TELECOM
Paris

IP PARIS

2023 | 2024

TÉLÉCOM PARIS RESEARCH *Overview*
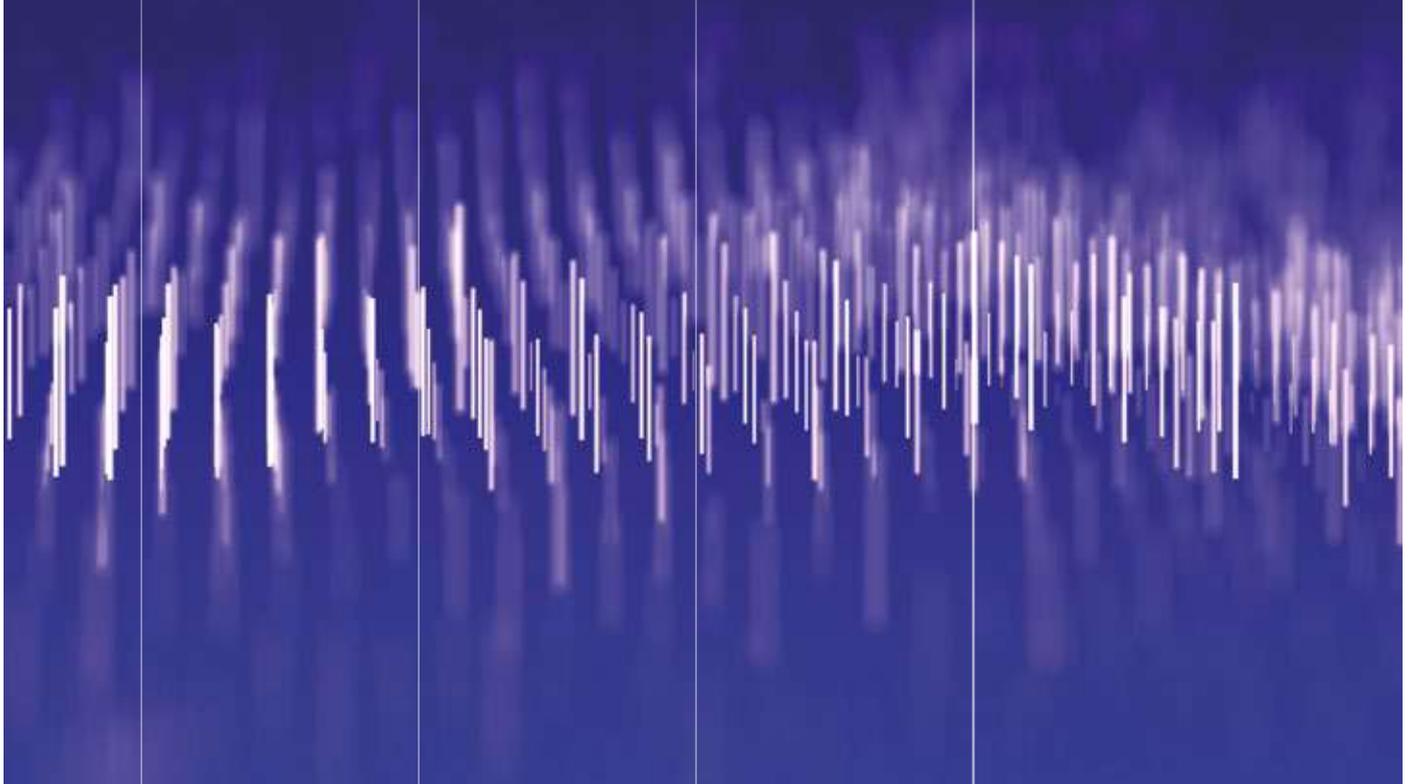
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Patrick Olivier
Director of Télécom Paris

Imagine, design and create digital futures

EDITORIAL

Research at Télécom Paris is central to our ambition: to imagine, design and create digital futures that are useful to humans, ethical, sustainable, reliable and sovereign.

In 2023-2024, our researchers produced more than 800 publications and contributed to major scientific advances in several digital fields, such as cybersecurity, artificial intelligence, quantum information processing and the communication networks of the future. They have received prestigious international recognition, such as the ERC Consolidator Grant awarded to Michèle Wigger in 2023 for her project on the fundamental limits of sensing systems.

Our scientific excellence is the foundation on which all our activities are based, from fundamental research to partnership-based and applied research, and ultimately innovation and transfer.

Télécom Paris is active across the entire chain of critical technologies, from electronic circuits to algorithms and mathematical models used to study the robustness and limitations of proposed solutions. With its broad spectrum of expertise, Télécom Paris contributes to major national and European strategic research and innovation programmes, such as those funded under France 2030, PEPR (priority research programmes and equipment) and Hi! PARIS Cluster 2030.

As a permanent part of the Institut Mines-Télécom and the Institut Polytechnique de Paris, we bridge the gap between fundamental research, practical applications and training talented individuals through research.

Our uniqueness also stems from our humanistic and multidisciplinary engineering school model. We train engineers who are able to connect technology with meaning, highlighting their versatility, adaptability and collaborative skills, in order to think about the impact of innovation and act with discernment. Our fundamental research feeds into our applied research, which together nourish our initial and continuing education programmes.

We are thus making our school a true digital laboratory, a unique place for imagination, design and collective experimentation. It is a place for dialogue between science and society in the service of tomorrow's digital technology, which will be more efficient, safer, more sober and ethical *by design*, and a source of emancipation and progress.

I would like to warmly thank all the teams who are driving this dynamic forward.

Thanks to you, Télécom Paris continues to blaze a unique trail in the landscape of research and higher education, both in France and internationally.

Happy reading!

01

LABORATORIES

Télécom Paris is a top-ranked public institution of higher education in the French Grandes Ecoles tradition, a member of Institut Mines-Télécom and a founding member of Institut Polytechnique de Paris. Télécom Paris is located in Palaiseau, France, in the heart of a rich ecosystem encompassing world-renowned universities, leading research centers and innovative companies.

The research activity of Télécom Paris covers a fairly broad spectrum of the field of information and communication sciences and technologies, ranging from computer science and electronics to applied mathematics, digital economy and social sciences.

Télécom Paris research teams benefit from and contribute to the work of three leading laboratories, renowned worldwide for the excellence of their research.

Center for Research in Economics and Statistics (CREST)
A joint research unit with ENSAE Paris, École polytechnique and the CNRS.

Information Processing and Communication Laboratory
A research unit specific to Telecom Paris.

Interdisciplinary Institute on Innovation
A joint research unit with École polytechnique, Mines Paris - PSL and the CNRS.

Core Research Areas

Data science and Artificial Intelligence

This research area focuses on the foundations of artificial intelligence and on the management and analysis of data in all its forms, including large-scale, complex, heterogeneous, unstructured, and multimedia data. It also addresses applications in fields such as healthcare, cybersecurity and defense, banking and finance, energy, and climate science.

In addition, Télécom Paris conducts interdisciplinary research in this area on issues with significant societal implications, including the explainability and regulation of AI.
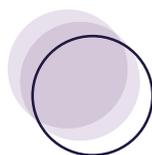
Digital trust

Digital trust refers to system dependability, encompassing reliability, safety, availability, maintainability, and cybersecurity. It builds on the classical confidentiality–integrity–availability (CIA) triad.

These issues are central to Télécom Paris and are investigated at every level, from electronic components and software layers to mathematical models and formal proofs.

Communication Systems and Networks

This research area focuses on the design of next-generation computing and communication infrastructures, ranging from supercomputers to cloud, edge, and Internet of Things (IoT) systems.

It integrates advanced techniques in hardware, networking, systems, modeling, programming languages, algorithms, middleware, databases, and artificial intelligence to enhance performance and scalability, reduce energy consumption, simplify administration, and strengthen reliability.

Quantum information processing and communication

This research area aims to explore and harness the properties of complex quantum systems by combining quantum information theory with digital technologies, enhancing our ability to process and protect data.

It addresses both theoretical and experimental aspects of quantum computing and quantum networks, including the development of new quantum cryptography protocols and experiments to create novel light sources for quantum communications. These efforts are designed to be compatible with fiber-optic telecommunications networks, supporting high-speed transmissions, advanced optical network architectures, next-generation lasers, integrated photonics, and distributed fiber-optic sensors.
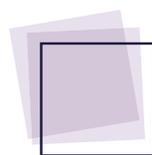
Digital innovation, economics and regulation

Digital innovation and entrepreneurship are entering a new phase of rapid transformation. This is reflected in the speed at which internet startups are reshaping the economy and society, influencing organizational practices, modes of interaction, work structures, and value creation.

This research area contributes to Télécom Paris's distinctive profile and reflects the breadth of its expertise, spanning digital economics, management science, law and regulation, sociology, ergonomics, and design.

Mathematical modeling
A cross-disciplinary research area

Mathematical modeling intersects and contributes to all of Télécom Paris's research areas. It is a major strength of the institution's research, addressing both theoretical and practical aspects of information and communication technologies (ICT)..

The Center for Research in Economics and Statistics (CREST) is a scientific research institution specialized in quantitative methods applied to the social sciences.

