Swiss River Network at GbRPR 2023

9.7 Publications

Journal Publications

- Anthony Gillioz, Kaspar Riesen: Building Multiple Classifier Systems using Linear Combinations of Reduced Graphs. Accepted for Publication in SN Computer Science (2023)
- Anthony Gillioz, Kaspar Riesen: Graph-based pattern recognition on spectral reduced graphs. Accepted for publication in Pattern Recognition (2023)

Refereed Conferences

- Anthony Gillioz, Kaspar Riesen: Two-Step Graph Classification on the Basis of Hierarchical Graphs. ICPRAM 2023: 296-303
- Corina Masanti, Hans Friedrich Witschel, Kaspar Riesen: Novel Benchmark Data Set for Automatic Error Detection and Correction. NLDB 2023: 511-521
- Mathias Fuchs, Kaspar Riesen: Graph Augmentation for Neural Networks Using Matching-Graphs. ANNPR 2022: 3-15
- Benjamin Fankhauser, Vidushi Bigler, Kaspar Riesen: Graph-Based Deep Learning on the Swiss River Network. GbRPR 2023: 172-181
- Mathias Fuchs, Kaspar Riesen: Matching-Graphs for Building Classification Ensembles. GbRPR 2023: 102-112
- Anthony Gillioz, Kaspar Riesen: Graph-Based vs. Vector-Based Classification: A Fair Comparison. GbRPR 2023: 25-34

9.8 Organization of Outreach Activities

- Master InfoTag, Kaspar Riesen, Mathias Fuchs, Corina Masanti, March 2023
- MINT Tag, Kaspar Riesen, Mathias Fuchs, Corina Masanti, March 2023

10 Research Center for Digital Sustainability Group

10.1 Personnel

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Other Staff:	Dr. B. Hitz-Gamper*	Tel.: +41 31 684 4712: email: benedikt.hitz@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 non-existent. 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)

11 Software Engineering Group

11.1 Personnel

Head:	Prof. Dr. T. Kehrer	timo.kehrer@unibe.ch
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Scientific Staff:	Dr. S. Greiner	sandra.greiner@unibe.ch
	Dr. M. Ohrndorf	manuel.ohrndorf@unibe.ch
	Dr. P. Rani	pooja.rani@unibe.ch (until 31.08.2022)
	C. Birchler	christian.birchler@unibe.ch (as of 01.02.2023)
	A. Boll	alexander.boll@unibe.ch
	T. Sutter	thomas.sutter@unibe.ch (as of 01.08.2023)
	P. V. Toledo	pablo.valenzuela@unibe.ch
	Dr. PD C. Tsigkanos	christos.tsigkanos@unibe.ch

11.2 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.

11.3 Research Projects

CaSSIS-Verif: Towards Verified Flight Software for Future Mars Missions

Research staff: Christos Tsigkanos, Timo Kehrer
Project partners: Prof. Nicolas Thomas, Miguel Almeida (Space Research and Planetology, Physikalisches Institut, University of Bern)
Duration: 2023 – 2024
Financial support: University of Bern

Software verification entails the algorithmic analysis of programs to mathematically prove properties of their executions - to prove that given certain assumptions, the code is correct and bug-free. Performing software verification in practice requires appropriately instrumenting the code at hand, invoking often complicated toolchains, and interpreting verification results. In CaSSIS-Verif, we seek to investigate semi-automation of this process in the context of mission-critical space software. We envision (i) appropriate abstractions and automation tools tailored to this challenging domain, as well as making steps towards (ii) integrating software verification into the development process of mission-critical space software.
The project leverages expertise of the Planetary Imaging Group in the Space Research and Planetology Division of the Physikalisches Institut and the Software Engineering Group at the Institute of Computer Science, towards the verification of CaSSIS flight software.

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?

11.4 Ph.D. Theses

- Manuel Ohrndorf. *A History-based Approach for Model Repair Recommendations in Software Engineering*. PhD thesis, University of Bern, July 2022.

11.5 Master's Theses

- M. Lajevardipour – "Supporting novice developers in finding similar questions on StackOverflow". Supervisors: Pooja Rani and Timo Kehrer.

11.6 Bachelor's Theses

- Jan Wolfensberger – "Leveraging Human-in-the-Loop for Variable Discovery within Metamorphic Testing with LLMs". Supervisors: Christos Tsigkanos and Timo Kehrer.

- Cindy Schneider – "Integrating LTL Learning to FRET for Requirements Specification". Supervisors: Christos Tsigkanos and Timo Kehrer.

- Severin Buchser – "An empirical study on the human role in merge conflict resolution". Supervisors: Alexander Boll and Timo Kehrer.

