Centre Universitaire d'Informatique

2024

Activity Report

CUI UNIGE

Nuit de la science, parc de la Perle du Lac (Geneva), July 7th 2024

UNIVERSITÉ DE GENÈVE

Foreword

The world continues witnessing rapid advances in the digital world, with Artificial Intelligence at the forefront of these innovations. Like all innovations, AI shows a bright side as a support tool for human information processing and decision-making and a dark side when this support is abused for illegitimate actions. However, the AI revolution goes beyond bringing a new technology. Unlike the steam engine that was supporting human muscular strength, AI is supporting our ability to think, which is a much more intimate part of human nature. This raises a number of questions extending beyond the mere technological questions, on legal, ethical and social implications, to name but a few. The need for transdisciplinary research, education and collaborations is therefore stronger than ever.

In that direction, the CUI is sheltering several research projects with such a transdisciplinary nature involving for example the Faculties of Sciences, GSEM, Translation and Interpretation (project RCNum). Via SciCoS, the CUI is recently proposing a Scientific Computing support available throughout the Institution. It has also developed since several years specific assets such as the Faclab and the Digital Innovation Hub. These make the CUI unique as a bridge between research, education and the general public in the domain of digital innovation.

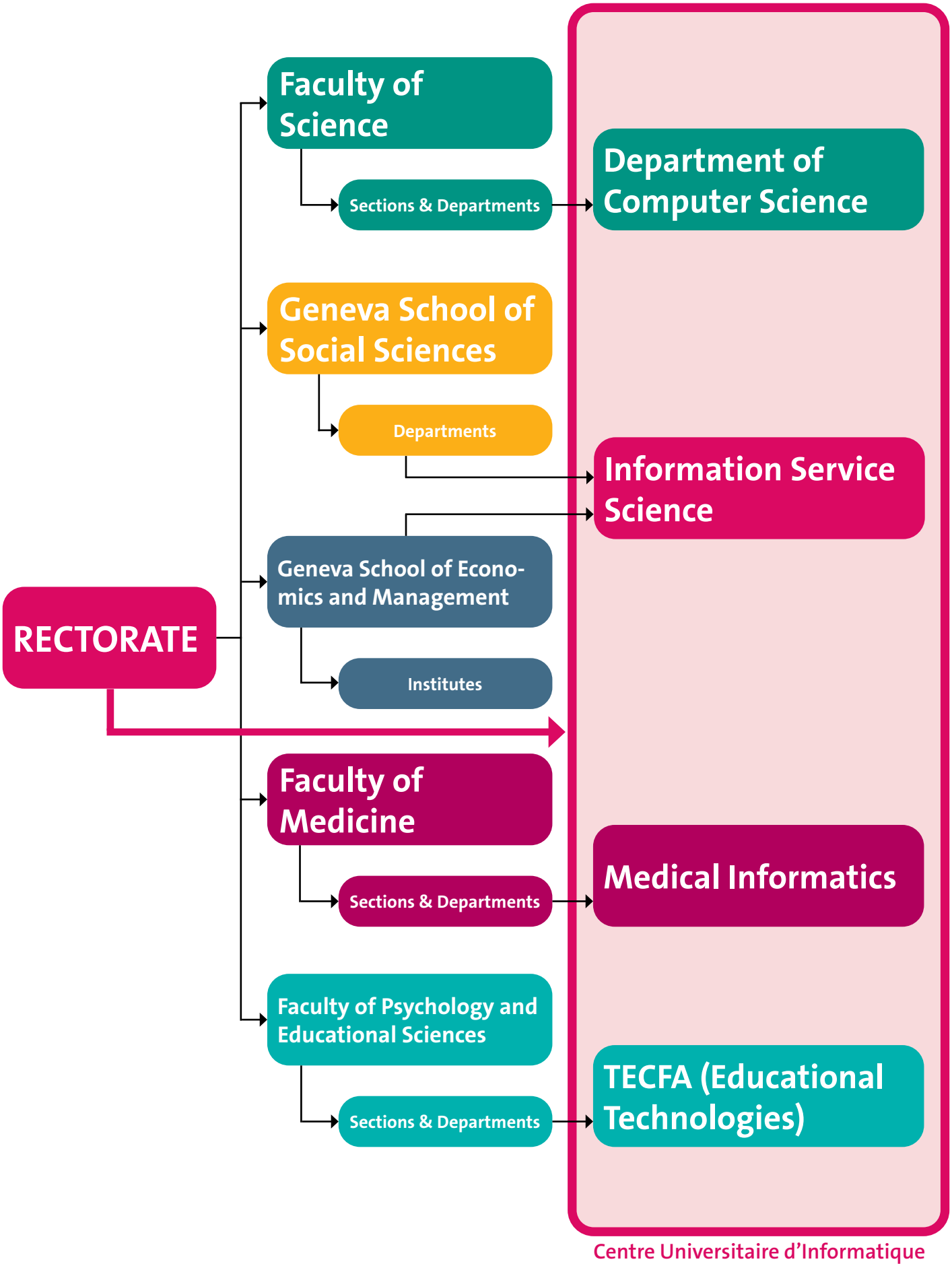
Synergy between education, research and industry is also a large part of CUI's activities with another very successful 2024 edition of the «Adopt a Skill» forum attracting more than 20 companies and more than 100 participants. In the same line, the CUI has been active in several social activities as diverse as the 2024 editions of «Focus Carrière Science» or «Nuit de la Science». To connect academic research and education with the future generation, CUI has developed since 2018 outreach activities with the Infoscope, offering workshops for Geneva's scholars from primary - and secondary - level schools. In 2024 again, these activities have met a large success.

Since now almost 50 years at the University of Geneva, the CUI has therefore gathered scientists of various disciplines around our common interests for digital science research and education. Its mission has evolved since the early ages where Computer Science and Informatics were themselves new fields. Since the end of 2024, CUI has started an in-depth evaluation process that will allow to rethink its mission and to redefine the position and needs for a transdisciplinary and inter-Faculty center for Digital Science. No doubt that the forthcoming year 2025 will be an important turn for the CUI.

I take the opportunity to thank all CUI members of staff, students and researchers for their hard work, commitment, innovation, reach out and research activities, all participating to our national and international visibility and excellence. 2024 has also seen the change of Director. I also thank former Director Prof. Giovanna Di Marzo Serugendo (now Adjunct Director for education at CUI) for her commitment to CUI during all past years.

Prof. Stéphane Marchand-Maillet
Director of the CUI
University of Geneva

Organisation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Information Service Science
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Medical Informatics
Faculty of Psychology and Educational Sciences
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TECFA (Educational Technologies)
Centre Universitaire d'Informatique

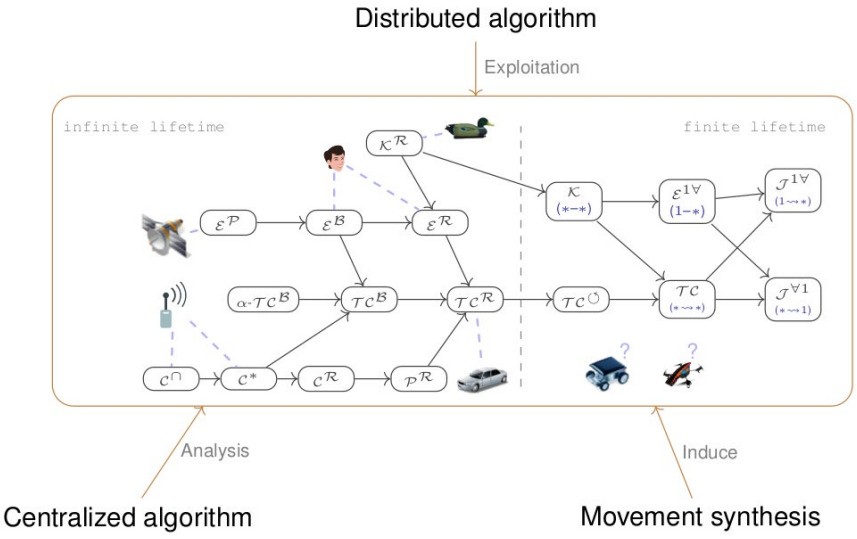
www.unige.ch/algo

ALGO

Algorithms, Graph theory, and Complexity

Domain activities

Our group is interested in the many facets of theoretical computer science and network science, ranging from distributed algorithms to graph theory, computational complexity, and quantum algorithms. Many real-world networks (e.g. networks of robots/drones, wireless sensors, and vehicular networks) are dynamic, which makes their modeling and study challenging. For this reason, the group has a strong focus on temporal graphs, i.e. graphs that change over the time and whose temporal properties are essential. For example, we study the shape of communication patterns in these new graphs and the computational complexity of related algorithmic questions like connectivity, spanners, and distributed computing in time-varying networks. We also revisit motion planning problems for mobile entities, using a discrete (algorithmic) approach. Finally, we recently started to investigate the connection between graph algorithms and quantum computing, in particular the role played by graph optimization problems such as maximum independent sets in the quantum annealing paradigm.



Director
Arnaud Casteigts
Full professor
H-index: 25

Pierre Leone
Senior Lecturer and Researcher
H-index: 16

ACG

Applied Complexity Group

Domain activities

The applied Complexity group (ACG), directed by Prof. Roland Bouffanais (Computer Science & Global Studies Institute, University of Geneva), conducts interdisciplinary research at the intersection of Complexity Science, Multi-Agent Systems, Network Science, Computational Social Science, Data Science, including Artificial Intelligence.

Director
Roland Bouffanais
Associate professor
H-index: 30

Our research involves a synergistic combination of computational and theoretical developments, with real-life experimental validations.

We foster cross-disciplinary exploration to gain insights into a range of complex systems including social networks, swarm intelligence, complex urban systems, human dynamics, etc. We maintain a constructive and open dialogue between science, society and industry.

Our team members hail from various fields and have expertise in a vast range of disciplines – including computational science, social sciences, machine learning, network science, robotics, and control theory.

A significant part of our funding comes from industry collaborations, with local industry or government agencies, as well as multi-national companies.

CCL

Citizen Cyberlab

Domain activities

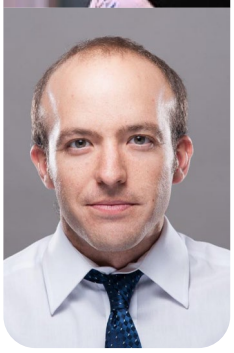
In the domain of Citizen Science, Citizen CyberLab (CCL) aims to design and develop new ways of enabling public participation in research. In 2024, CCL completed a citizen science initiative for gathering data about water resources in Nigeria, as a result of its collaboration with UNICEF and the Botnar Foundation. This initiative, called DonateWater, was co-created with a team of four young Nigerians through an online innovation methodology developed as part of the EU project Crowd4SDG.

Since March 2024, Citizen Cyberlab is participating in an EU Horizon Europe project called ALBATROSS, coordinated by the University of Bologna with 18 partners. The project aims to develop strategies which simultaneously support sustainable development and climate resilience in diverse African contexts, using citizen science to and nature-based solutions to tackle the impact of climate-induced migration on local ecosystems.

The task within the project led by Citizen Cyberlab concerns the implementation of a challenge-based innovation cycle called the SDG Olympiad. This task is carried out together with several African University partners and in collaboration with the social network for youth Goodwall (a Swiss SME). The SDG Olympiad will use a Citizen Science Solution Kit developed in a previous EU Project led by Citizen Cyberlab, Crowd4SDG.