CREST is a joint research unit (UMR 9194) bringing together researchers and faculty members from GENES, École polytechnique, CNRS, and Télécom Paris (Economics - ECO team of the Department of Economic and Social Sciences).

The research carried out by the ECO team focuses mainly on the digital economy, employing methods from empirical and theoretical industrial economics.

This research area investigates how digital transformation affects traditional markets, fosters the emergence of new markets, and drives companies to adapt their strategies accordingly. It also examines the public policies needed to mitigate potential negative effects of digital transformation.

The work is carried out in collaboration with a broad network of academic partners, as well as industry, businesses, and public organizations, including through Research Chairs.

The Interdisciplinary Institute on Innovation (I^3) was launched in 2012 by Mines Paris – PSL (formerly Mines ParisTech) and Télécom Paris, joined by École polytechnique in 2014 and the CNRS in 2015, thus becoming a CNRS joint research unit (UMR 9217). I^3 is composed of six research teams focusing on innovation issues and social sciences. I^3 is composed of six research teams focusing on innovation issues and social sciences, two of them are part of the Economics and Social Sciences Department of Télécom Paris.

The research conducted by I^3 is organized around four transdisciplinary themes:
- Companies, organisations and markets faced with the contemporary challenges of responsible innovation;
- Theory, practice and politics of design and creative action;
- Policies, instruments and innovations for the ecological transition;
- Innovating differently: alternatives, critiques, resistance to innovation.

LTCI *Laboratoire Traitement et Communication de l'Information*

The Information Processing and Communications Laboratory (LTCI) was created in 1982 and is characterized by its extensive coverage of topics in the field of information and communication sciences and technology. The laboratory is also active in issues related to systems engineering and applied mathematics. Organized into 15 research teams, it addresses three main fields:

- Communications and Electronics – physical and hardware basis of processing and design/modeling/integration of objects in an information system;
- Computer Science and Networks – infrastructure, systems and digital networks, with a special focus on mathematical modeling, protocols and functions of next generation networks, computing architecture of systems and services, in their algorithmic and software aspects;
- Images, Data and Signal Processing – study and analysis of signals and images in all their forms, study and development of algorithms and statistical processing methods for learning, optimization and data analysis.

Teams research topics

CREST team

ECO

Economics

Team leader: Patrick Waelbroeck

Keywords: Digital platforms, Data, Innovation, Telecommunications, Infrastructure, Strategy, Digital transformation, Public policy, Regulation, Competition policy, Intellectual property, Privacy, Industrial organization, Econometrics, Qualitative methods.

I³ teams

INTERACT

Interaction, Technology, Activity

Team leader: Isabelle Garron

Keywords: Interaction, Activity, Mobility, Collaboration, Community, Interaction design, Creative design, User experience, Technology-mediated interaction, Social robotics.

NOS

Digital Technologies, Organization and Society

Team leader: David Massé

Keywords: Science and technology, studies, Participation, Democratization, Citizens, Digital labor, Design, Art-science.

LCTI teams

ACES

Autonomous Critical Embedded Systems

Team leader: Samuel Tardieu

Keywords: Digital Trust, Cybersecurity, Safe and secure distributed computing, Software and systems engineering, Real-time critical embedded systems, Autonomous and Energy Aware Systems.

C²

Cybersecurity and Cryptography

Team leader: Duong Hieu Phan

Keywords: Cryptography, Privacy, Network security, Internet of Things, V2X communications security, Coding, Combinatorics, Graph, Algebraic geometry.

C2S

Circuits & Communications Systems

Team leader: Patricia Desgreys

Keywords: Smart AMS systems, Frugal signal processing, Smart radio, Cyber-physical system interfaces.

DIG

Data, Intelligence and Graphs

Team leader: Thomas Bonald

Keywords: Database, Knowledge, Logics, Language, Intelligence, Graphs.

DIVA

Design, Interaction, Visualization & Applications

Team leader: James Eagan

Keywords: Human-computer interaction (HCI), Visualization, Virtual reality, augmented reality, mixed reality, Design.

GTO

Optical Telecommunications

Team leader: **Moustapha El-Kurdi**

Keywords: Innovative optical components, Laser dynamics, Optical fiber communication, Optical networks, Optical sensors, Optoelectronics, Quantum communication, Quantum metrology, Time-frequency quantum information processing.

IMAGES

Image, Modeling, Analysis, GEometry, Synthesis

Team leader: **Yann Gousseau**

Keywords: Mathematics and artificial intelligence for images, Stochastic image modeling, Machine learning and deep learning, Image and video restoration, Image and video synthesis and editing, Discrete mathematics, Algebraic and structural models, Symbolic AI, Computer graphics, Geometrical and topological analysis, Rendering, Simulation, Remote sensing imaging, SAR imaging, Medical imaging, Computational photography, Creative industrie.

LabSoc

Laboratory on System on Chip

Team leader: **Rabéa Ameur-Boulifa**

Keywords: Architecture exploration, Formal validation, Model-based system engineering, Safety, Cybersecurity, Security of electronic circuits, Security of the micro-architecture of processors, Software/hardware architecture for signal processing applications, AI for model-based system engineering.

MIC

Mathematics of Information & Communication

Team leader: **Aslan Tchamkerten**

Keywords: Information theory, Network data processing, Coding, Distributed optimization, Security.

MM

Multimédia

Team leader: **Enzo Tartaglione**

Keywords: Image and video compression, Transport and orchestration of multimedia content, Deep neural network compression, Graph Neural Networks, AI-based generative models, Frugal and Efficient AI, Geometric deep learning, Multimodal learning.

QTY

Quriosity: Quantum Information Processing and Communications in Saclay

Team leader: **Romain Alléaume**

Keywords: Quantum Information Theory, Quantum Cryptography, Quantum Computing, Quantum Algorithms, Learning, Mathematics, Quantum Communications and Photonics.

RFM²

Radio Frequency, Microwaves & Millimeter waves

Team leader: **Christophe Roblin**

Keywords: Theory and modeling of RF systems, Antenna and RF circuit design, RF instrumentation.

RMS

Networks, Mobility and Services

Team leader: **Laurent Decreusefond**

Keywords: Mobile networks, Cellular networks, 5G, 6G, Future Internet, Internet of things, Data centers, Cloud, Virtualization, Performance analysis, Optimization, Mathematical models, Algorithm design.

S²A

Signal, Statistics and Learning

Team leader: **Stephan Clémençon**

Keywords: Probability & Statistics, Machine-Learning and Optimization, Audio Data Analysis and Signal, Processing, Natural Language Processing.

SSH

Secure and Safe Hardware

Team leader: **Lirida Naviner**

Keywords: Architecture and design methods for embedded systems, Hardware security of embedded systems against physical and cyber attacks, Hardware reliability of embedded systems.

02

ECOSYSTEMS

This section highlights

Télécom Paris's ecosystem. The institution thrives at the center of a dynamic network, fostering synergies between academia, industry, and society. Partnerships with leading companies, startups, and research institutions drive cutting-edge innovation and transformative projects.

National

Île-de-France region

Plateau Orsay Palaiseau Saclay

Institut Polytechnique de Paris

Université Paris-Saclay

HEC

EDF R&D

Thales Research and Technology

Horiba

CEA-List

Major areas of research and innovation Ile-de-France region
- DIM RFSI
- DIM Math Innov
- DIM SIRTEC
- DIM AI4IDF
- DIM Quantip

Competitiveness clusters
- Cap Digital
- Systematic

Inria

CNRS

IMT / Fondation Mines-Télécom

Institut Carnot Télécom & Société Numérique

- FMJH: Fondation Mathématique Jacques Hadamard
- École Doctorale de Mathématiques Hadamard
- Quantum-Saclay
- Paris Saclay Cancer Cluster

Institut Polytechnique de Paris

Télécom Paris

EDUCATION
- Doctoral School
- Graduate School

RESEARCH
Interdisciplinary centers
- E4H
- E4C
- CIEDS
- SPIRAL
- Hi! PARIS

HEC

Université Paris-Saclay

Alliance H@rvest → **AgroParisTech**

MVA Master → **CentraleSupélec**

- SATT Paris-Saclay
- IRT SystemX

Quantum-Saclay

Laboratories, students, manufacturers, and startups—the Plateau de Saclay hosts a vibrant quantum ecosystem. **Quantum-Saclay** is an interdisciplinary center for research, training, and innovation that brings these forces together, supported by the National Quantum Plan.

Researchers are harnessing the properties of quantum systems to develop novel algorithms and explore new approaches to communications. One example is the **Quriosity research team**, jointly run by Inria, Télécom Paris, and the Institut Polytechnique de Paris, which focuses on quantum information processing and both the theoretical and experimental aspects of quantum communications.

"For example, we are developing new communication systems for quantum networks, on which we are also developing a hybrid cryptography combining classical computational methods and quantum methods," explains **Romain Alléaume** (QTY).

Romain Alléaume, **Marc-Olivier Renou** (Inria) and around twenty other faculty members are working together to build a Quantum, Mathematics and Computer Science (QMI) Master, coordinated by Télécom Paris, CentraleSupélec, École polytechnique and Université Paris-Saclay.

quantum-saclay.fr

Télécom Paris is involved in interdisciplinary Centers at the Institut Polytechnique de Paris

Télécom Paris' teams are involved in the interdisciplinary Centers at the Institut Polytechnique de Paris, notably Hi! Paris, E4H, E4C and CIEDS. They combine their expertise with that of researchers and partners in the ecosystem to address major societal issues by drawing on the complementary perspectives and methodologies of each discipline.