11.7 Activities

Scientific Boards, Steering Committees, Organizations

Timo Kehrer

- GReTA — International Seminar Series on Graph Transformation Theory and Applications – Scientific Board Member
- VariVolution — International Workshop on Variability and Evolution of Software-Intensive Systems – Steering Committee Member

Sandra Greiner

- VariVolution - 5^{th} International Workshop on Variability and Evolution of Software-Intensive Systems – Co-Organizer

Christos Tsigkanos

- 2nd DISCOLI Workshop on DIStributed COLlective Intelligence (DISCOLI 2023) – Co-Chair

Program Committees

Timo Kehrer

- European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE) 2023 – Demo Track
- ACM/IEEE 26th International Conference on Model-Driven Engineering Languages and Systems (MoDELS) 2023 – Research Track
- ACM/IEEE 26th International Conference on Model-Driven Engineering Languages and Systems (MoDELS) 2023 – Workshps
- 27th Systems and Software Product Line Conference (SPLC) 2023 – Journal First Track
- 27th International Conference on Evaluation and Assessment in Software Engineering (EASE) 2023
- 23rd International Working Conference on Source Code Analysis and Manipulation (SCAM) 2023

- Software Engineering 2023 – Research Track
- Software Engineering 2023 – Student Research Competition

Sandra Greiner

- 17th International Working Conference on Variability Modelling of Software-Intensive Systems (VaMoS 2023)
- 26th ACM / IEEE International Conference on Model Driven Engineering Languages and Systems (MODELS), 2023 – Artifact Evaluation Track

Christos Tsigkanos

- ACM Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE) 2023
- European Conference on Software Architecture (ECSA) 2023
- International Symposium on Software Engineering for Adaptive and Self-Managing Systems (SEAMS) 2023
- Third Workshop on Agents and Robots for reliable Engineered Autonomy 2023

Reviewing Activities

Timo Kehrer

- IEEE Transactions on Software Engineering
- ACM Transactions on Software Engineering and Methodology
- Journal of Systems and Software
- Software and Systems Modeling
- Information and Software Technology
- Journal of Object Technology
- Information and Software Technology
- Journal of Software: Practice and Experience

- Connection Science
- Deutsche Forschungsgemeinschaft

Sandra Greiner

- Journal on Software and Systems Engineering (JSS)
- Empirical Software Engineering (EMSE)
- Deutsche Forschungsgemeinschaft (DFG)

Christos Tsigkanos

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

Manuel Ohrndorf

- European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE)

Presentations

Timo Kehrer

- Managing Software Evolution in Space and Time: From Model-Based to Data-Centric Software Engineering. CHOOSE Junior Meeting, University of Zurich, Switzerland, Sep. 2022

Sandra Greiner

- Transformation Case Introduction at TTC; Leicester, UK, July 2023
- Invited Talk, JKU Linz, Austria, June 2023
- Guest Lecture, University of Athens, May 2023
- FOSD Meeting, University of Ulm, March 2023
- On Preserving Variability Consistency in Multiple Models (VaMoS 2021 Snapshot) VaMoS 2023, Odense, Denmark, Jan 2023

- Pre-VaMoS Conference, IT University of Copenhagen, Denmark, Jan. 2023
- Promotionsvortrag, University of Bayreuth, Germany, Oct. 2022
- CHOOSE Junior Meeting, University of Zurich, Switzerland, Sep. 2022

Christos Tsigkanos

- HiPEAC Vision, Brussels, Belgium. Invited talk, 2023.
- Variable Discovery with Large Language Models for Metamorphic Testing of Scientific Software. ICCS 2023.
- Large Language Models: The Next Frontier for Variable Discovery within Metamorphic Testing? SANER 2023.

Manuel Ohrndorf

- A summary of ReVision: History-based model repair recommendations. SE 2023, Paderborn, Germany.
- CHOOSE Junior Meeting, University of Zurich, Switzerland, Sep. 2022.

Pablo Valenzuela

- MSR 2023, Melbourne, Australia: EGAD: A moldable tool for GitHub Action Analysis, May 2023.

Christian Birchler

- ICSE 2023, Melbourne, Australia: Single and Multi-objective Test Cases Prioritization for Self-driving Cars in Virtual Environments, May 2023.