Directors
François Grey
Associate professor
H-index: 38

Jose Luis Fernandez-Marquez
Senior Lecturer and Researcher
H-index: 16



clcl.unige.ch

CLCL

Computational Learning and Computational Linguistics

Domain activities

The Computational Linguistics and Computational Learning (CLCL) Research Group (http://clcl.unige.ch/) is concerned with interdisciplinary research combining linguistic modelling with machine learning techniques.
We participate in two major projects.

Director
Paola Merlo
Associate professor
H-index: 25

In our SNF Advanced Grant project Disentangling linguistic intelligence: automatic generalisation of structure and meaning across languages, we set the challenging goals of investigating higher-level linguistic abilities in machines, in more realistic settings. We identify these abilities as the intelligent ability to infer patterns of regularities in unstructured data, generalising from few examples, using abstractions that are valid across possibly very different languages. We study if current neural network architectures have these properties with a new set of tasks inspired by IQ intelligence tests, called Blackbird Language Matrices. We have developed data for some linguistic tasks, concerning both grammar and meaning, developed new architectures for solving our BLM task, and investigated if current LLM (ChatGPT4) can pass our BLM tests (no, it does not solve it well yet), establishing some interesting parallels with human problem-solvers.
For more information, visit our Github site: https://github.com/CLCL-Geneva/BLM-SNFDisentangling

We continue our participation in the NCCR Evolving Language, where we are studying the basic mechanisms that structure communicative expressions, i.e. the mechanisms of combination and division that distinguish a given expression from a holistic signal in non-human animals and also whether prosody enhances the cortical encoding of syntactic representations.

As a whole, the Swiss National Centre of Competence in Research (NCCR) Evolving Language is a nationwide interdisciplinary research consortium bringing together research groups from the humanities, from language and computer science, the social sciences, and the natural sciences at an unprecedented level. Together, we study how our species developed the capacity for linguistic expression, language in the brain, and for consistently passing down new variations to the next generation. We also ask how our capacity for language will change in the face of digital communication and neuroengineering.
For more information see https://evolvinglanguage.ch/

CVML

Computer Vision and Multimedia Laboratory

Domain activities

The **Computer Vision and Multimedia Laboratory** (CVML, http://cvml.unige.ch), divided into three groups, carries out research in multimedia data processing, multimedia data management and security, as well as in multimodal human-machine interaction. Research applies to media such as text, audio tracks, sounds, images and videos, and to physiological signals.

Information Retrieval and Machine Learning group (Viper, Prof. S. Marchand-Maillet, Prof. A. Kalousis, http://viper.unige.ch): develops strategies for the efficient modeling, indexing, retrieval and exploration of large-scale datasets. The group studies fundamental machine learning strategies to provide efficient and accurate understanding and access to large-scale collections of complex data. Research themes include information retrieval, recommendation systems, data analytics and exploration, learning over sequential and temporal data, structured and kernel learning, regularization techniques for neural networks. Applications are considered in the fields of data visualization, forecasting, IoT, chemoinformatics, biomedicine.

Stochastic Information Processing group (SIP, Prof. S. Voloshynovskiy, http://sip.unige.ch): studies various aspects of information-theoretic machine learning. The applications mostly cover several domains : physical object security, generative models and anomaly detection in high energy physics, astrophysics and next generation imaging techniques for the radio-astronomy.

Social Intelligence and Multi-Sensing group (SIMS, Dr. G. Chanel, http://sims.unige.ch): Social Intelligence and Multi-Sensing group (SIMS, Dr. G. Chanel, http://sims.unige. ch): conducts research in artificial intelligence, socio-affective computing, multi-sensing, human machine interaction, entertainment and games. Our objective is to better understand human behaviors in their daily environment particularly when interacting with machines and multimedia. Our approach is based on multimodal sensing and artificial intelligence to make meaning out of several measures including audio, videos, eye-movements, physiological signals such as EEGs (electroencephalograms), EMG (electromyograms), blood pressure, galvanic skin resistance (GSR), skin temperature, and breathing rate. The SIMS group is also part of the Institute for IT Engineering and Telecommunications from HEPIA and tightly collaborate with the Swiss Center for Affective Sciences (faculties of psychology, literature and medicine).

Co-Directors

Sviatoslav Voloshynovskiy
Full professor
H-index: 38

Stéphane Marchand-Maillet
Associate professor
H-index: 29

Alexandros Kalousis
Full professor
University of Applied Studies, Geneva School of Business Administration
H-index: 37

Guillaume Chanel
Senior Lecturer and Researcher (also affiliated with the Swiss Center for Affective Science)
H-index: 31

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ISS

Institute of Information Service Science

Collective Adaptive Systems

Director
Giovanna Di Marzo Serugendo
Full professor
H-index: 34

Domain activities

Collective Adaptive Systems are complex systems made up of diverse, autonomous entities that interact without centralised control. These entities adapt to their environment to pursue individual or shared goals, with intelligent behaviour emerging through swarm or collective intelligence. This field intersects with multi-agent systems and distributed AI.

We lead cutting-edge research in:

- Modeling natural systems (biological, social, human) using agent-based simulations to uncover core mechanisms and interaction patterns.
- Designing artificial collective systems such as swarm robotics, smart city ecosystems, and higher-order emergent behaviours.
- Ensuring system reliability and trustworthiness before real-world deployment.
- Developing digital twins and AI services to support evidence-based policy-making.
- Exploring semantic-based multi-agent systems and digital twin architectures.
- Transforming business processes through semantic AI, multi-agent systems, and generative AI.
- Providing AI based design patterns

We also drive innovation in academia. Through student-led projects, we launched the Science & Services Accelerator and an R&D unit to turn prototypes into scalable services. We are pioneers in this field within the Swiss academic sector, regularly mentoring BSc/MSc students, hosting internships, and delivering expert mandates.

Our expertise is recognized beyond academia—we serve as advisors to various institutions, including our appointment to the Strategic Council for Geoinformation of the Canton of Geneva.

http://unige.ch/cui/cas/
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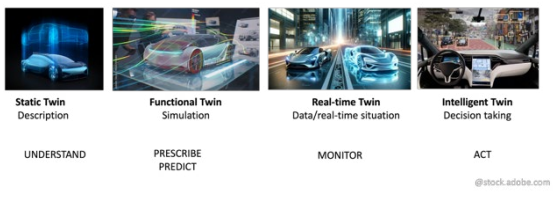
Digital Twins for policy-making – 4 Levels



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Digital Trust, from Decentralized Finance to Augmented Human & Metaverse

Domain activities

For ages, humans have used the human notion of trust as a means to cope with uncertainty, to engage in an action in spite of the risk of a harmful outcome. More recently, computational models of this human notion of trust have been researched in order to be able to use trust in the digital world as well, between computers and/or digital accounts controlled by remote humans, from direct observations to recommendations and online reputation. Technical decentralized trust solutions such as blockchains are revolutionizing many business domains from finance to supply chain certification. In the near future, it is even envisioned that humans and computers merge together, possibly creating a metaverse. We have contributed to this trend with the organization since 2010 of the augmented human international conferences focusing on scientific contributions towards augmenting or retrieving human capabilities through technology. We are researching how these augmented human technologies can improve computational trust assessment not only of machines but also of humans.

Director
Jean-Marc Seigneur
Senior Lecturer and Researcher
H-index: 22

https://www.linkedin.com/in/jmseigneur/

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Institute of Information Service Science

Digital Rights & Policy

Domain activities

As our society and economy continues to move towards interwoven digital services and systems, blending the real and the artificial world, our research activities continue to investigate some of the complex challenges and issues towards a more sustainable and responsible digital society. Information Protection and Control (IPC) in general and the growing need for Data Protection have become recognized area where increased research is needed. We continue our work in those areas with a particular look at distributed ledger technologies (blockchain) as a mechanism to support new services and designs to support increasingly complex requirements. Major examples of these research issues we are currently working on include data marketplace ecosystems, dispute resolution and arbitration, data protection and digital rights and policy management.
From July 2016 to July 2017, Jean-Henry Morin is on sabbatical leave in South Korea where he is Invited Professor at Korea University Business School and Yonsei School of Business. During this time, he is also invited researcher at Fasoo.com where he investigates blockchain technologies in Information Security.

Director
Jean-Henry Morin
Associate professor

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Institute of Information Service Science

Digital Transformation

Domain activities

Director
Jolita Ralyté
Senior Lecturer and Researcher
H-index: 23

Digital transformation is not just the adoption of new information technologies and the computerization of human activities. It embraces much broader strategic ambitions and involves fundamental changes in the activities, structure and even culture of the organization, with the primary goal of innovating and creating value. Service Science plays a driving role in digital transformation by providing key concepts, such as information service and service system, that facilitate business innovation through the integration of digital technologies. The approach for information service and system engineering must be necessarily exploratory, agile, and contributory, as the implementation of new services transforms the daily life of many people, and affects the organisation's activity and even its position in the ecosystem. Such transformation has to be understood, assessed and accepted by all parties. To be successful, it must be value-driven and ensure the involvement of all stakeholders by making them responsible co-creators. The transdisciplinary is another dimension to be considered in service co-creation as it allows to cross the borders of the conventional information system engineering and create new capabilities and new values. To make the approach holistic, we need to consider many other service-related aspects, such as ethics, accountability, compliance to the regulatory framework, and risks. The robustness and sustainability of services will depend not only on the quality but also on the situational-fitness of the approach. Indeed, the context and requirements of each organisation facing the digital transformation challenge is different, and therefore requires a situation-specific approach. We apply situational Method Engineering principles and techniques for developing our approach and defining contextual criteria for its configuration and application.

https://cui.unige.ch/~ralyte/
https://matis.unige.ch
https://www.linkedin.com/in/jolitaralyte/
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https://www.researchgate.net/profile/Jolita-Ralyte

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Institute of Information Service Science

Information Security Lab (I-SEC)

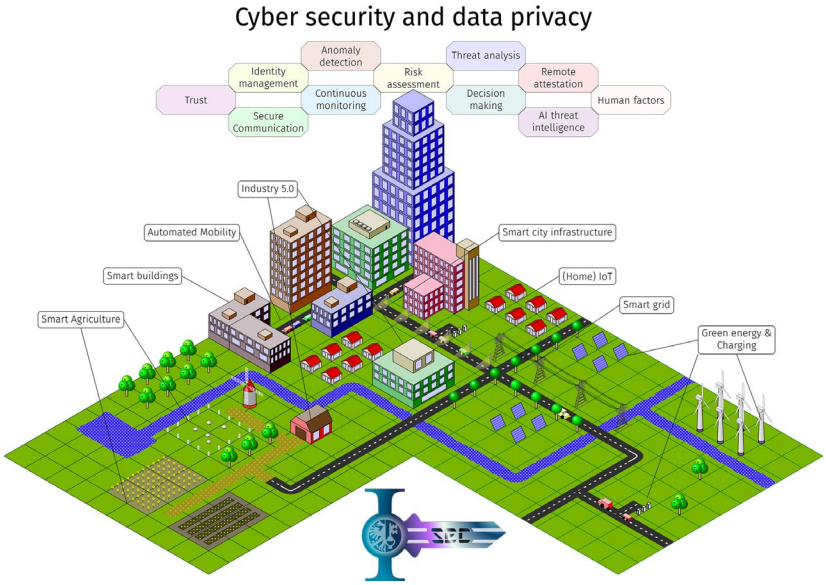
Domain activities

In the domain of cybersecurity, the institute's Information Security Lab (I-Sec) aims to translate the complex nature of cybersecurity into an easily comprehensible way to understand, monitor, and control the risks of employing current and future technologies. With a strong commitment to co-designed solutions with end-users, we research new ways on how to expose and present the raised implications on privacy, risk, security, and safety. In 2024, I-Sec has been working on several EU projects, namely ULTIMO, ENFLATE, OPEVA and AutoTRUST, in the domains of the Internet of Things (IoT), Connected (autonomous) vehicles, Smart Cities, and (critical) infrastructure. I-Sec's research works vary from risk assessment, threat identification, anomaly detection, privacy preservation, usability in security and privacy to mitigation advisory.

isec.unige.ch

Director
Niels Alexander Nijdam
Senior Lecturer and Researcher

Anastasija Collen
Senior Researcher
H-index: 12



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Institute of Information Service Science

Mobile Services

Domain activities

The CCAMLab's research continued to play a pivotal role in shaping policy and regulatory frameworks for Connected, Cooperative, and Automated Mobility (CCAM) across Switzerland and Europe. Its expertise contributed directly to the development of new legislation and mobility service regulations in Switzerland, Germany, Luxembourg, and Denmark. Through its participation in European Commission high-level strategy groups, the lab influenced Horizon Europe's priorities for CCAM research and deployment.