- Supported by the Ministry of the Armed Forces and the Defence Innovation Agency, the **Interdisciplinary Center for Defence and Security Studies (CIEDS)** devises and develops responses to the technological needs of the defence sector.

- The interdisciplinary **Energy4Climate Center (E4C)** is involved in the energy transition through research, training and innovation. Télécom Paris' laboratories are working within E4C on four transversal themes to reduce greenhouse gas emissions, improve energy efficiency, deploy renewable energy distribution and evaluate public policies.

- The **Engineering for Health (E4H) Interdisciplinary Research Center** brings together researchers from the physical, mathematical, and social sciences to apply a highly quantitative and interdisciplinary approach to the life sciences and medicine. Through E4H, several researchers from Télécom Paris are involved in the **Paris-Saclay Cancer Cluster (PSCC)**, created in 2024, which serves as a catalyst for transforming potentially revolutionary approaches into industrial diagnostic and therapeutic solutions for cancer. The ultimate goal is to make screening and treatment more predictive, precise, and effective for the benefit of patients.

"Startups and the scientific community in laboratories and hospitals are our core audience. We offer them a catalog of cutting-edge services to support their maturation projects by providing solid expertise in data science, statistical learning and mathematics as concerns Télécom Paris researchers." stresses **Elsa Angelini**, Professor at Télécom Paris and specialist in medical image computing and Deep Learning.

- **Hi! Paris**, the interdisciplinary center for artificial intelligence and data analysis aims to create one of the world's leading centers for research, training and innovation in AI for the benefit of society. In 2024, Hi! Paris was officially appointed as an "AI Cluster" by the French government as part of the "France 2030" program.

www.ip-paris.fr/cieds
www.ip-paris.fr/e4c
www.ip-paris.fr/e4h
www.hi-paris.fr

03

PLATFORMS

This section presents Télécom Paris' main research platforms. Most laboratory research activities are supported by platforms equipped with state-of-the-art experimental tools. The equipment is operated, supervised, and maintained by experienced technical and scientific staff who work closely with our research teams.

Quantum communication platform.

OPTICAL PLATFORMS FOR COMMUNICATION AND SENSING

The Optical Communication Team (GTO) *performs advanced research on novel concepts in optical communications, focusing on devices, protocols and communication systems and networks. This is made possible by the presence of state-of-the-art experimental platforms on **quantum communication**, **distributed acoustic sensing** and **infrared laser devices**.*

Quantum communication platform

The **Quantum Communication Platform** focuses on high-speed quantum key distribution using continuous variables (CV-QKD), a technique that leverages technological advances in classical optical communications to enhance quantum security. Managed in collaboration with the Quriosity team, the platform was designed to demonstrate joint classical and quantum communication using the same encoding devices. It has been employed to study detector noise and to develop a new calibration technique offering improved performance and greater tolerance to imperfections compared with existing methods.

G. Ricard, Y. Jaouën, and R. Alléaume, Receiver Noise Calibration in CV-QKD Accounting for Noise Dynamics arXiv:2509.07549.

R. Alleaume, Y. Jaouën and G. Ricard, "Refined Noise Estimation in Continuous-Variable Quantum Key Distribution", pending european patent n° 24306773.3, 22 octobre 2024.

Distributed acoustic sensing platform

The Distributed Acoustic Sensing (DAS) is a measurement technique that allows to monitor an optical fiber by sending a modulated laser signal and measuring the light reflected by the fiber itself due to the Rayleigh effect by using a coherent receiver. Digital processing of the received signal enables the detection of deformations along the optical fiber. The platform contains a spread-spectrum DAS interrogator developed to allow data transmission and sensing in the same band on the same fiber with a spatial resolution of 50 cm and a sampling frequency of up to 6 kHz. This platform is used in collaborative projects with Invisensing.io and Orange Innovation. GTO also contributed to other DAS platforms developed through industrial partnerships with Nokia Bell Labs and SNCF.

Alex Chedid, Ali Kabalan, Tarik Hammi, Gabriel Papaiz Garbini, Renaud Gabet. Railway track monitoring using distributed acoustic sensing (DAS) with standard telecom cable. 29th International Conference on Optical Fiber Sensors, May 2025, Porto, Portugal. pp.348.

Pallab Kumar Choudhury, Élie Awwad. Wavelength and Code Orthogonality Based Distributed Acoustic Sensing over a Passive Optical Network. Optical Fiber Communications Conference, Optica, Mar 2025, San Francisco, United States

P. K. Choudhury and É. Awwad, "In-Band Sensing and Communication for Optical Access Networks Using Δɸ-OTDR With Simplified Transceivers," in IEEE Sensors Letters, vol. 8, no. 10, pp. 1-4, Oct. 2024, Art no. 3502704.

Mid-wave and long-wave infrared laser devices

Mid-wave infrared (MWIR, 3-5 µm) and long-wave infrared (LWIR, 8-12 µm) wavelengths present superior transmission performances through adverse atmospheric phenomena such as fog, clouds and dust, together with enhanced security thanks to the intrinsic thermal noise. The platform present in the laboratory allows for the characterization of quantum cascade lasers emitting in the MWIR and LWIR and their utilization for free-space optical communication. Thanks to this platform, the group has demonstrated the feasibility of high-speed and secure data transmission.

P. Didier, H. Dely, O. Spitz, T. Bonazzi, E. Awwad, E. Rodriguez, A. Vasanelli, C. Sirtori, and F. Grillot. Progress in high-speed optical links in the 8-12 microns thermal atmospheric window from the perspective of unipolar quantum technology. In Laser Technology for Defense and Security XVIII, page 10, Orlando, United States, Apr. 2023. SPIE.

P. Didier, H. Knötig, O. Spitz, L. Cerutti, A. Lardschneider, E. Awwad, D. Diaz-Thomas, A. Baranov, R. Weih, J. Koeth, B. Schwarz, and F. Grillot. Interband cascade technology for energy-efficient mid-infrared free-space communication. Photonics research, 11(4):582, 2023.

Pierre Didier, Sara Zaminga, Olivier Spitz, Jiagui Wu, Élie Awwad, et al.. Data encryption with chaotic light in the long wavelength infrared atmospheric window. Optica, 2024, 11(5), pp.626-633.

T. Bonazzi, H. Dely, P. Didier, D. Gacemi, B. Fix, M. Beck, J. Faist, A. Harouri, I. Sagnes, F. Grillot, A. Vasanelli, and C. Sirtori, Metamaterial unipolar quantum optoelectronics for mid-infrared free-space optics (Invited), APL Photonics 9, p. 110801, 2024.

F. Grillot, T. Poletti, and S. Pes, Progress in mid-infrared optoelectronics for high-speed free-space data throughput (Perspective), APL Photonics 10, p. 010905, 2025.

Device characterization platform.

HI-AUDIO ONLINE PLATFORM: BRIDGING MUSIC AND RESEARCH

*A **platform** developed at ADASP (Audio Data Analysis and Signal Processing), a research group within the S²A LTCI team.*

The Hi-Audio online platform is a key initiative of the ERC HI-AUDIO project that aims to build controllable and frugal machine listening models based on expressive generative modelling and Hybrid deep learning models with application to audio scene analysis, music information retrieval and sound transformation and synthesis.

The HI-Audio online platform is an open-source system designed to support musicians and researchers in the field of Music Information Retrieval (MIR)[1]. It facilitates the recording, uploading, and sharing of multitrack musical works, with the objective of developing an open-access audio database that
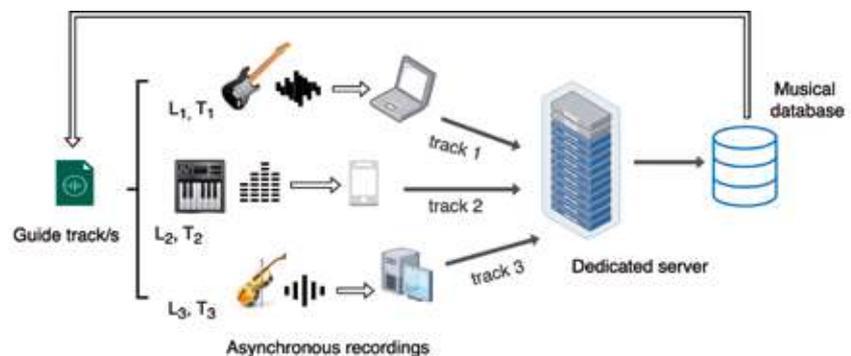
*Illustration presenting the overall recording framework for three tracks (from [1]). The recording process is **distributed**, occurring across different locations (Li), and **asynchronous**, conducted at distinct times (Ti). A **guide track**, hosted within the database, serves as a reference to allow synchronized performances among participants.*

Prof. Gaël Richard showing the platform to attendees during ISMIR 2023.

advances research in music technology. Upon synchronization with the server, uploaded files are automatically analyzed using signal processing techniques and machine learning models to generate comprehensive metadata. In addition to these automated processes, users can contribute manual annotations, further enhancing the depth and quality of the dataset.