Awards

- Sandra Greiner: Best reviewer award at the 17th International Working Conference on Variability Modelling of Software-Intensive Systems (VaMoS '23)

11.8 Publications

Journal Papers

- Alexander Schultheiß, Paul Maximilian Bittner, Alexander Boll, Lars Grunske, Thomas Thüm, Timo Kehrer: RaQuN: a generic and scalable n-way model matching algorithm. Software and Systems Modeling, 2022.
- Christof Tinnes, Timo Kehrer, Mitchell Joblin, Uwe Hohenstein, Andreas Biesdorf, Sven Apel: Mining domain-specific edit operations from model repositories with applications to semantic lifting of model differences and change profiling. Autom. Softw. Eng., 2023.
- 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, 2023.
- Claudio Menghi, Christos Tsigkanos, Mehrnoosh Askarpour, Patrizio Pelliccione, Gricel Vázquez, Radu Calinescu, Sergio García. Mission Specification Patterns for Mobile Robots: Providing Support for Quantitative Properties. IEEE Transactions on Software Engineering, 2023.
- Tiago Amorim, Alexander Boll, Ferry Bachman, Timo Kehrer, Andreas Vogelsang, Hartmut Pohlheim. Simulink bus usage in practice: an empirical study. Journal of Object Technology, 2023.

Conference Papers

- Alexander Schultheiß, Paul Maximilian Bittner, Thomas Thüm, Timo Kehrer: Quantifying the Potential to Automate the Synchronization of Variants in Clone-and-Own. ICSME, 2022.
- Anh Duc Vu, Timo Kehrer, Christos Tsigkanos: Outcome-Preserving Input Reduction for Scientific Data Analysis Workflows. ASE, 2022.
- Sebastian Müller, Valentin Gogoll, Anh Duc Vu, Timo Kehrer, Lars Grunske: Automatically finding Metamorphic Relations in Computational Material Science Parsers. e-Science. 2022
- Laura Wartschinski, Yannic Noller, Thomas Vogel, Timo Kehrer, Lars Grunske: VUDENC: Vulnerability Detection with Deep Learning on

a Natural Codebase for Python - Summary. Software Engineering. 2023

- Christos Tsigkanos, Pooja Rani, Sebastian Müller, Timo Kehrer. Variable Discovery with Large Language Models for Metamorphic Testing of Scientific Software. ICCS 2023.

- Anh Duc Vu, Christos Tsigkanos, Jorge-Arnulfo Quiané-Ruiz, Volker Markl, Timo Kehrer. On Irregularity Localization for Scientific Data Analysis Workflows. ICCS 2023.

- Christos Tsigkanos, Pooja Rani, Sebastian Müller, Timo Kehrer. Large Language Models: The Next Frontier for Variable Discovery within Metamorphic Testing? SANER 2023.

- Paul Maximilian Bittner, Christof Tinnes, Alexander Schultheiß, Sören Viegener, Timo Kehrer, Thomas Thüm: Classifying Edits to Variability in Source Code - Summary Software Engineering (SE), 2023.

- Alexander Schultheiß, Paul Maximilian Bittner, Thomas Thüm, Timo Kehrer: Quantifying the Potential to Automate the Synchronization of Variants in Clone-and-Own - Summary Software Engineering (SE), 2023.

- Alexander Schultheiß, Paul Maximilian Bittner, Sandra Greiner, Timo Kehrer: Benchmark Generation with VEVOS: A Coverage Analysis of Evolution Scenarios in Variant-Rich Systems. 17th International Working Conference on Variability Modelling of Software-Intensive Systems (VaMoS), 2023.

- Manuel Ohrndorf, Christopher Pietsch, Udo Kelter, Lars Grunske, Timo Kehrer: A summary of ReVision: History-based model repair recommendations Software Engineering (SE), 2023.

- Pablo Valenzuela-Toledo, Alexandre Bergel, Timo Kehrer, Oscar Nierstrasz: EGAD: A moldable tool for GitHub Action analysis. IEEE/ACM 20th International Conference on Mining Software Repositories (MSR), 2023

Workshop Papers

- Sandra Greiner, Nicolas Maier, Timo Kehrer: Experiences with Using a Pre-Trained Programming Language Model for Reverse Engineering Sequence Diagrams Workshop Software-Reengineering & -Evolution, 2023.

12 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
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 Member of the Quality Assurance and Development expert committee (as of August 2023)
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 (until April 2023) Deputy Managing Director of INF (as of 1.8.2022) Representative to CUSO Doctoral School in Computer Science Member of Hauskommission Engehalde
P. Favaro:	Managing Director of INF (as of 01.08.2022)
T. Kehrer:	Deputy Director of Studies (as of May 2023)
K. Riesen:	Member of Library Committee on behalf of INF Representative to CUSO Doctoral School in Computer Science
T. Studer:	Member of Hauskommission Exakte Wissenschaften