The CCAMLab iniated and leads the ULTIMO project, the largest Horizon Europe project in automated mobility, with €40 million in funding and 24 international partners. ULTIMO is pioneering the deployment of fully automated, on-demand public transport services at scale, with a focus on societal integration, service orchestration, and energy sustainability.

The lab also contributes to the SINOGENES project, advancing hydrogen-powered vehicles for sustainable public transportation deployment in collaboration with the TPG.

Directors
Dimitri Konstantas
Full professor
H-index: 35

Maher Ben Moussa
Senior Researcher
H-index: 15

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Institute of Information Service Science

Quality of Life Technologies (QoL)

Domain activities

Director
Katarzyna Wac
Full professor
H-index: 32

The Quality of Life Technologies (QoL) Lab explores how mobile and emerging sensor-based technologies can be used to measure and improve human behavior, well-being, and quality of life. Using a large-scale Living Lab established in 2012—with thousands of smartphone users testing various services—we carry out both fundamental and applied research. Our work has real-world impact, influencing health policy and decision-makers.

We focus on accurate, personalized, real-world assessment of life quality as it unfolds naturally over time and context. This includes leveraging longitudinal "quantified-self" and N-of-1 data approaches, treating everyday life as something that can be examined, diagnosed, and improved—similar to how a physician would examine a physical organ. We have been supported by more than 45 grants so far and published around 200 peer-reviewed papers across computer science, human-computer interaction, and health informatics.

In a past Geneva-wide initiative, our lab contributed policy recommendations based on resident well-being data, helping guide sustainable improvements in the region. Recent projects address chronic and acute conditions like migraine, type 2 diabetes, obesity, hip replacement recovery, and breast cancer self-management. These studies validate digital endpoints that reflect life quality, moving beyond traditional medical metrics toward patient-centered outcomes.

Our contributions are shifting the focus in healthcare: from tracking only clinical or bio-physiological signals to integrating data-driven insights into life quality. This shift supports better disease risk assessment, diagnosis, and evaluation of therapeutic interventions. As a result, the lab's work plays a pivotal role in the future of personalized, digital healthcare.

qol.unige.ch
https://www.**youtube**.com/channel/UCohpE4xXEDXLcoT_IIcl-7g
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Institute of Information Service Science

Travelling and Mobility (TaM)

Domain activities

The TaM group of the University of Geneva has proved, for many years, that they are able to contribute to the scientific state of the art by publishing in peer review journals or conferences. Machine learning techniques are mastered up to the state of the art. The success of the Innosuisse projects Alina (2023), HorseTrack (2021), QueueForMe (2020) and Recover@home (2018) are the perfect examples of why our team is the most relevant when dealing with machine learning in applied research in various fields. During the last two projects we published in the AI4I conference. One of this work led to a best paper award that was attributed to a member of our team. Beyond machine learning techniques, our group is experienced in working with different kinds of sensors and the special data post treatment they require. Finally our research group is used to working with private companies and their constraints. TaM's infrastructure is perfect for deep learning computing thanks to batch job access to run heavy computation on the cloud.

Keywords: artificial intelligence, machine learning, data processing, sensor data analysis, fusion algorithms, indoor positioning, indoor localisation, indoor navigation, GPS, maps, Geographic Information Systems, health tracking, health monitoring, eHealth

Director
Michel Deriaz
Senior Lecturer and Researcher
H-index: 16

tam.unige.ch

mlg.unige.ch

MLG

Machine Learning Group

Domain activities

The Machine Learning Group of the computer science department investigates the development of novel machine learning methods with a particular interest for their algorithmic cost and sample efficiency.

Learning from data is a key element in modern techniques of artificial intelligence and has demonstrated remarkable performance for real-world tasks that require to deal with complex large dimension signals such as images.

The first downside of these methods is the requirement for very large training sets, recorded sensor data accompanied with a human-generated «ground truth» that specifies the ideal response an AI system should generate. Such ground truth is difficult to generate and often suffers from undesirable and problematic biases. The second downside of high-performance leaning-based AI methods is their computational requirements, that often translate to tens of thousands of computer hours, with the associated financial cost and environmental impact.

We aim at mitigating both to allow a wider use and lesser impact of AI.

Director
François Fleuret
Full professor
H-index: 53

PIG

Proteome Informatics Group

Director
Frédérique Lisacek
Senior Lecturer and
Researcher
H-index: 45

Domain activities

The Proteome Informatics Group (PIG) is involved in bioinformatics. Bioinformatics is a recently created discipline in which computer technology is applied to the understanding and effective use of biological data (see http://www.sib.swiss/bioinformatics-for-all/what-is-bioinformatics). At PIG, we concentrate on the study of proteins that are the active molecules of the cell. Extracting and studying proteins from a cell or a tissue requires the use of sophisticated experimental methods which generate large datasets. The analysis of this experimental data entails the identification and quantification of proteins, the determination of their cellular location, modifications, interactions and, ultimately, their function. This information is crucial to decipher cellular processes. This strongly motivates our group to develop software and databases that support data analysis and knowledge discovery in cooperation with Life scientists. These resources are made available through the ExPASy server (http://www.expasy.org). Our software tools mainly support experimental mass spectrometry data analysis, focused on the detection of post-translational modifications. Our databases store knowledge of carbohydrates (sugars) attached to proteins as well as protein-carbohydrate interactions.

In 2020, the group has been actively involved in collecting carbohydrate-related information describing the Sars-Cov-2 surface protein known as the main target of vaccines (spike protein). It provides a striking example of a phenomenon called the «sugar shield» which helps the virus escape the vigilance of the immune system. The figure below illustrates a 3D model of the bare protein on the left and the shielded protein on the right. Collected data on the sugar shield is made available to the scientific community through our resources.

http://www. sib.swiss/lisacek-frederique

smv.unige.ch

SMV

Software Modeling and Verification

Director
Didier Buchs
Full professor
H-index: 23

Domain activities

Symbolic Model Checking was developed with the idea of verifying complex high level models with a reasonable amount of work for the user. In particular we propose to separate the model to the informations for performing eficiently model checking (clustering, anonymization, partial unfolding). The introduction of new kind of decision diagrams (∑ -DD) based on a generalization of the Shannon decomposition principles allow us to perform model checking for models with huge combinatorial explosion of states (around 10E4500 symbolic states). We are currently exploring the systematic use of rewriting of set of terms principles based on decision diagrams and operational control based on strategies as a metalevel in model checkers.

We currently develop several tools such as StrataGEM for the set rewriting principles, Stew as an abstraction over StrataGEM and Ardoises a meta-environment for managing formalisms and their veri cation tools. We also continue to organize a model checking contest in the conference Petri Nets in order to be able to compare existing model checkers on significant benchmarks. We also study programming language construction that check that the use of memory is alias safe. This language SafeScript is extending JavaScript in an elegant way. We also develop methods to adapt our formalisms (CREST) to the domain of modeling and verification of cyber-physical systems.

Several application domain have been covered by the team such as the development of a domain specific language for computing on sets (Trexmo Tool for the SECO). This language is applied successfully for expressing various models of toxicology analysis in the context of health in the workplace.

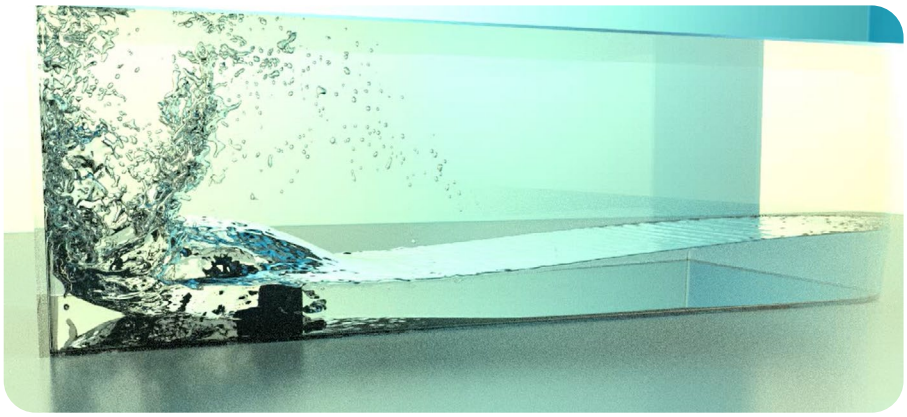
SPC

Scientific and Parallel Computing

Domain activities

The Scientific and Parallel Computing laboratory (SPC, https://spc.unige.ch/en/), divided into two groups, dedicates its research to the fields of computational science and high performance computing, with a special focus on the study of complex systems and modelling approaches based on cellular automata, lattice Boltzmann, and multi-agent techniques. Massively parallel programs and algorithms are developed, capable to explain or reproduce natural phenomena with the help of computer simulations executed on CPU and GPU-based supercomputers. The SPC lab develops and maintains the open-source software Palabos (www.palabos.org), which is widely used and acknowledged by the simulation community and has been used as a tool for more than 300 publications by universities world-wide. Palabos is used as a tool to spread the research of the UNIGE internationally, establish collaborations, and assess the expert position of the UNIGE in the field of lattice Boltzmann modeling.

https://spc.unige.ch/en/
https://www.unige.ch/hpfs/



Co-Directors

Bastien Chopard
Full professor
H-index: 46

Jonas Lätt
Associate professor
H-index: 26

Jean-Luc Falcone
Senior Lecturer
H-index: 18

Franck Raynaud
Senior Lecturer and
Research Associate
H-index: 17

TCS

Theoretical Computer Science

Director
José Rolim
Honorary professor
H-index: 26

Domain activities

Experimental driven research on Topology Control Protocols for Wireless Sensor Networks (WSN) using transmission power and throughput rate feedback schemes. The goals include link qualification in terms of symmetry and coherence and link quantification. Transmission power constitutes the link «generator» and throughput rate the link «regulator» to meet the qualitative and quantitative criteria for links between WSN nodes .

Research on designing a geographic routing algorithm for large scale networks, which is an extension to the Virtual Raw Anchor Coordinate localization based geographic routing. The goal is to perform routing in wireless ad-hoc network in a hierarchical manner, where in the top level routing is done between two geographic regions and in the bottom level performing routing to the exact node. A randomized protocol is designed and evaluated with simulations.