The platform is fully accessible at https://hiaudio.fr/

[1] *José M Gil Panal, Aurélien David, Gaël Richard, The Hi-Audio online platform for distributed music recordings, preprint on HAL, https://hal.science/hal-05153739/ (Submitted to EURASIP Journal on Audio, Speech, and Music Processing, 2025*

RAMSES: A DESIGN SUPPORT PLATFORM FOR EMBEDDED SYSTEMS

RAMSES is a design support platform for mission-critical real-time embedded systems. Specifically, it offers an AADL (Architecture Analysis and Design Language) modeling environment based on a standardized language used to describe embedded systems architectures. Users can model their system, which RAMSES then analyzes to provide information for optimizing the design. In this way, the platform helps to design systems that are more efficient, thanks to the precise evaluation of several performance properties, which are critical for embedded systems. This allows for optimizing the management of resources to their degree of criticality. A new extension for complex robotics systems is currently under development based on a rich component library and a new methodology that greatly reduces the modeling efforts thanks to a better usability.

RAMSES is a platform accredited by the Institut Carnot Télécom & Société numérique and Télécom Paris, a member of the Institut Mines-Télécom (IMT). It also benefited from two prematuration projects funded by Institut Polytechnique de Paris and support from the Institut Polytechnique de Paris's Design Innovation Lab to improve user experience.
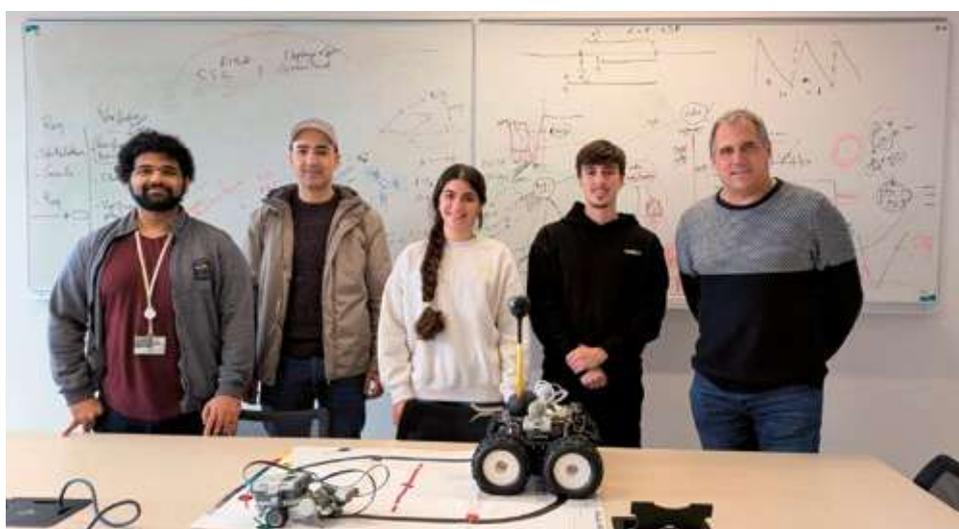
The contributors of RAMSES also developed a tutorial for PhD students on model analysis and code generation for robot systems.

Watch the RAMSES platform presentation video.

PLATFORMS ENABLING END-TO-END WIRELESS NETWORK EXPERIMENTATION

RMS (Networks, Mobility and Services) team has designed a set of research platforms that make it possible to perform experiments remotely at every level of a radio communication system. Technologies supported include cellular systems such as 2G (GSM/GPRS/EDGE), 3G, LTE, NB-IOT, LTE-M, 5G NSA, 5G SA, 5G NTN, 5G O-RAN. It also supports ISM technologies such as IEEE 802.15 or WLAN. The research platform relies on a dedicated research infrastructure deployed on a separated network. Two rooms have been built to support different experimental use cases. For experiments requiring a protected radio environment, network entities can all be located inside a Faraday Cage for a fully protected and isolated environment. A second room is used to operate devices in ISM bands. More recently, facilities for conducting experiments in both indoor and outdoor environments in the B38 band have become available. AI embedded devices connected to communication devices (at cellular IoT UE devices or RAN level) have also started to be deployed in the Faraday cage.

For works requiring the support of virtualization technologies, a set of servers, located in the Telecom Paris Data center, are available to deploy customized VM for experiment purposes.

A metrology framework can also be used to monitor the system performance at every level of the system architecture and protocol stack. Specific sensors are also deployed to monitor received powers and to assess EMF exposure levels. Data generated by these different experiments can be retrieved remotely by users for further processing and investigation.

The following sections describe the different platforms that are currently deployed or under deployment.

Experiments on 5G and future networks in the Faraday cage.

IMT SDR Lab

This platform aims to enable the design, development, and evaluation of new network functionalities in a software radio environment. It is installed in a ZRR equipped with a Faraday cage (40 square meters), in which a complete 4G/5G system is deployed. It also supports 5G NTN experiments. It will soon support 6G RIS experiments. This Platform is used to develop specific code, such as Free5GRAN project (open-source implementation of 5G physical layer) or 5G physical layer acceleration (Kalray, GPU acceleration, FPGA acceleration).

FIT IoT-Lab and evolution towards NGC AIoT

FIT IoT Lab (for more information on FIT, see https://www.iot-lab.info/.) is a legacy testbed that has been designed to perform experiments with small wireless sensor devices and heterogeneous communicating objects. It provides an ISM Band experimentation room dedicated to 802.15.4, WiFi and LoRa technologies. This room is part of the Equipex FIT and is currently evolving towards a national platform called NGC AIoT, making part of the PEPR future networks project. It will soon be integrated into the SLICES-FR project. The room is available to the research community for developing and deploying images based on open-source operating systems, with the aim of conducting experiments on connected objects. NGC AIoT intends to extend the range of experiments combining the usage of cellular IoT and AI embedded (at UE and Edge level).

IPEPR future networks and SLICES-FR

This platform provides a 5G SA-based O-RAN infrastructure. It relies on open-source solutions such as Openair interface and SRSAN. It also provides FR1 and FR2 UE simulators based on the Amarisoft testbed, along with a 5G FR1/FR2 base station. The platform will be connected to the French SLICES-FR cluster (via RENATER, with links to INRIA Lyon and Sofia, Eurecom, and PSL) as part of the SLICES European project.

04

KEY
figures

The document concerns the research activity of Télécom Paris in 2023-2024. In order to obtain the most representative figures possible, unless otherwise stated, the statistics shown in this report correspond to the activity of our research teams in 2024.
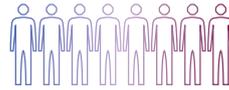
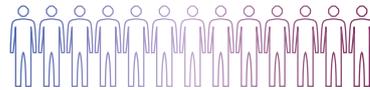## Staff

As of December 31, 2024

493

Total Research Staff

157

Permanent researchers and faculty members

246

PhD students

44

Postdocs

46

Administrative and technical staff

Publications

959

Total publications

331
Articles

576
Conference papers

52

Books and book chapters

ERC Grants

Since the beginning of the ERC Program

ERC starting grants

👤 Mansoor Yousefi (2018)

👤 Michèle Wigger (2016)

👤 Alexandre Gramfort (2015)

ERC advanced grant

👤 Gaël Richard (2022)

ERC consolidator grants

👤 Michèle Wigger (2023)

👤 Yanlei Diao (2016)

Research Funding

As of December 31, 2024

12%
CIFRE Thesis and bilateral contracts

7%
Chairs and joint labs

17%
European public funding

15M€
Grant and Contract Revenue

64%
National public funding

Transfer and innovation

5-year consolidated figures

5
Spinoff creation

17
Maturing projects

144
Registered patents

18
Registered software

1
Registered know-how

05

HIGHLIGHTS

In recent years, the laboratories of Télécom Paris have been marked by several significant events and projects. The following pages highlight some of the most important.

Kick-off of the Intelligent Cybersecurity for Mobility System (ICMS) Chair

Picture taken during the kick-off in July 2025.

The automotive industry has recently undergone a radical shift. Beyond the widespread electrification that is already well underway, vehicles are becoming increasingly connected and moving towards greater autonomy. These developments offer an almost unlimited range of innovative features, particularly by improving the ability of these systems to communicate with each other and with the outside world. However, they also come with new attack surfaces, some of which are completely new. In particular, the increase in electronic equipment and embedded software in vehicles can bring with it a host of new threats and vulnerabilities. These potential dangers pose a serious risk to the integrity and reliability of vehicles, as well as to the safety and privacy of their occupants.

A chair combining academic excellence and industrial applications

"This is a key issue for the coming years, both in industry and in the world of research", says Sébastien Canard, professor of cybersecurity at Télécom Paris and also head of the ICMS chair's scientific committee. "Our school has a duty to be a leading figure in this field on an international scale". That is why, in February 2024, we launched the Intelligent Cybersecurity for Mobility System (ICMS) chair. This initiative follows on from work carried out by the Connected Cars and Cyber Security (C3S) Chair, with the aim of furthering knowledge and raising the profile of Télécom Paris and its partners within the scientific community through high-quality publications directly linked to the needs of manufacturers in the field.