Design of a distributed publish/subscribe algorithm for an ubiquitous sensing scenario. We consider unstructured and free-geocoordinates sensing networks in which no network protocol is provided. Our solution, which avoids implying all the nodes of the network in the dissemination process, uses a distributed notification service defined by Directional Random Walks (DRW). A DRW is a probabilistic technique able to go forward into the network following a loop-free path. The principle assumed in our research is that two lines in a plane cross.

Also research on Future Networks, Internet of Things and Crowdsensing. Our efforts focus on problem modeling aspects and incentive formulation regarding the crowd participation in tasks that aim at optimizing spatial and temporal coverage issues.

Also, research on radiation aware wireless networking; studying the cumulative impact on ERM caused by multiple wireless sources in terms of numbers, topology, protocol, etc.

Thesis completed

Meriem Benyahya

Doctor ès Economy and Management, mention Information Systems

3rd June, 2024

Directors: Prof. Dimitri Konstantas,
Dr. Niels Alexander Nijdam,
Dr. Anastasija Collen

An Enhanced Threat Analysis and Risk Assessment for Connected and Automated Vehicles Unifying upon Security and Privacy Standards

Protecting Connected and Automated Vehicles (CAVs) from cyber attacks and data breaches is one of the main challenges facing the deployment of driverless vehicles nowadays. The CAV embedding cutting edge sensors, advanced Electronic Control Units (ECUs), innovative artificial intelligence (AI) components, and connection to
everything, has the potential to beneficially change the transport dimensions in the near future. Six levels, varying from L0 (no automation) to L5 (fully automated), were predefined by the Society of Automotive Engineering (SAE) [385]. To assure the CAV's highly autonomous navigation of SAE L4 and L5, the vehicle intelligently compiles inputs from both its internal (including cameras and sensors) and endless external connections to the Intelligence Transport System (ITS) infrastructure as well as to end-users. However, such high automation, complex in-vehicle components and ubiquitous connectivity impose the CAV to inherit cybersecurity and data privacy challenges and open up caveats for security assessments.

Both literature and industry have witnessed potential attacks that can dramatically impact the CAV's acceptance and jeopardise its passengers' safety and privacy. The recorded attacks vary from taking control over the braking and the steering systems [330], tracking passengers' locations and identities [304], to blinding the vehicle sensors and leading to a crash [462]. In light of the growing need to shield the CAV's ecosystem, Threat Analysis and Risk Assessment (TARA) is considered, by the core regulations and standards, as the efficient way to keep systems at an acceptable level of risk [114]. While numerous TARA versions are available, they are not-ready-to-use methods, do not sufficiently tackle the properties of L4 and L5 CAVs and do not consider data privacy threats at the forefront of secure CAV's implementation.

In this thesis, and within the frame of ULTIMO [89]- the Horizon Europe project, we propose and showcase an improved TARA methodology, named TARA 2.0. This endeavour involves thorough investigations aiming to identify the enhancement avenues across three research pillars: cybersecurity, data privacy and regulations & standards. For this purpose, a holistic view of existing cybersecurity and data privacy threats as well as their related regulation and standardisation requirements were put forward. Based on this knowledge, the gaps and shortcomings of the key legislation publications were spotlighted. Furthermore, we conducted a systematic study on recent TARA methodologies and simulated the most prominent standard to determine their limitations in adequately modelling CAV's threats and compiling their related risks. These efforts led to the development of TARA 2.0, which was implemented and validated through a proof of concept.

The results showed that our framework incorporates fine-grained analysis of data privacy threats as well as the CAV's automation level throughout the assessment process. Additionally, our findings indicate a strong promise that, in the context of expert-dependent assessments, TARA 2.0 enhances objectivity by transparently addressing the experts involvement within the assessment. Moreover, while the proposed solution offers a step-by-step guide for future replications to internal or external assessors, it servers as a significant reference point for any academic researcher, policymakers, smart cities operators, data controllers and service provider aiming to integrate CAVs into their respective landscapes.

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Cinzia Carrodano Tarantino

Doctor ès Economy and Management, mention Information Systems

20th March, 2024

Director: Prof. Dimitri Konstantas

Holistic Risk Assessment based on continuous data from the user's behaviour and environment

In contemporary society, risk is omnipresent and intrinsically linked to our safety, which has become a major priority. Each individual evaluates and accepts the risks they are willing to assume based on personal criteria. This thesis explores how risks can be assessed in a complex environment and the potential impact of third-party actions and events on this assessment. The concept of holistic risk assessment (HoloRisk) aims to develop a methodology and a model that consider elements outside the direct influence of the individual to provide a personalized risk assessment.

HoloRisk is based on the idea that in the future, we will be able to collect and process massive amounts of data about an individual and their environment in real time. The interaction and correlation of these data are essential for this assessment. This thesis proposes to integrate various data sources to recognize the complex relationships between different risk factors, thereby surpassing traditional assessment methods that do not capture the dynamic and multifaceted nature of modern risks.

The practical applications of HoloRisk, such as traffic management, illustrate the real implications and benefits of this innovative approach.

In conclusion, my thesis makes a significant contribution to our understanding of risks in an interconnected world, anticipating the challenges and opportunities of an era marked by rapid technological changes, and provides a solid framework to address these issues.

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Flann Chambers

Doctor ès Social Sciences, mention Information Systems

19th December, 2024

Director: Prof. Giovanna Di Marzo Serugendo,
Prof. Christophe Cruz (Uni Bourgogne)

Autonomous Generation of a Public Transportation Network by an Agent-Based Model: Mutual Enrichment with Knowledge Graphs for Sustainable Urban Mobility

This thesis develops agent-based models of land cover change and mobility inside the canton of Geneva, and demonstrates that, given the establishment of dedicated infrastructure, agent-based models become self-adaptive digital twins of urban systems, which foster communication around its inner workings, state and future trajectories among a wide variety of audiences, and provide valuable guidance for policy-making.

Working towards the sustainability of our cities is one of the greatest challenges of this century, and its assessment requires the development of tools dedicated to holistically capturing the complexity of such urban systems. It is not sufficient to analyse separately each of their components (such as urban mobility, land cover change, etc.), because the interactions between these components are of capital importance to the evolution of the system as a whole.

Agent-based models are highly capable at integrating key characteristics of these complex systems, such as individual behaviours and population heterogeneity, and hold great value in the eyes of policy-makers in their ability to provide insights for decision-making processes. However, research in the agent-based modelling field has encountered a wide array of hurdles, ranging from its data hungriness, and the lack of standardised infrastructure for real time incorporation of real-world data, to drowning out the user in a wealth of parameters to calibrate and output data to visualise efficiently.

In this thesis, we develop three models of urban mobility, commuting patterns and land cover change due to urban expansion, for the canton of Geneva and the Greater Geneva region. We identify four major shortcomings of the current state of the art in the agent-based modelling field and show that our studies adequately address them.

The first model, of commuting patterns along the Cornavin-Meyrin-CERN axis, showcases the capability of agent-based models to capture population heterogeneity, by customising the commuter agents' timetables based on their age class. The results show that decreasing public transportation offer will drastically deteriorate the commuting experience, with overcrowded trams preventing the boarding of many passengers along this axis. Conversely, increasing the public transportation offer will dampen the influx of commuters caused by the emergence of a new residential district.

The second study harnesses a DPSIR analysis of residential choices based on public transportation offer in the canton of Geneva. Results show that people would rather relocate in homes that are closer to the city centre, and that when this preference is denied by high rent prices and low housing availability, priority shifts to residences located near modes of public transportation with high passenger capacity and travelling speed.

In the third study, we coupled an agent-based model with an ontology and knowledge graphs for representing the history and future of public transportation network development in the Greater Geneva region. The model is able to replay the development of the tram line network, predict future tram line extensions and generate an artificial network from scratch, by building tram lines based on the existing road network and the spatial distribution of the population and aiming to maximise the amount of people reached by the tram lines. Results show that the artificially generated networks closely resemble their real-world counterpart, and both the knowledge graphs and the agent-based model are enriched by the outputs of their consort.

This thesis highlights the strengths of agent-based models in capturing the complexity and emergent phenomena of urban systems. These models integrate the heterogeneity of populations, individual behaviours, and enable the exploration of various hypothetical scenarios, providing valuable insights for policy-making. The works conducted during this thesis make use of additional techniques, such as the DPSIR framework for supporting the establishment of evidence-based model evolution rules, and knowledge graphs, for enhancing communication about the research paradigm among project members and other audiences (such as the general public), as well as for streamlining the design of hypothetical scenarios to explore in the model.

This thesis also addresses four major hurdles that hamper the widespread use of agent-based models in the researcher community as well as for guiding policy-making. The data hungriness of such models is solved by advocating for the establishment of large geomatic databases in open access for the studied system. Decoupling the visualisation of agent-based models' results, a computationally intensive yet crucial process for unlocking the full powers of such models, from the simulation course, leads to the creation of standalone data exploration platforms. Their deployment to web applications further fosters an efficient communication of these results. Coupling agent-based models with knowledge graphs greatly simplifies the model's parametrisation process and the design of scenarios, and unifies project members around a common vocabulary and grammar ruleset. Real-time integration of real-world data allows agent-based models to function as self-adaptive digital twins, monitoring the state of the system and its key indicators, predicting its future evolution and allowing for the exploration of hypothetical scenarios. With these barriers lifted, this new generation of «agent-based digital twins» provides a goldmine of insights for guiding political decision-making processes, and helps shape the sustainable cities of tomorrow.

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Anjani Kiritbhai Dhrangadhariya

Doctor ès Sciences, mention Computer Science

9th April, 2024

Directors: Prof. Stéphane Marchand-Maillet,
Prof. Henning Müller

Natural Language Processing and Deep Learning Approaches for Systematic Review (Semi-)Automation

Advances in natural language processing are the talk of the town, yet these advances have not materialized into their widespread adoption into systematic review automation. Systematic reviews are resource-consuming and multifaceted processes and could cost anywhere between USD 16-18 million per year for companies and research institutions. The process encompasses searching and retrieving all possible evidence to write the review, meticulously filtering studies to find relevant ones, critically appraising it for biases, extracting and collating data from these studies, performing statistical analysis and writing manuscripts. Automation is imperative to reduce workload and cut down the review cost.

Automatic citation screening methods have been suggested to reduce the initial study filtering workload, but their uptake in commercial settings has been limited due to discrepancies between existing approaches and real-world workflows. Methods in automatic information extraction could aid in chaffing multiple data types from studies. These methods, however, are limited by static hand-labelled datasets and varying data extraction needs depending on the review question. Finding a manually annotated dataset covering all necessary data types is impractical. Approaches for cheaply extending static, manually annotated datasets with new information types are necessary. Critical appraisal, particularly the bias assessment process, is the most intellectually demanding phase of review writing. The scarcity of hand-labelled datasets essential for evaluating the NLP techniques hinders their adoption into SR automation.

In this thesis we have explored methods for automation of these three stages: automatic citation screening, data extraction and bias assessment. To address the research gap in prospective methods for citation screening, we explore active citation screening methods designed and evaluated for future-facing prospective scenarios aligned with industrial processes. Additionally, we adapt and develop weak supervision methodologies to obtain labels for varied data types necessary for the data extraction stage economically. Finally, we develop a resource for evaluating state-of-the-art NLP approaches for bias assessment and provide preliminary results of language model evaluation for the resource developed. Automated methods offer the potential to make the systematic review processes cheaper, more transparent, accountable, and reproducible.

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Frantzeska Lavda

Doctor ès Sciences, mention Computer Science

27th June, 2024

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Improving the capabilities of Variational Autoencoder Models by exploring their latent space

A fundamental goal in developing of Machine Learning (ML) is to build systems that are able to mimic the capabilities of humans and animals. This drives the field towards the creation of algorithms and architectures capable of mastering a vast array of tasks, from basic pattern recognition to complex decision-making under and drug design uncertain conditions. Recent advancements in deep learning have shown that neural networks can make significant advances by using large amount of data and computing power. Particularly, the last decade deep generative models, have achieve great achievements in fields like computer vision, natural language processing, that we could not even imagine two decades
ago. These achievements highlight the potential of deep learning and underscore the ongoing effort to narrow the gap between human intelligence and machine intelligence.

This thesis delves into the advancement of deep generative modeling, particularly focusing on Variational Autoencoders (VAEs), to tackle significant challenges such as out-ofdistribution (OOD) generation, catastrophic forgetting, and the learning of multi-modal probabilistic structures. Inspired by human cognitive abilities to learn from minimal observations and adapt to new environments, our work seeks to learn similar capabilities within machine learning models, thereby narrowing the gap between human intelligence and artificial intelligence. Through three main contributions, we address limitations of current generative modeling approaches and propose solutions to improve their performance.

We explore first, the ability of VAEs to achieve OOD conditional generations. Although conditional generation is already a challenging task because the model might ignore these conditions, our research goes further into a more complex task. As humans' brains are able to understand and produce new combinations of familiar elements, we develop a novel framework that is capable of generating data with desired property values combinations not included in the training data. Our method, leveraging conditional Variational Autoencoders with a back-translation mechanism, can handle a diverse range of input–attribute pairs that may not be present in the training data, thus enhancing its capability to handle OOD data. Moreover, the back-translation procedure preserves the content of the input data while manipulating their attribute values, enabling style transfer.

Then, we examine another challenging task for machine learning, namely, continual classification learning. In continual learning, the objective is to learn from a continuous stream of tasks, incorporating new information while retaining previously acquired knowledge. In this thesis, we tackle this challenge by introducing a joint generative model approach, combining naturally a generative model with a classifier in the latent space, relying on the joint generative model to replicate the data distribution with the corresponding labels of the previously seen tasks. Our method jointly produces labels and generates input data, resulting in a shared latent variable that is optimally suited for both tasks simultaneously.

Finally, we study the limitations of VAEs, focusing on their inability to produce generations from the individual modalities of data originating from mixture distributions, reflecting humans' ability to understand and process complex, heterogeneous information. To address this, we propose a 2-level hierarchical latent variable model, which introduces both continuous and categorical latent variables, thereby offering a richer representation of data. By integrating a more flexible variational posterior and an informative conditional prior, mirroring the same structure, our method substantially improves the model's capacity for capturing and generating the complex probabilistic structures.Then, we examine another challenging task for machine learning, namely, continual classification learning. In continual learning, the objective is to learn from a continuous stream of tasks, incorporating new information while retaining previously acquired knowledge. In this thesis, we tackle this challenge by introducing a joint generative model approach, combining naturally a generative model with a classifier in the latent space, relying on the joint generative model to replicate the data distribution with the corresponding labels of the previously seen tasks. Our method jointly produces labels and generates input data, resulting in a shared latent variable that is optimally suited for both tasks simultaneously.

Finally, we study the limitations of VAEs, focusing on their inability to produce generations from the individual modalities of data originating from mixture distributions, reflecting humans' ability to understand and process complex, heterogeneous information. To address this, we propose a 2-level hierarchical latent variable model, which introduces both continuous and categorical latent variables, thereby offering a richer representation of data. By integrating a more flexible variational posterior and an informative conditional prior, mirroring the same structure, our method substantially improves the model's capacity for capturing and generating the complex probabilistic structures.

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Teri Lenard

Doctor ès Economy and Management, mention Information Systems

23th September, 2024

Directors: Prof. Dimitri Konstantas,
Prof. Béla Genge, Dr. Niels Alexander Nijdam,
Dr. Anastasija Collen

Trusted Software-Defined Vehicles

Software-Defined Systems (SDSs) emerged in the past decades as a promising Service-Oriented Architecture (SOA) that leverages the hardware of the underlying system to provide an agnostic basis for building controllable and feature-rich software environments. A SOA encapsulates groups of software services distributed across a networking system. Through a SOA, system designers can define flexible standardized communication interfaces, service separation and abstraction from the underlying hardware through virtualization, continuous over-the-air updates, system monitoring and management. The technological and operational benefits of a SOA have started to be adopted by manufacturers that develop Electrical/Electronic Architectures (EEAs). The motivation for this phenomenon lies in several limitations imposed by an EEA, in terms of system maintenance, software updates, or feature deployment. An EEA requires physical access and usually human intervention to perform these operations. Consequently, EEA devices (e.g., sensor, control unit) were designed with long life expectancy.

The EEA of automotive systems was designed to be self-contained and disconnected from the Internet. The automotive EEA is a distributed system that offers a reliable communication infrastructure, resilient against network errors, that can safely manage driving tasks. The contemporary and future vehicle architecture is expected to incorporate complex software features, capable of processing sensors information (e.g. GPS, LiDAR, ultrasound, video) to achieve vehicle autonomy, communication with the infrastructure to optimize route planning, or cloud data reporting for service management. Consequently, this implies the need for interconnectivity with the infrastructure, and the maintenance of vehicle-to-cloud service connections.

Nowadays, the automotive EEA is complemented with a SOA, transforming the traditional vehicle into a Software-Defined Vehicle (SDV). The foundation of SDVs consists of the functional hardware (e.g., digital and analog sensors, control units), which is interconnected by the communication channels offered by the EEA, on top of which a functional and control software is implemented to handle vehicle functions. The first layers of the SOA consists of a real-time operating system and a middleware for service communication, on top of which the service layer of SOA. Thus, vehicle functions are implemented as functional or service applications. Lastly, cloud services assist and communicate with the onboard (i.e., in-vehicle) SDV service layer.

The complexity introduced by this additional layer of software features, the fast-paced and feature-oriented development process frequently associated with a SOA, together with safety requirements of automotive systems, raises concerns in terms of security and trust in SDVs. Moreover, at each layer of the SDV architecture different security mechanisms must be considered. The EEA layer received significant attention from the scientific and industry communities, proposing security protocols to ensure communication security, firewalls and intrusion detection to filter communication traffic and to detect malicious behaviour.

In this thesis, we design, analyze and validate a Trusted Software-Defined Vehicle (T-SDV). A system of security services is proposed to provide defense mechanisms against SDV threats and malicious interventions. The proposed services were designed to leverage security hardware as a root-of-trust. With the integration of security hardware in the design process of security services, the T-SDV ensures the protection of security primitives (e.g., cryptographic keys), allows secure distribution of long-term encryption and short-term authentication cryptographic keys with state-of-the-art standards, message authentication tags can be aggregated under a single data structure and can be verified independently, the network is monitored with a rule-based stateful firewall and an intrusion detection system, and security alerts are securely logged.

We formalize and model trust as the ability of the security services to react, resist, and protect the system from threats and malicious interventions. A Markov Decision Process (MDP) based approach is considered to model trust and to understand the consequences and propagation of an attack in the system. The outcome of the proposed trust analysis provides quantitative results through which we were able to determine the most important service parameters that contribute to the probability of a successful attack, and thus adjust the system's parameters such that the probability of a successful attack is minimized.

The proposed services were validated through extensive security analysis, experimentation, and evaluation. From a formal point of view, the design of the proposed security services was verified through a Burrows–Abadi–Needham (BAN) logic analysis and an automated formal analysis under the Dolev-Yao adversary model. A testbed platform was designed and implemented to show the functionalities of the proposed security services. On the testbed, a
performance evaluation was conducted to measure the computational and network overhead of the security services. In addition, security experiments were performed on the testbed. The results obtained demonstrate the correctness of the proposed security services, together with their feasibility and applicability in SDVs.

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Michele Marro

Doctor ès Economy and Management, mention Information Systems

8th April, 2024

Directors: Dr. Laurent Moccozet,
Prof. David Vernez, Prof. Dimitri Konstantas

Predicting ocular exposure to natural and artificial light by means ofnumerical simulations

The human eye possesses an inherent photosensitivity that makes it vulnerable to the harmful effects of radiation. Overexposure to light can thereby lead to the development of ocular pathologies. Ultraviolet radiation and blue light are particularly hazardous in this context as they represent the most energetic portion of the absorbed spectrum. Various pathologies, such as cataracts, eyelid tumors, and age-related macular degeneration, are associated with exposure to these radiations. The determination of ocular exposure and the factors influencing it are therefore of crucial importance from a health prevention perspective. However, while the relationship between light and disease is widely studied and quite understood, it remains challenging, often impossible, to determine ocular exposure in arbitrary lighting situations. The multitude of lighting conditions and the wide range and combination of light sources present difficulties in assessing the potential hazards that might be encountered. Additionally, the eye has a sensitive surface that, in terms of spatial extension, position, and orientation in space, continuously changes during the exposure period. Consequently, the development of a reliable method capable of adapting to the wide variety of possible scenarios is of extreme importance.

This study addresses this challenge by proposing a numerical approach. Light sources are modeled using 3D computer techniques, as well as the geometry of the head and the intricate details of the ocular region. The radiative exchange between light sources and the eye is simulated by employing numerical algorithms. The estimation of the light dose received by each ocular component is achieved by using a computational 3D eye model, created from physiological data. The numerical approach enables the creation and the management of arbitrary scenarios and the study of factors influencing ocular exposure, facilitating the identification of potentially hazardous scenarios for human health.

The final assessment of the resulting model involved a comprehensive evaluation through diverse comparisons. The outcomes substantiate the model's validity in relation to both analytical and experimental references. In conclusion, the model can be effectively employed to fulfill its intended purpose.

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Damien Morard

Doctor ès Sciences, mention Computer Science
29th April, 2024

Director: Prof. Didier Buchs

Global Symbolic Model Checking based on Generalised Intervals

Nowadays, the complexity of systems continues to grow to the extent that it becomes impossible to analyse them in their entirety most of the time. Many of these systems govern our daily lives, from financial management to transportation and the surrounding industries. A problem in any of these systems can lead to dramatic repercussions, potentially causing loss of life. An illustrative example is the millions of vehicles recalled by manufacturers each year worldwide due to various software issues jeopardising the lives of their users.

In an effort to combat these errors, software modelling and verification have become two axes whose popularity has grown over the decades. Modelling focusses on the representation of the problem to be solved. It highlights the consideration of «what», meaning concentrating on the objectives to achieve in response to the posed problem. Subsequently, modelling can provide an initial solution to the «how» by establishing an abstract solution that meets the initial specifications. Verification, based on a formally defined model, is a process that aims to ensure that the model/system behaves as expected. For example, one might want to ensure that a beverage dispenser returns the change correctly after payment. The combination of modelling and verification is an undeniable asset in the software creation process, allowing the formulation and verification of ideas without the need for a complete implementation of the final system.

Although the approach is commendable and theoretically allows for the identification of all states causing malfunctions, the reality is different. The major challenge encountered in implementing these solutions is the inherent complexity of the systems to model and analyse. Indeed, verifying a system through a model requires the ability to enumerate all its states. However, describing all of these states is a task of great difficulty, easily reaching a number of states exceeding 10100. It is even more challenging than being able to reason about this state space. Consequently, a naive approach quickly becomes obsolete, necessitating the discovery of tricks to overcome these limitations.