ICMS aims to deliver results that can be applied in the short term in industry. It currently has six partner companies: Renault Group and its subsidiary Ampere, SOLENT, Thales, Valeo, ZF Group and BCG. In addition to these, there is the SystemX Institute for Technological Research, which will facilitate transfers between the worlds of academic research and industry. "We are committed to reconciling the needs of these two worlds, even if they do not always seem compatible", says Sébastien Canard. "That is why we have set up a new model, with a scientific committee bringing together researchers from the school and representatives of industrial partners. This allows us to co-construct the scientific vision of the chair and the associated projects".

In addition, PhD theses conducted within the framework of ICMS will be supervised by a team bringing together lecturers and researchers from Télécom Paris and experts from industrial partners. This will give doctoral students the opportunity to work on concrete use cases proposed and jointly supervised by industrial partners. They will also have the opportunity to carry out part of their research work within companies.

Télécom Paris is proud to establish a new research-industry partnerships with IRT SystemX, Renault, Solent, Thales, Valeo, ZF Group, and the BCG who hosted this event!

The aim of the Chair, aligned with the purpose of Télécom Paris, is to implement an innovative operational model and ecosystem by:

▶ Enhancing research excellence in intelligent cybersecurity, particularly for mobility systems.

▶ Strengthening applicability and fostering technology transfer through appropriate interaction between fundamental research, applied research and the needs of industry.

▶ Building a world-class, internationally acclaimed chair.

A joint research laboratory between STMicroelectronics and Télécom Paris

"By uniting Télécom Paris's excellence in digital sciences with STMicroelectronics's know-how and innovation capacity, the partnership seeks to accelerate the transformation of research into tangible technological solutions."

Paris, July 2024 – Télécom Paris and STMicroelectronics France SAS established a strategic partnership, formalized through the signing of a framework agreement, to deepen research collaboration, accelerate technological innovation, and enhance the training of future experts and leaders in microelectronics, embedded systems, and digital technologies.

This long-term partnership reflects the shared ambition of both partners to tackle major scientific and industrial challenges linked to the digital and energy transitions. By combining Télécom Paris' academic excellence with STMicroelectronics' industrial expertise, the agreement aims to foster cutting-edge research, develop advanced educational programs, and strengthen innovation ecosystems that reinforce France's technological sovereignty.

The framework agreement provides a structured foundation for joint research initiatives and high-impact projects across several strategic domains. Key areas of collaboration include next-generation semiconductor technologies, low-power and secure embedded systems, advanced sensing and signal processing, AI for hardware design and edge computing, and the development of sustainable, energy-efficient architectures.

The collaboration also promotes the creation of shared research platforms, co-supervised PhD theses, and the active participation of researchers, engineers, and students in a joint laboratory and exploratory projects. These initiatives are designed to stimulate breakthrough innovations, particularly in hardware–software co-design, resilient and trustworthy systems, and intelligent semiconductor-based devices for applications in mobility, healthcare, telecommunications, and the Internet of Things.

Beyond research, the partnership strengthens the training ecosystem in microelectronics by promoting internships, project-based learning, and academic–industrial exchanges. It contributes directly to the national ambition of reinforcing France's and Europe's technological sovereignty in semiconductors and advanced electronics.

Through this agreement, Télécom Paris reaffirms its role as a key academic partner in shaping the future of microelectronics and embedded intelligence, while STMicroelectronics gains privileged access to world-class research and emerging talent to support its long-term innovation strategy.
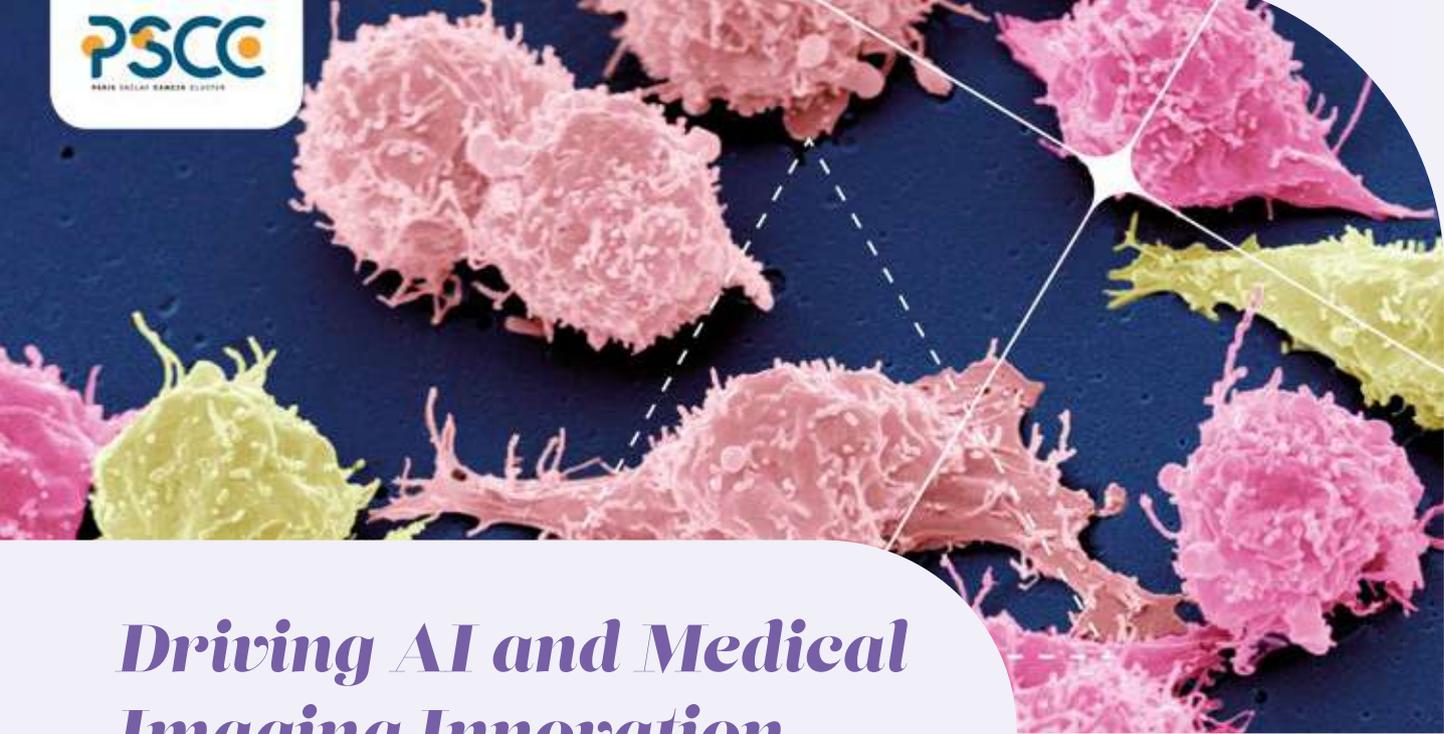
© sciencephoto-Canva

Cancer cells under a scanning microscope.

Driving AI and Medical Imaging Innovation within the Paris-Saclay Cancer Cluster

Télécom Paris has taken an active role in the Paris-Saclay Cancer Cluster, bringing its digital-science and medical-imaging expertise to a large, multi-partner biocluster created to accelerate oncology innovation.

Throughout 2023–2024 Télécom Paris focused on three concrete lines of contribution.

- First, the school supplied targeted training and educational resources: existing courses in machine learning, medical-image representation and data ethics were opened to innovators and startup teams supported by the PSCC, and Télécom Paris signalled intent to develop short, practice-oriented offerings (masterclasses / summer schools) tailored to the needs of biotech and medtech partners. This educational integration helps bridge academic knowledge and industry maturation.

- Second, Télécom Paris contributed technical leadership on the PSCC's data and platform efforts. The cluster's plan for a shared oncology data platform – anonymized, cleaned, interoperable clinical, imaging and biological datasets accessible across sites – draws on Télécom Paris expertise in data modelling, interoperability and AI methods designed to perform with limited labelled data. A key milestone reported for 2024 was the signature of agreements bringing the first three hospital partners onto the cluster's data platform, an important step for multi-centre data access and federated research.

- Third, Télécom Paris researchers have been involved in project selection and scientific support inside the PSCC ecosystem, offering access to methodological

> *"As part of the Institut Polytechnique de Paris community, Télécom Paris contributes faculty expertise (notably Professor Elsa Angelini as IP-Paris academic correspondent for the PSCC) and research capacity in biomedical imaging, machine learning and data science — domains that are central to the cluster's ambition to make cancer diagnosis and treatment more predictive and precise."*

know-how, experimental infrastructures and doctoral talent – creating pathways for technology transfer from algorithmic research to clinical and industrial validation. These activities sit alongside broader PSCC funding and structuring (France-2030 supported resources) that scaled up the cluster's activities in 2023–2024.

In sum, over 2023–2024 Télécom Paris's contribution to the Paris-Saclay Cancer Cluster combined domain expertise (medical imaging, AI), educational outreach and active participation in the cluster's data-platform buildout – positioning the school as a technical and training partner in an ambitious, regionally anchored effort to shorten the trajectory from oncology research to patient impact.