To tackle this, in this thesis, we introduce a novel symbolic method for encoding state of a model called Petri nets. It is based on the use of generalised intervals on vectors, as opposed to existing methods based on vectors of intervals such as Interval Decision Diagrams. We develop a formalisation of these intervals, show that they possess homomorphic operations for CTL model checking on Petri nets, and define a canonical form that provides good performance characteristics. Our structure facilitates the symbolic evaluation of CTL formulas in the realm of global model checking, which aims to identify every state that satisfies a formula. Tests on examples of the model checking contest (MCC 2022) show that our approach yields promising results. Furthermore, we have also implemented efficient computations based on saturation principles derived from other symbolic model checking techniques. We thus demonstrate promising results with our method that the top tools in this competition have failed to achieve.

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Pierre-Alain Daniel T. Toupance

Doctor ès Sciences, mention Computer Science

26th August, 2024

Director: Prof. Bastien Chopard,

Complex control systems: an information theoretic approach

In this thesis, we focused on the problems of control theory in the context of complex systems. We addressed the link between the controllability or observability of a complex system and information-theoretic concepts. The model chosen for the numerical applications is a voter model based on the representation of social links (influence) in a scale-free graph. We first looked at the temporal causality between agents in these systems, which could be quantified by the delayed mutual information defined in this thesis. We defined the delayed multi-information, which quantifies the influence of an agent on the whole system. This approach provided us with a mean of directing actions to move the system towards a desired state. We have also highlighted the importance of noise in this control process, and shown that an agent's radius of action is limited and characterized by a control distance. We linked this control limit to the notion of transmission channel capacity as it is defined in information theory.

The delayed mutual information also allowed us, without a priori knowledge on the system topology, to obtain structural information about the network: we were able to recover the topology of the interconnection graph from the evolution of the agents' states. This approach allows to detect changes in system topology over time, by calculating the delayed mutual information over a sliding time window. Finally, information theory enabled us to determine a decomposition of the system into communities. The resulting partition of the system into communities suggests a reduction by agregation of the system. The principle of this reduction was first presented and tested on 1D cellular automata (CA), and then generalized to probablistic CA defined on a graph. We used mutual information itself to assess the quality of the reduction.

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Denis Adrien Ullmann

Doctor ès Sciences, mention Computer Science

28th May, 2024

Director: Prof. Svyatoslav Voloshynovskyy

Information-theoretic frameworks for Machine Learning on Solar Data

Over the last century, astronomy has greatly evolved with the changing world: theories have largely been influenced by general relativity, industrial and technological revolutions have enabled the use of launchers to send exploration satellites into space, and computers have enabled intensive simulations and calculations. Recently, the development of photo and video acquisition systems, efficient data transmission and the low cost of multimedia storage have paved the way to a new paradigm in modern astronomy: that of Big Data with massive observations of space. Modern observations are often automated or planned, and multi-modal, with an object being observed at different wavelengths, on different time and spatial scales.

As Machine Learning (ML) proposes to solve complex tasks by data-intensive computational methods, it certainly offers an ultimate opportunity to meet the challenges posed by modern astronomy. Data-driven methods are acknowledged to solve a multitude of tasks, including, but not limited to, novelty detection, classification, clustering, generation, data reduction, data representation, knowledge discovery in database, forecast, but they do not come without their own challenges. Astronomical big data is rarely fully annotated, and often multimodal, multidimensional, unbalanced, events of interest being eventually sparsely lost in the mass of data, and eventually without spatio-temporal standards of observation, even data collected by a single telescope. Such characteristics make ML on astronomical data very challenging, also because the data differs from data usually captured on the Earth and used to train ML methods.

This Thesis focuses on ML for solar data acquired by a NASA's small exploration satellite, the Interface Region Imaging Spectrograph (IRIS), and investigates challenging scenarios raised by some specificities of astronomical observations. IRIS takes spatial videos but also spectral videos of portions of the atmosphere of the Sun at preselected wavelengths. The addressed challenges include multidimensional data, non standard observation parameters, limited telecommunication, limited onboard hardware of spatial telescopes, and also the question of decentralized, and eventually sensitive, data obtained by worldwide multi national collaborative observations, like the for the Event Horizon Telescope that could recently synthesize an image of a black hole. The study is organized around three main ML tasks for astronomy: detecting specific or novel events such as solar flares, which are extreme eruptions of energy from the Sun that release large amounts of radiation across the electromagnetic spectrum; classifying data for highly decentralized systems; and forecasting future events.

Flare detection on IRIS data is performed by human assessment, usually specialized solar physicists, by visual examination of videos, rather than only images, but small flares and special events may be missed. ML detection usually needs labeled data, allowing learning precise statistics of the considered classes or by estimation of the corresponding conditional probabilities like in Bayes detection theory. The Thesis proposes data-driven and handcrafted methods to perform detection on IRIS data. An innovative deterministic transform based on Fourier decomposition is designed to provide important statistics of non perfectly aligned spatio-temporal video data of the Sun. The efficiency of these statistics is revealed for flare detection. A second study investigates the possibility of solar activity detection on compressed representations of spectral data. The challenges of flying telescopes off-line automated observations, and limited onboard memory are addressed. The Information Bottleneck (IB) principle is formulated to interpret and guide the study. A comparison of the obtained performance with other competitive methods is performed on IRIS data. The third study aims at detecting new events, that differ from a given class of labeled events. The IB formulation is applied for the task of novelty detection, designing data-depend statistics of a given class that are sufficient to detect novelties. The proposed method is evaluated on IRIS data, leading to a competitive accuracy of flare prediction, compared with the state-of-the-art on magnetic solar data.

The Event Horizon Telescope and particularly radioastronomy are the current spearheads of collaborative astronomical observation, where several observatories from different institutions or countries cooperate to develop a common observations. This context, where

some data may be sensitive or challenging to transfer, raises new challenges for ML. The Thesis investigates the task of ML classification for extremely distributed systems where no data nor information are shared between local nodes. Each node is assigned to a ML

reconstruction task on one class of data, and a central node classifies the event based on a minimal information about the local nodes, the reconstruction loss. The IB is formulated for this new setup to help interpret and design such challenging classification. Evaluations performed on benchmark non astronomical data, but already challenging, show the efficiency and promising results.

An additional crucial task is that of forecasting astronomical data. Unobserved events or missing data can be synthesized, forecasts can guide the efficient planning of eventually automated observations, and also provide a means of comparing simulations. Events like solar flares can also cause harm on the Earth, which reinforces the need to forecast. Forecasting observational data can be considered more challenging than only forecasting their class. Observational data are often multidimensional and present much variety, while classes of events are categorical low dimensional data. A novel approach is designed with a new formulation of the IB for multidimensional time series data to forecast several steps ahead of observations. Evaluations on IRIS and non-astronomical data show the competitive performance of the proposed method and the preservation of the physics in the forecast.

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Haozhou Wang

Doctor ès Humanities, mention Linguistics

9th December, 2024

Director: Prof. Paola Merlo

Adversarial Learning for Cross-Lingual Word Embeddings

In the field of natural language processing, current neural network systems are hungry for labelled data. However, large amounts of human-annotated or human-corrected labelled data are only available for a limited number of languages. Previous studies have demonstrated that using cross-lingual word embeddings that associate similar words across different languages with similar vector representations allows us to apply the system trained from data in one language to data in another language directly, thus making it possible to enable model transfer from high-resource languages to lowresource languages and solve the low-resource problem.

Traditional methods of learning cross-lingual word embeddings use bilingual dictionary. More recent unsupervised methods have shown that adopting the Generative Adversarial Networks (GAN) can facilitate the learning of cross-lingual word embedding without using any bilingual resources. While GAN-based method has competitive or even better performance compared to supervised methods on learning cross-lingual embeddings across typologically similar languages, it is often criticized for its poor performance on learning embeddings across typologically distant languages. This thesis aims to advance the path of using the adversarial network to learn cross-lingual embeddings. Our work not only focuses on improving the cross-lingual transfer between typologically similar languages, but also on the transfer between typologically distant languages. The contribution of this thesis can be divided into three parts.

Firstly, we observe that sampling words from the whole distribution of embedding spaces in source language and target language makes it difficult to train similar words across languages together, and some cross-lingual resources such as Wikipedia concept-aligned data are not as expensive as high-quality dictionary. Based on this, we propose a weakly-supervised adversarial training method. The main novelty of our weakly supervised adversarial method lies in the use of Wikipedia concept-aligned article pairs in the discriminator, which encourages the generator to align words from different languages that are used to describe the same concept. The results of our experiments on bilingual lexicon induction and cross-lingual word similarity confirm our intuition that mapping across languages performs better at the concept level than at the word level.

Secondly, based our experiment on translating the top 50,000 most common English words into Chinese and French, we demonstrate that the hypothesis behind the current unsupervised GAN-based system that similar words across two languages are related by a single linear relation doesn't hold true in reality. Instead, we assume that the crosslingual mapping, especially across typologically distant languages, is only piece-wise linear and propose a multi-adversarial learning method. This novel method learns different linear mapping for different subspaces of word embeddings. Our experimental results on bilingual lexicon induction and cross-lingual document classification on both close language pairs and distant language pairs prove the cross-lingual embedding model learned via multi-linear mappings exhibits better cross-lingual transferability, especially across distant languages.

Finally, we extend our work from traditional static embedding models to dynamic contextualized embedding models and propose a cross-lingual adversarial fine-tuning method that aims to stimulate the multilingual contextualized embedding models to generate similar representations for tokens in similar sentences across languages. Our experiments on different cross-lingual zero-shot tasks verify that the multilingual contextualized embedding model achieves better cross-lingual transfer performance after our cross-lingual adversarial fine-tuning.

Doctorat thesis: Univ. Genève, 2024 - L. 1164 - 2024/12/09
https://archive-ouverte.unige.ch/unige:182847

Shervin Zakeri

Doctor ès Economy and Management, mention Information Systems

7th February, 2024

Director: Prof. Dimitri Konstantas

The theory of everything: A model that provides a unified solution for dealing with uncertainty in solving MCDM problems

Uncertainty is a fundamental aspect of the decision-making process, especially in Multi-Criteria Decision Making (MCDM) problems, where every stage of problem-solving involves some degree of uncertainty. MCDM problems are characterized by a framework of multiple criteria and alternatives, designed to achieve one or several objectives of the decision-making process. Ranging from everyday issues to highly complex industrial, military, and political challenges, MCDM problems have outcomes that can significantly impact many lives or incur substantial financial costs. Therefore, developing solutions that produce the least uncertain outputs is crucial.

Uncertainty in decision-making typically arises when decision-makers lack complete information about the elements of decision analysis or its outcomes. The primary aim of this paper-based doctoral dissertation is to offer a comprehensive solution, termed the 'theory of everything,' that addresses all sources of uncertainty in MCDM problems. Thirteen sources of uncertainty have been identified, including:

- Decision-making goals
- Decision-makers
- Linguistic variables and scales
- Conversion of uncertain to certain values
- Weighting methods
- MCDM method processes
- Time
- Missing information
- Multi-layer problems
- Philosophies and policies, encompassing the decision-making paradox
- Validation
- The Rank Reversal Paradox

To tackle each of these sources, various MCDM algorithms, statistical measures, novel scales, new numerical sets, a game, and a new theoretical framework were proposed. These solutions are detailed across eighteen scientific articles. In the final chapter, the unified model, including its components, properties, and limitations, is thoroughly discussed, offering a holistic approach to managing uncertainty in MCDM.