Visit the Paris Saclay Cancer Cluster website

Visionerves: Advancing Surgical Planning with Patient-Specific AI Models

In 2023–2024, the Visionerves project emerged as one of Télécom Paris's flagship achievements in the realm of medical imaging and AI-driven surgical planning. Rooted in fundamental research from the IMAGES team at LTCI under the leadership of Isabelle Bloch and Pietro Gori, Visionerves has successfully bridged the gap between theoretical image analysis innovation and translational clinical impact.

That omission presents a serious risk: inadvertent nerve injury is a significant cause of functional damage in pelvic surgeries. Visionerves addresses this blind spot by automatically segmenting both the anatomical structures and the nerve pathways, enabling a more complete and safer preoperative visualization.

From a methodological perspective, Visionerves combines a deep segmentation model with symbolic reasoning based on anatomical knowledge. In the first stage, relevant pelvic organs and tissue regions are segmented via a neural network. In the second stage, the system performs tractography and nerve recognition by encoding spatial relationships – employing fuzzy logic and spatial reasoning rules – to trace nerve trajectories in a reproducible, automated way, without needing manually defined regions of interest.

This hybrid approach has been validated in a clinical-use context: when applied

At the Datacraft Awards (July 2023), Visionerves won the audience award for the most daring AI project.

The range of innovative solutions is the result of research conducted by Isabelle Bloch and Pietro Gori at Télécom Paris.

to cases of suspected endometriosis, focusing on the lumbosacral plexus of patients, Visionerves demonstrated significant gains over standard tractography. Reported improvements include up to 25% increases in Dice similarity scores, and spatial errors reduced to under 5 mm. These results showcase the potential for enhanced diagnostic fidelity and safer surgical planning for pathologies with nerve involvement.

Recognition of Visionerves's promise was swift. In July 2023, the project won the **Datacraft Award** for "boldest AI project" as voted by the public. It was also selected in the official shortlist of the **Prix Galien France 2023**, a prestigious international accolade in health innovation. In early 2024, Visionerves secured further support by being named a winner of the **Prémat' DeepTech call** of the Institut

"At its core, Visionerves is a hybrid AI framework designed to generate patient specific 3D digital twins of pelvic anatomy –including, critically, the peripheral nerve networks. Traditional 3D reconstructions in surgical planning rely on imaging modalities such as MRI and CT; however, until now these reconstructions have rarely included the complex branching nerve structures."

Polytechnique de Paris, positioning it among the leading MedTech projects in the IP Paris ecosystem. More recently, in 2024, Visionerves was honored with the **Prix Béatrice Denys** for its innovation as a medical research software solution.

Beyond accolades, Visionerves is already yielding concrete outcomes. The core technology underlies the development of a spin off (Replico[1]), which is already converting the research into clinical grade software tools that transform MRI images into precise 3D anatomical models enriched with nerve structures.

In summary, Visionerves stands as a model of Télécom Paris's capacity to deliver high impact, cross disciplinary research anchored in AI, geometry, medical imaging, and symbolic reasoning.

Podcast *"Révolutionner la chirurgie : l'IA au service de l'imagerie médicale"* Télécom Paris Ideas
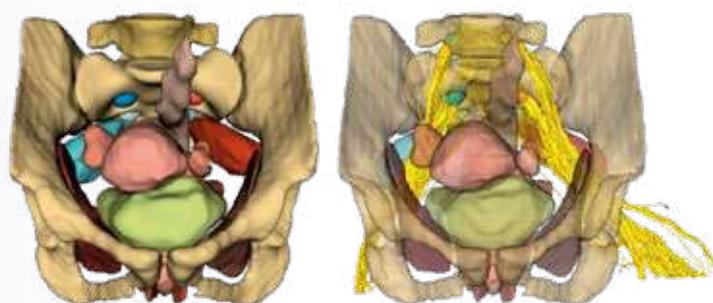
In the image, the left side shows a 3D model without nerve representation, while the right side displays the same model including a precise visualization of the nerves.

[1] *www.replico.tech.*

FinAI-LAB, a joint laboratory between BNP Paribas and Télécom Paris

Kick off of FinIA-Lab.

At the end of 2024, Télécom Paris and BNP Paribas agreed to create a joint laboratory dedicated to artificial intelligence for financial and large-scale applications.

The goal of the joint lab is to conduct world-class research across all five research themes. It also aims to identify theoretical solutions that can be transformed into operational tools with tangible impact on the performance of BNP Paribas group.

The laboratory also aims to actively contribute to the open-source ecosystem by sharing technological building blocks and frameworks beneficial to the scientific and industrial community.

Fin AI-Lab is organized around five research areas and one transversal area dedicated to trustworthy AI.

- ➡ The first research area focuses on **Online and Continual Learning**, aiming to design adaptive AI models and systems capable of continuously learning from evolving, dynamic, and heterogeneous data streams. It aims to ensure robust and dynamic adaptation of systems to the variability of environments and information flows. It is led by Albert Bifet (Télécom Paris) and Mariam Barry (BNP Paribas).

- ➡ The second area on **Cybersecurity** leverages behavioral and graph-based approaches to detect subtle intrusions often invisible to traditional tools. It is led by Rida Khatoum (Télécom Paris) and Frédéric Legac (BNP Paribas) on cybersecurity of AI models including Trustworthy AI aspects and Risk management.

"FinAI-LAB aims to accelerate the development of robust and responsible AI solutions to address the industrial and applicative challenges of the financial sector, especially in highly regulated contexts where reliability, transparency, and performance are essential."

- ➡ The third research area, **Fundamental Models for Large-Scale Financial Data**, focuses on leveraging foundational model technologies to design architectures tailored to global financial data. It aims to identify key technological building blocks for constructing a foundational model dedicated to financial applications. It is led by François Roueff (Télécom Paris) and Laurent Carlier (BNP Paribas).

- ➡ The fourth research area is dedicated to **Fraud and Money Laundering Detection** through the use of AI, in particular to help identify suspicious patterns that evade rule-based detection tools and generate alerts that are explainable. This research theme is led by Yanlei Diao (École polytechnique) and Joseph Gesnouin Maarek and Aude Rousseau from BNP Paribas.

- ➡ The fifth research area, which spans all others, is **Trustworthy AI**. How can powerful AI tools be deployed in the highly regulated environment of financial institutions where accountability and trust are paramount? This theme will focus on the interplay between the European AI Act and financial services regulations, as well as on questions of explainability, fairness, and liability. This theme is led by Winston Maxwell and Thomas Le Goff from Télécom Paris, and Martin Pailhes and Léa Déliris from BNP Paribas.

ARTIST: A Pioneer of Representativeness and Reliability in Artificial Intelligence

"Today, AI is too often viewed primarily through the lens of technology and deployment, rather than through that of scientific guarantees. It is important to guard against certain biases," notes Stephan Clémençon, Professor at Télécom Paris and initiator of the ARTIST project.

At a time when artificial intelligence (AI) and machine learning (ML) systems underpin critical decision-making in finance, healthcare, and public policy, ensuring their reliability is essential. The ARTIST project (ARTificial Intelligence & Scoring Trees), led by Professor Stephan Clémençon at Télécom Paris, stands at the forefront of this challenge.

The performance of AI systems fundamentally depends on the assumption that the training data—whether tabular data, images, spectra, or text—are distributed in a manner that is representative of the data encountered in real-world deployment. In other words, the learning source must accurately reflect the target population. This property is commonly referred to as generalization capability. The ARTIST project operates within the domain of trustworthy AI and leverages both generative AI and training methodologies to address representativeness issues. In response to this challenge, ARTIST provides a technological framework that:

1. verifies whether two large datasets share the same distribution, thereby assessing their representativeness and consistency;
2. when discrepancies arise (i.e., when the assumptions underlying the learning framework are violated), explains how these distributions differ, for example by identifying over - or under - representation of specific population segments; and
3. corrects detected biases by automatically learning and applying weighting schemes – analogous to those used in survey sampling – to rebalance the data distribution.

In practice, AI systems are often trained on web-sourced data, which may poorly represent the operational context in which the system will be applied. For instance, it would be straightforward to train a facial recognition system for identity verification using images collected online and to deploy it at border controls. However, such a system would likely exhibit suboptimal performance because the abundance of celebrity photographs available on the web is not representative of the population actually encountered at customs checkpoints. In this scenario, ARTIST would enable the quantification of distributional differences between the two populations and the reweighting of web-collected datasets to match the target population, thereby supporting more appropriate model training.

Numerous additional examples can be found in healthcare. AI solutions trained predominantly on Caucasian populations have, in some cases, been applied to more diverse populations, leading to significant performance failures. More broadly, the issue of data representativeness is central to the European AI Act, and it is precisely this issue that ARTIST addresses. This interdisciplinary approach not only advances scientific knowledge but also delivers practical tools and frameworks that enhance trust in AI systems, in alignment with Télécom Paris's mission to foster innovation with societal impact.

JokaJobs, a game, a job!

The JokaJobs mobile app, created based on research by sociologist Dana Diminescu, Associate Professor at Télécom Paris, focuses on gamification and the mobility of job seekers to promote integration and local employment. Already in use in the Île-de-France region since 2020, it was rolled out in Hauts-de-France in March 2023, marking the first deployment in partnership with France Travail. In 2024, the JokaLycées experiment demonstrated the relevance of a fun, mobile and geolocation-based approach to promoting access for secondary school pupils to internships and initial work experience. Its goal is to encourage job and internship seekers to increase their mobility and form weak ties through a "serious game" that is accessible to all, regardless of digital literacy or available equipment.

JokaJobs, a game, a job! A geolocation-based application for exploring and searching for professional experience.

An application from the world of research

In 2006, the Economics and Social Sciences (SES) department at Télécom Paris conducted a study on equipped mobility, which led to the development of a geolocation-based application. Its aim was to encourage job seekers and internship applicants to be more mobile and create weak ties through a "serious game" that would appeal to everyone, regardless of their level of digital maturity and equipment.

Although an initial scenario was developed quickly, it was not until 2014 that a more refined version emerged.

During this period, Dana Diminescu refined her project by studying other media and geolocation-based games. The project took shape, and a startup was launched in 2025. A first application was quickly made available in app stores. The platform was trialed with approximately one hundred young people in the Paris region before being rolled out in the North and Hauts-de-France regions. It was also tested during the 2024 Olympic Games in collaboration with Arte France Développement, which allowed the game to be adapted to different regional contexts.

An application that is both engaging and rewarding

Designed by Éditions Volumique, JokaJobs is a simple, user-centered tool that helps users (re)connect with the job market in an engaging way by providing the resources needed to find a job or internship. "*The application geolocates the player on a map, similar to Pokémon Go. Opportunities are displayed around them, including job offers, internships, training courses, and relevant events. Users must move around the map and explore their environment to access these opportunities,*" explains Dana Diminescu.

While the app indicates places of interest remotely, users must approach these locations to view the details of each offer. This encourages them to build their network and meet recruiters in their area. Gamification further motivates engagement through points, badges, and exploration of new areas. Users can also contribute by adding offers they discover to the application.

At a time when AI is increasingly shaping HR processes, JokaJobs rehumanizes recruitment by incorporating a solidarity component, fostering social interaction and active engagement.

Smart Garden: Demonstrating the Effect of Urban Greening on Temperature

With rising temperatures, driven in part by global warming, urbanization, and the heat island effect, greening urban environments offers a promising way to bring both coolness and greenery to cities. However, planting a few trees or greening a courtyard is not enough: these oases must be maintained, watered, protected from disease, and, crucially, their real impact on temperature and humidity must be measured. How can we verify that parks, gardens, and patios truly deliver on their promises?

This is the challenge addressed by Smart Garden, a project launched in 2022–2023 by Ada Diaconescu, Tarik Graba, Philippe Martins, Laurent Pautet, and Samuel Tardieu, in collaboration with the E4C (Energy for Climate) interdisciplinary center at the Institut Polytechnique de Paris. The project equips these green spaces with compact monitoring stations capable of measuring environmental conditions almost as accurately as high-end stations, but at lower cost and with installation as simple as a home automation device. Certain maintenance operations, such as watering, can also be automated if necessary.

This approach improves water efficiency, reduces maintenance costs, monitors biodiversity, and allows residents to actively participate in preserving their living environment. Tested against reference stations, the first Smart Garden units have demonstrated reliability, affordability, and the ability to transmit data via low-cost networks. Their energy needs are largely met by small solar panels.

Two patios at Télécom Paris already serve as demonstration sites—one with vegetation and one without—forming an open-air laboratory, or Living Lab. These sites allow the effectiveness of these "islands of coolness" to be compared with supporting data, and in the future, their maintenance will be automated.

Demonstrate, optimise, save

The objectives of Smart Garden are to demonstrate the benefits of vegetation on temperature and humidity in urban environments, using sensors and optimised energy management. Eight sensors per patio are installed to monitor temperature and humidity

- Greening urban spaces (especially gardens),
- Maximising the desired environmental service (coolness in summer, warmth in winter, air quality, water purification, preservation of flora and fauna, etc.),
- Minimising environmental costs (energy savings, water conservation, carbon cost minimisation, etc.).

Ecosystem monitoring and management are optimised using low-cost connected objects (SmartHomes or home monitoring systems). This is also the case for watering management (neither too much nor too little), which saves energy and water resources. This protects ecosystems from harmful human activities, diseases and insect pests.

Photovoltaic panels located in a garden between buildings optimise energy consumption for computing and communications based on solar energy production. Connected objects are thus made more efficient by harvesting energy as close as possible to where it is needed.

To learn more about the Living Lab

06

INTERNATIONAL
cooperation

International cooperation

at Télécom Paris takes many forms, including research partnerships, research visits and sabbatical exchanges, joint workshops and seminars, and also joint PhD supervision that can lead to a double degree PhD diploma. It also gives rise to numerous publications in major scientific journals and conferences and other joint results. We highlight some of our international cooperation projects in these pages.

Canada
Carleton University • OCAD University • Simon Fraser University • University of Calgary • University of Victoria BC

United States
Sandia National Laboratories • United States Department of Energy • University of California at Santa Barbara • University of Central Florida • University of Maryland, Baltimore County • University of New Mexico

Mexico
Universidad de Guadalajara

Brazil
University of Campinas (UNICAMP) • University of São Paulo (USP)

Morocco
College of Engineering and Architecture • TICLab • Université Internationale de Rabat

Tunisia
Carthage University • COSIM laboratory • Sup'Com

Senegal
Cheikh Anta Diop University of Dakar (UCAD)

Austria
St. Pölten University of Applied Sciences • TU Wien

Belgium
Hasselt University • KU Leuven • University of Liege

Denmark
Aalborg University • IT University of Copenhagen • University of Copenhagen

Finland
Nokia

Germany
Bauhaus-Universität Weimar • Chemnitz University of Technology • Karlsruhe Institute of Technology • Leibniz Institute for Information Infrastructure • Saarland University • Technical University of Munich • Technische Universität Darmstadt • University of Cologne • University of Münster • Witten/Herdecke University

Ireland
Munster Technological University

Italy
University of Trento • University of Turin

Netherlands
Eindhoven University of Technology

Spain
Complutense University

Switzerland
Swiss Federal Institute of Technology Zurichto •
University of Genevato • University of Zurich

United Kingdom
Bangor University • Imperial College London •
University of Edinburgh • University of Glasgow

Israel
Tel Aviv University

Bangladesh
Khulna University of Engineering and Technology

India
Bnn Speag • IIT Hyderabad • Indraprastha Institute of
Information Technology Delhi • Sathyabama Institute
of Science and Technology • School of Technology and
Computer Science • Tata Institute of Fundamental
Research

China
Shanghai Jiao Tong University

Hong Kong
Hong Kong Polytechnic University •
Shenzhen Research Institute

Japan
Kyoto University • RIKEN

Singapore
Centre for Quantum Technologies •
ETH Singapore Centre • Future Cities Laboratory •
Nanyang Technological University

Taiwan
Hon Hai (Foxconn) Quantum Computing Centre •
National Center for Theoretical Sciences • National
Taiwan University

Wietnam
Faculty of Information Technology • Le Quy Don
Technical University

Australia
University of Sydney • University of Wollongong

New Zealand
University of Waikato • Victoria University of Wellington

AI APPLIED TO MEDICAL IMAGING

Columbia University, New York
Imperial College, London

Prof. **Elsa Angelini** (LTCI, IMAGES) has maintained continuous collaboration with the Heffner Biomedical Imaging Laboratory in the Department of Biomedical Engineering at Columbia University (CU) since her first appointment at Télécom Paris in 2004. She also contributed to the development of a double-degree program, allowing Télécom Paris engineering students to complete their third year at CU while earning a Master of Science in Biomedical Engineering.

This research collaboration has been supported by several US-based grants from the NIH, on which she serves as Co-Investigator, through a local adjunct researcher position. Several PhD students have been co-supervised, and multiple joint articles have been published in leading technical and clinical journals, including JAMA.

Over the past ten years, the collaboration has focused on exploiting very large cohorts of lung CT scans to discover new imaging biomarkers for lung emphysema and its subtypes, as well as for lung airway trees, all related to Chronic obstructive pulmonary disease (COPD) diagnosis and monitoring.

**Watch the video to learn more about
AI applied to medical imaging**

UNE COLLABORATION AVEC LE LABORATOIRE NEUROSPIN POUR LE DIAGNOSTIC DES TROUBLES PSYCHIATRIQUES

THE ROLE OF SOCIAL MEDIA IN CRISIS MANAGEMENT

Institut de Recherche pour le Développement (IRD), Vietnam

Caroline Rizza (i[3], NOS) has been working on the role of social media in crisis management since 2014.

At a time when climatic disasters are occurring at an ever-increasing rate, Caroline Rizza offers her views as a researcher on crisis management and the resilience of populations faced with these increasingly violent and recurrent climatic hazards, and on the role that digital technology can play in this.

At the end of 2023, the Council of Europe adopted the recommendations presented by Caroline Rizza on the use of digital technology, and in particular social media and mobile applications, for crisis communication in the context of climate threats. At the same time, she became an associate researcher at the ACROSS laboratory of the Institut de Recherche pour le Développement (IRD) in Hanoi, Vietnam. At the end of April 2025, she was received by the French Ambassador to Indonesia and the Indonesian Minister of Tourism in Jakarta to present the results of her research project "Transdisciplinary research strategy on crisis management and population resilience".