Doctorat thesis: Univ. Genève, 2024 - GSEM 138 - 2024/02/07
https://archive-ouverte.unige.ch/unige:182825

pin.unige.ch

CUI UNI GE

Digital Innovation Hub

DIGITAL INNOVATION HUB
University of Geneva

As part of the University's digital strategy, the **Digital Innovation Hub** (https://pin.unige.ch) active since March 2019, hosts creativity and innovation activities in the field of digital services. The purpose of the hub is to be transverse to the University and to reach the City, i.e. Geneva State as well as companies and organisations of the Geneva area. It is part of the network of innovation hubs of the University (https://www.unige.ch/collaborateurs/innovation/).

The Digital Innovation Hub has the following missions:

- Support students and researchers with digital projects that lead to commercial exploitation or social impact;
- Provide a meeting place and collaboration with the public and private sector in the region;
- Develop innovative services for the university community.

To carry out its missions, the Digital Innovation Hub has developed a series of tools.

Accelerator of digital sciences and services

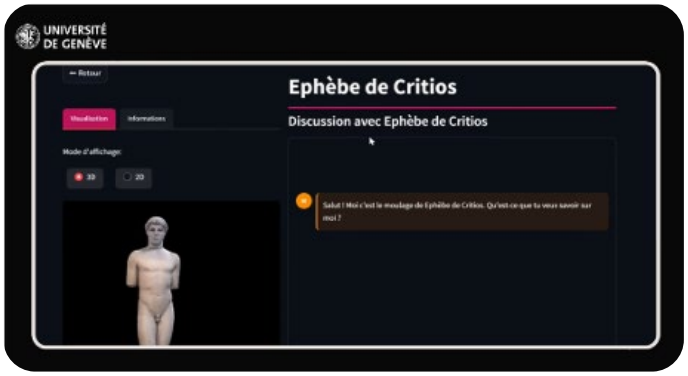
The Accelerator of digital sciences and services (https://cui.unige.ch/fr/pin/accelerateur/) is born from the joint effort of two entities of the University: the Information Systems Division (DISTIC) providing expertise in developing professional digital services to the whole University community, and the Computer Science Center (CUI), providing innovative technologies arising from research. Through the Accelerator and a joint coaching (from DISTIC and CUI), students' or institutional projects undergo an innovation process, going from ideation up to a fully working service prototype. The final user or stakeholder interested by the service takes over the final stages of deployment and maintenance. The Accelerator works closely with the R&D Unit and together they contribute to the third mission of the Digital Innovation Hub.

Managed by a dedicated team, the accelerator regularly offers new initiatives and innovative projects for the university community. Concretely these projects are put into practice in the form of bachelor's work, internship, research project in coordination with the DISTIC, the CUI, and final users of stakeholders.

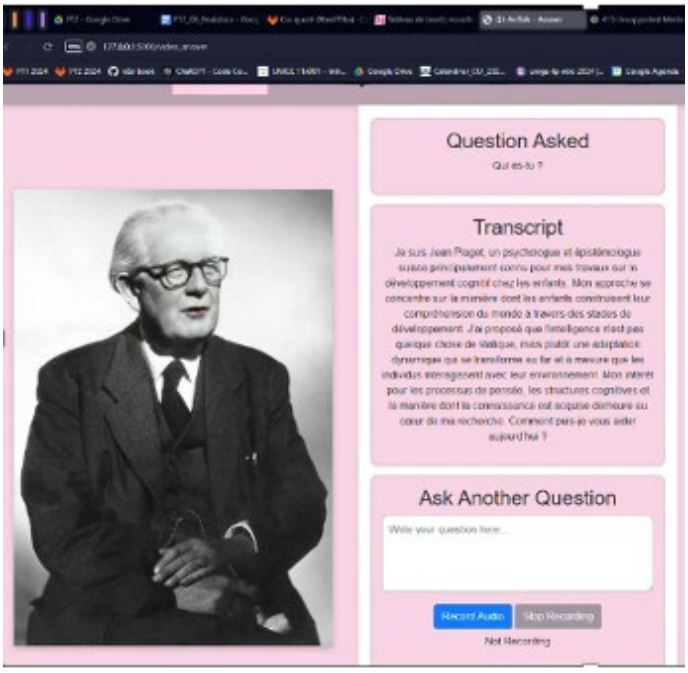
So far, the Accelerator of digital sciences and services has supported more than 120 projects of which 100 functional PoC and 40 pilots, and 10 deployed services made available to the university community.

The 2024 novelties concern the development of specialised LLM-agents (AI Agents) as well as multi-agent LLM systems (Agentic AI). We provided innovative services employing various workflows such as RAG, GraphRAG, Semantic AI using Knowledge representation and open-linked data. Notable projects of the Accelerator in 2024 include:

- A multi-agent LLM system favouring the interaction with specific artefacts, such as castings of Ancient Greek and Roman statues;
- a RAG-based system for interacting with the UNIGE Memento pages (gathering directives and regulations on various subjects), thus facilitating the search of information;
- "Reviving" or providing a realistic interactive representation of a deceased scientist from archive media such as audio, video or photographic images and exploiting further archives and research data for nourishing the interactive scientific discussion;
- together with the FacLab capabilities we developed the concept of digital twin for underwater archeological sites and participated in the Immersum exhibit in December 2024.



https://youtu.be/vwp3QZZXNcM
@Aichatou Orou Bade



@Projet Transverse I, CUI

Since 2020, the Accelerator has annually awarded the Digital Innovation Award to outstanding projects developed by students in the BSc in Information Systems and Service Science or in the MSc in Digital Systems and Services. In 2024, the Accelerator delivered the Digital Innovation Award to Anas Guetarni and Antonin Sedoh for their joint MSc thesis on Analysis, design and development of an ontology-based chatbot for drug interactions https://www.unige.ch/stic/innovation/actu/prix-de-laccelerateur-2024

https://www.unige.ch/stic/innovation

AI clinic

The new AI Clinic of the Digital Innovation Hub established in 2023 serves as a communication platform for exploring Artificial Intelligence (AI). It offers a pipeline of tools and frameworks enabling researchers and other university members to experiment with and use the power of open source LLMs (chatGPT, etc.) with their own data, processed on the University's servers. It addresses various topics, including the explanation of Large Language Models (LLMs), the societal and ethical implications of AI, and the practical application of AI tools.

The expressed needs regarding AI can be categorised into three main areas, that are: "Scientific AI", "AI as a Service"" and "Everyday AI". The AI Clinic addresses these needs by setting itself the following missions:

- Responding to Inquiries : The AI Clinic responds to AI integration requests from UNIGE and external organizations, offering practical guidance from experts, students, and researchers on using current AI tools effectively.
- Advisory activities : The Digital Innovation Hub and R&D Unit advise national and international bodies on AI. Internationally, they contribute to the EU AI Act "Code of Practice" as experts appointed by the European Commission (https://www.cio.com/article/3543237/eu-taps-ai-experts-to-develop-compliance-framework-for-ai-regulations.html). Nationally, they advise the Swiss Academy of Engineering Sciences (SATW) and its SAI-ROP platform. This work resulted in the creation of an AI guide for Swiss SMEs. At the cantonal level, they participate in Geneva's Strategic Council for Geoinformation and Geneva's Advisory Commission for Data Protection and Transparency.
- Educational programs : The AI Clinic provides short certified and non-certified courses in Python, Data Science, AI, Ethics, and Education, tailored for a broad audience, including non-specialists. Courses include Python, Applied Data Science, and practical AI for non-specialists, as well as AI in Ethics and Education. In 2024, it delivered 11 sessions to 149 participants and issued 88 micro-certifications.
- Short hands-on training sessions : Beyond its formal programs, the AI Clinic offers short, hands-on Copilot Chat training. A session is planned for the University Library Office, with more in high demand across other departments.
- Open source on-premise LLM infrastructure : The AI Clinic has deployed its own infrastructure, Hactar, a two-GPU node supporting projects from the Accelerator and Digital Forge programs. In 2024, over 20 projects ran on Hactar. The goal is to build expertise for transfer to the future DiSTIC GPU infrastructure, enabling scalable AI deployment. This initiative exemplifies effective collaboration and knowledge transfer from academia to professional services.

https://cui.unige.ch/fr/pin/clinique-de-l-ia/

Coding Dojo

In September 2021, the PIN launched a programming club called the Coding Dojo, which is a collaboration between UNIGE and HEG. The Coding Dojo, based at the FacLab, has a dual mission: to provide coaching, tutoring, and mutual support for students (learning new programming languages, tools, or paradigms, and helping with specific programming problems), and to promote programming awareness among secondary school and vocational training centre students.

Since the start, the Coding Dojo develops specific programs for the following audiences: High school Students, University Students, Researchers. During this period, we coached more than 150 trainees. We delivered 17 certificates of 3 ECTS for advanced University studies to high school students. Girls are well represented, forming 33% of the high-school students.

https://cui.unige.ch/fr/pin/club-de-programmation/

Digital forge

The digital forge is a laboratory of scientific and technical expertise that forges ideas into products. The digital forge is directed towards the technical realisation of proof-of-concepts (POC) and rapid prototyping of digital project ideas. Strongly anchored between digital scientific research and the Swiss economic fabric, the forge joins forces with companies or organisations to support and help them in their phases of ideation, validation and production of prototypes.

The digital forge brings scientific expertise in IoT, Blockchain, Big data, the various forms of AI and covers fields such as smart city, digital health, fintech, cybersecurity, administration, or pharmacy. The Digital Forge works closely with the R&D Unit and contributes to the second mission of the Digital Innovation Hub.

In 2024, the Digital Forge participated in various events: invited speakers at SITC 2024 on AI and IT Education, and the organization of a workshop on AI assistants for administrative tasks in Higher Education institutions at Educa 2024. The Digital Forge and the R&D Unit, through BSc/MSc students and coaching, also contributed to developing innovative service for our external partners.

- We developed an ontology-based self-adaptive digital twin for electric transformers for a French Energy company.
- We develop a TAG (table advanced generation) service for dynamically creating graphics from quantitative data for a private company in Geneva.
- We developed an advanced tool for OBSAN (the Swiss Health Observatory project under the Swiss Federal Office of Statistics) that transforms datasets into RDF format, fully compliant with LINDAS principles and standards. This solution also includes features for data anonymization and the protection of sensitive information.
- For the Geneva University Hospitals (HUG) pharmaceutical service, we created a chatbot designed to answer questions about drug interactions. It leverages a structured knowledge base built on ontologies that encompass pharmaceuticals, their interactions, and broader medical concepts. The intelligent agent uses this semantic framework to deliver accurate and context-aware responses to user queries.
- For the Canton Geneva State Personnel Service, we developed a GenAI service based on Retrieval-Augmented Generation (RAG) that delivers comprehensive and efficient answers by retrieving information from the extensive HR knowledge base of the Canton of Geneva. This tool enhances access to critical HR information and serves as a valuable resource for the entire cantonal administration.

https://cui.unige.ch/fr/pin/forge-numerique/

Digital Innovators

Digital Innovators is a monthly seminar series launched in February 2021, showcasing cutting-edge digital innovations and their real-world applications. Since its inception, the series has hosted 32 sessions, each highlighting a unique use case and fostering dialogue around emerging technologies and their impact.

https://cui.unige.ch/fr/pin/digital-innovators/

FacLab

The FacLab is an academic fabrication laboratory (FabLab) that supports the University of Geneva's core missions in education, research, and community service. It offers a dedicated space where students, researchers, and faculty engage in hands-on fabrication, prototyping, and creative exploration. Grounded in the principle of learning by doing, the FacLab fosters interdisciplinary collaboration and practical skill development, contributing to innovation across a range of fields.

Established through participatory design and integrated into the University's Digital Strategy, the FacLab operates within a 320m² facility equipped with a range of digital fabrication tools—including 3D printers, CNC machines, and laser cutters, alongside co-design resources and flexible collaborative workspaces.

The FacLab is part of the university's wider innovation ecosystem, which includes several internal hubs and international partnerships such as the 4EU+ network. It contributes to the development of future-oriented teaching and research practices and is increasingly recognised as a distinctive feature of the University of Geneva's academic offering. The FacLab is accessible also to the public during the usual opening hours of UNIGE.

The FacLab also hosts ephemeral residencies for projects aligned with the university's broader educational and societal goals. In 2024, five active residencies explored a range of socially engaged themes: enabling community intelligence to foster socially sustainable technologies (Katametron), promoting digital and computational skills through project-based learning (Lesa.teliers), advancing personal data reappropriation (PersonalData.io), reimagining how talents and companies connect (Tungxten), and evaluating the educational benefits of the Beekee Box during study trips (Beekee).

Since early 2024, the FacLab has benefited from the support of six paid student volunteers (Bachelor's and Master's students from the CUI, each working at 0.05 FTE). Their contributions (welcoming users, providing training, and maintaining equipment) have helped expand and sustain the FacLab's activities.

The FacLab also supported specialised academic requests, including the design of a large-scale 3D-printed topographical model for the exhibition IMMERSUM: Diving into the Past led by Professor Julien Beck. The installation allowed visitors to visualise shifting water levels over time at an archaeological site in Argolide, Greece.

Throughout 2024, the FacLab organised and hosted over 30 training sessions, workshops, and hackathons for participants from both the university and the wider public. Highlights included a week-long workshop on 3D modeling and 3D printing, held in collaboration with CO Montbrillant secondary school, which welcomed 18 students for hands-on learning.

https://faclab.unige.ch/

Innovation clinic

The development of the Innovation Clinic began in 2019. The Innovation Clinic supports innovative student projects, whatever the field, from ideation to actual impact. These projects benefit from a personalised guidance process, visibility and the opportunity to connect with other interested students. The process is based on proven methods for carrying out innovation and transformation projects. Members of the project team learn while participating in the innovation process, in a spirit of empowerment. The Innovation Clinic allows students to learn how to innovate by actually doing it. The Innovation Clinic participates in the first and third missions of the Digital Innovation Hub.

In 2024 the PIN's Innovation Clinic continued its support for a student startup aiming to promote students' internships through specific mandates.

https://cui.unige.ch/fr/pin/clinique-de-linnovation/

R&D Unit

Founded in 2021, the R&D Unit is a key force within the Digital Innovation Hub (PIN) . Situated within the DiSTIC (Information Systems Division of the University of Geneva), it pioneers digital solutions and accelerates the adoption of high-potential innovations across the university community. The R&D Unit makes major contributions to lifelong learning, data valorisation, and AI literacy, while also strengthening its collaboration with the Digital Innovation Hub, particularly through its Accelerator, the Digital Forge and the AI Clinic programs. This synergy enables the coaching, development, and deployment of the most promising digital services created by CUI students, turning ideas into real-world solutions for both the University and external organisations.

The R&D Unit also leads the RDF (Resource Description Framework) and Linked Data Interest Group, a cross-functional initiative active at UNIGE since 2018. This group brings together experts and enthusiasts from across the university to explore and advance the use of Linked Data and the Web of Data.

Coordinated by members of the R&D Unit, the group hosts monthly meetings that dive into a wide range of topics, from semantic data modeling and ontology design to real-world applications of RDF technologies. It serves as a collaborative platform for sharing knowledge, fostering innovation, and promoting best practices in data interoperability and open standards.

SciCoS (Scientific Computing Support)

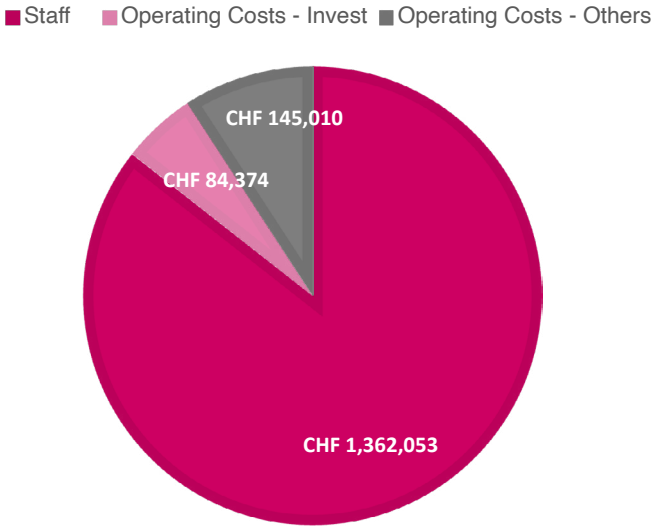
SciCoS is a team of experts in scientific informatics, dedicated to supporting researchers from the University of Geneva and the Applied Universities of Geneva (HES-GE). The services provided include: operational support for high performance computing (HPC) and data processing, development of scientific applications, consulting and training for researchers. SciCoS contributes to the third mission of the Digital Innovation Hub. SciCoS is a new tool from the Digital Innovation Center which will offer its services from March 1, 2021. Initially funded by the State of Geneva (PL12146), SciCoS is fully funded by the researchers who requests its services. In 2024, a convention was signed between the University and the Hospital of Geneva (HUG), facilitating the provision of services to clinical researchers.

https://www.unige.ch/scicos/

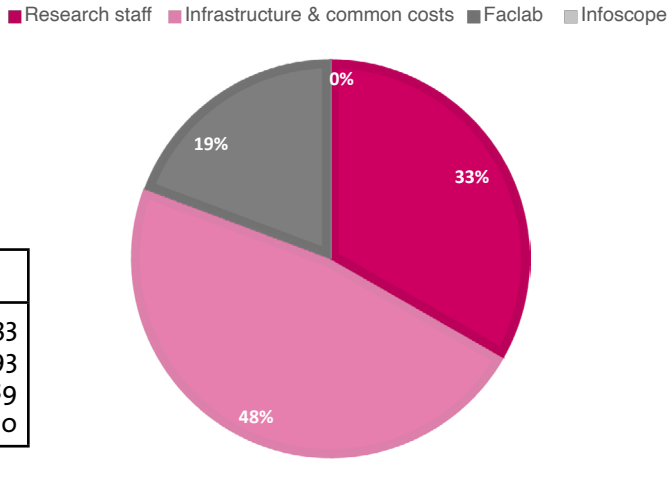
Financial Report 2024

Financial Resources State of Geneva (DIP)

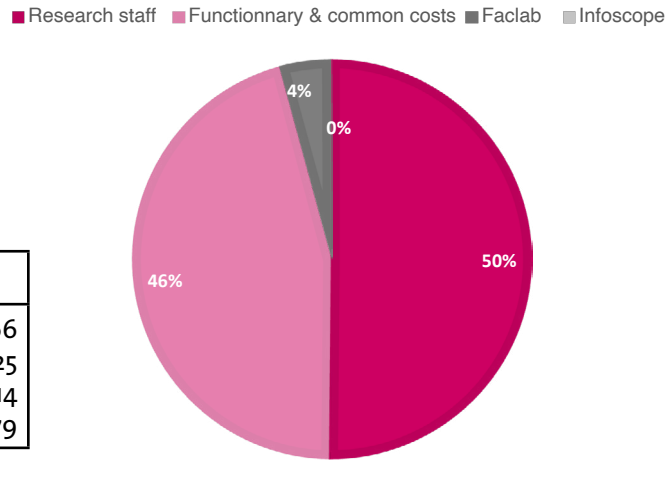
	Budget
Staff	CHF 1'362'053
• Academic	CHF 393'492
• Administrative and Technical	CHF 697'318
• Employer's social contributions	CHF 256'075
• Others	CHF 15'168
Operating costs - Investment	CHF 84'374
Operating costs - Others	CHF 145'010
Total Budget 2024	**CHF 1'591'437**



Main operating costs - Investment	Budget
• Research staff	CHF 27'233
• Infrastructure & common costs	CHF 38'793
• Faclab	CHF 15'789
• Infoscope	CHF 0



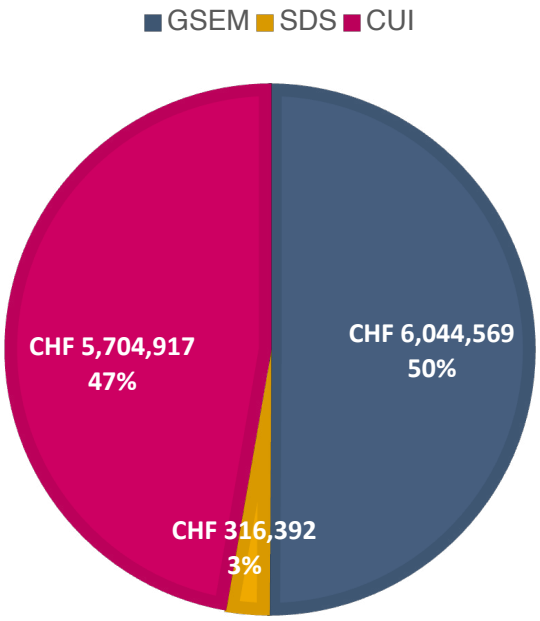
Main operating costs - Others	Budget
• Research staff	CHF 59'966
• Functionnary & common costs	CHF 54'625
• Faclab	CHF 4'914
• Infoscope	CHF 79



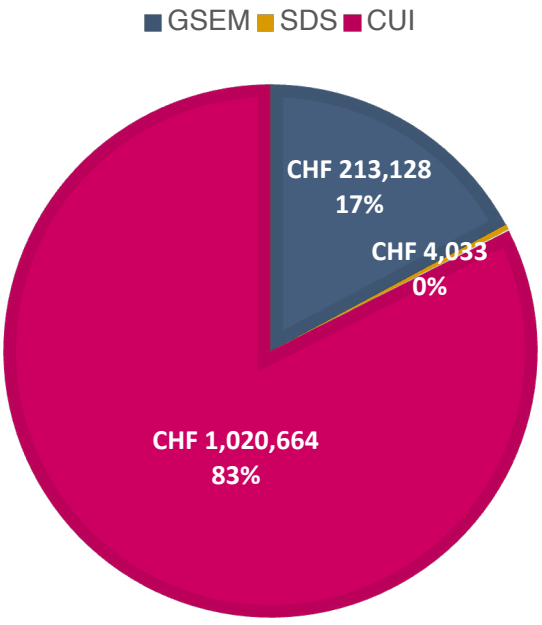
Funds with administrative workload on CUI (Contrats, Finances, Accounting)

	Total allocation for the projects	2024 allocation
GSEM registered projects	CHF 6'044'569	CHF 213'128
SDS registered projects	CHF 316'392	CHF 124'514
CUI registered projects	CHF 5'704'917	CHF 1'020'664
Total Credit	**CHF 12'065'878**	**CHF 1'237'825**

Total allocation for the projects



2024 allocation



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