QUANTUM PHOTONICS AND SECURE COMMUNICATIONS

University of New Mexico (UNM) &
University of California Santa Barbara (UCSB), United States
Université Laval, Canada

During 2023–2024, **Frédéric Grillot**'s research at Télécom Paris was significantly reinforced through international collaborations, particularly with the University of New Mexico (UNM), the University of California Santa Barbara (UCSB), and Canadian partners at Université Laval. These partnerships have been instrumental in advancing their work on quantum photonics, semiconductor lasers, and secure optical communications.

At UNM, their joint efforts focus on nonlinear dynamics, photonic integration, and optical chaos in semiconductor lasers. A recent highlight of this collaboration is the first monolithic integration of InP-based whistle-geometry microring lasers (WRLs) with distributed-Bragg-reflector (DBR) lasers, specifically designed for strong optical injection locking. This architecture suppresses detrimental back-reflections while enabling efficient injection from the DBR master laser into the WRL cavity. Such devices have the potential to extend the modulation bandwidth of directly modulated semiconductor lasers far beyond conventional limits—an essential capability for next-generation optical transceivers in data centers and high-performance communication systems.

In parallel, a strong collaboration has been established with UCSB, particularly with Professors John Bowers and Galan Moody. This partnership focuses on the physics of quantum dot (QD) devices and integrated photonic systems for classical and quantum communication. Recent joint work has investigated the generation of nonclassical light in semiconductor micropillar cavities containing QDs, with a particular emphasis on quadrature squeezing. These results represent a major step toward practical semiconductor-based squeezed-light sources that could directly support the deployment of high-speed, large-capacity quantum communication systems.

A third cornerstone of their international activity is the ongoing development of a joint international laboratory on quantum photonics with Université Laval in Québec. The laboratory is being structured around three main research areas: quantum photonics, dedicated to the generation and manipulation of quantum states of light; coherent sources, emphasizing QD lasers and frequency combs; and enabling technologies, including advanced optical components and integrated photonic circuits for scalable implementation.

The added value of this initiative lies in the complementarity between modeling and experimentation, which will accelerate the transition from theoretical concepts to laboratory demonstrations. It also provides a structured framework for long-term collaboration between Télécom Paris and Université Laval, consolidating transatlantic cooperation in quantum photonics. In addition, the laboratory is designed to broaden its outreach toward the European Union, Canada, and industrial partners, serving as a hub for innovation, talent training, and technology transfer within the rapidly evolving quantum ecosystem.

By leveraging complementary expertise across France, the United States, and Canada, these partnerships not only amplify their scientific impact but also open new opportunities for innovation, mobility, and sustainable institutional cooperation.

A FORMAL FRAMEWORK FOR SCIENTIFIC AND EDUCATIONAL EXCHANGES WITH THE VIASM (VIETNAM)

Vietnam Institute for Advanced Study in Mathematics (VIASM), Vietnam Institut Polytechnique de Paris (IP Paris), France

In September 2023, the two institutions signed a Memorandum of Understanding (MoU) establishing a formal framework for scientific and educational exchanges between them. Télécom Paris is fully committed to this cooperation, particularly thanks to its recognised expertise in mathematics, computer science and applications in promising fields such as data science, artificial intelligence, cryptography, scientific computing and climate change.

Following the MoU (Memorandum of Understanding) signed between VIASM (Viêt Nam Institute for Advanced Study in Mathematics) and IP Paris (Institut Polytechnique de Paris) on September 15, 2023, the first Student Research Workshop was organized at VIASM, in Hanoi, Viêt Nam, on 6 & 7 September 2024 by **Minh Ha Le** (VIASM, Viêt Nam), **Minh Duc Nguyen** (HUST, Viêtnam) and **Van Tam Nguyen** (Télécom Paris, IP Paris, France).

The aim of the workshop was to introduce our research training opportunities, in computer science, data science and electrical engineering, at the Institut Polytechnique de Paris to high-potential Vietnamese undergraduate and postgraduate students who are considering pursuing graduate studies in a master's or doctoral program. This will open up international career prospects in leading academic institutions or companies, and enable them to acquire, develop and practice research skills in the fields of computer science, data science and electrical engineering.

CAN GPT-4 DO TAXES?

Johns Hopkins University, United States

OpenAI introduced GPT-4 during a livestream on Youtube, on March 14, 2023. To showcase GPT-4's abilities, the presenter prompted GPT-4 to solve a tax-related problem: he provided the model with (1) legal statutes describing tax laws, and (2) a description of Alice and Bob, a married couple, their son Charlie, and their respective income. This problem was taken directly from the StAtutory Reasoning Assessment (SARA), a research dataset developed at Johns Hopkins University and published in 2020, with **Nils Holzenberger** (then-PhD student at JHU, now faculty at Télécom Paris) as one of the authors. The livestream prompted further discussion in the AI and law communities, with some lauding GPT-4's new ability to understand laws and compute taxes, and some explaining why GPT-4's response was incorrect. It was indeed incorrect under current American tax law, but correct under the statutes of the SARA dataset, which were a simplified form of actual tax statutes.

Taking this demo as a starting point, we evaluated GPT-4 on the full SARA dataset, measuring its ability to predict the amount of taxes owed by a specific taxpayer for a specific taxable year. We found that GPT-4's correct answer during the livestream was not representative of the majority of its answers: it predicted the correct tax amount (within $1) in less than a third of cases. But its predictions were within 10% of the correct amount in 76% of cases, a notable departure from the limited performance of previous Natural Language Processing systems. We further emphasized that SARA is a semi-synthetic dataset, and relies on a deliberately simplified form of tax law. In practice, tax practitioners must deal with a much larger volume of information and must deploy more complex reasoning. Perfectly solving the SARA dataset does not imply one can "do tax". Since this paper was published, the research community has invented Large Language Models with the ability to reason, further pushing the performance boundaries on SARA-type tasks.

OpenAI Cribbed Our Tax Example, But Can GPT-4 Really Do Tax? Andrew Blair-Stanek, Nils Holzenberger and Benjamin Van Durme, Tax Notes Federal, August 14, 2023.

07

SCIENTIFIC
publications

In the following pages, we present a selection of scientific contributions authored by our researchers. This compilation highlights the excellence and dynamism of their research, illustrating how their work not only contributes to academic discourse but also influences practical applications and technological advances in industry and society.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Unbiased Supervised Contrastive Learning

Carlo Alberto Barbano, Benoit Dufumier, Enzo Tartaglione, Marco Grangetto and Pietro Gori

Many datasets are biased, namely they contain easy-to-learn features that are highly correlated with the target class only in the dataset but not in the true underlying distribution of the data. For this reason, learning unbiased models from biased data has become a very relevant research topic in the last years. In this work, we tackle the problem of learning representations that are robust to biases. We first present a margin-based theoretical framework that allows us to clarify why recent contrastive losses (InfoNCE, SupCon, etc.) can fail when dealing with biased data. Based on that, we derive a novel formulation of the supervised contrastive loss (-SupInfoNCE), providing more accurate control of the minimal distance between positive and negative samples. Furthermore, thanks to our theoretical framework, we also propose FairKL, a new debiasing regularization loss, that works well even with extremely biased data. We validate the proposed losses on standard vision datasets including CIFAR10, CIFAR100, and ImageNet, and we assess the debiasing capability of FairKL with -SupInfoNCE, reaching state-of-the-art performance on a number of biased datasets, including real instances of biases "in the wild". ●
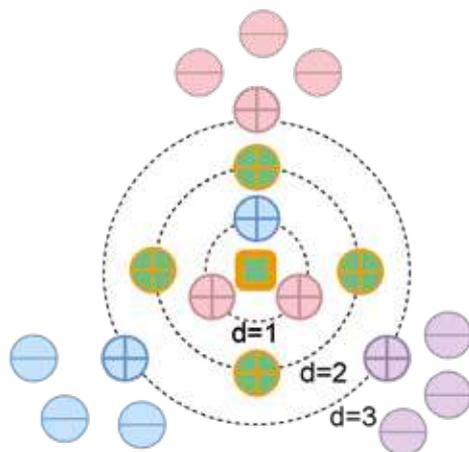
Figure 1.
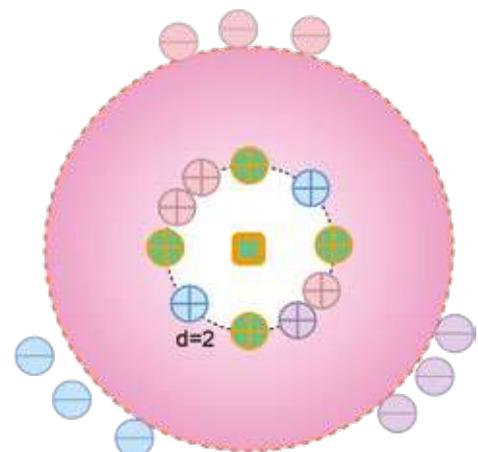
Figure 2.

Positive (+) and negative (–) samples are semantically similar and different from a selected sample (the anchor, square in the middle), respectively. Semantically similar means that the samples belong to the same latent class, for instance two images containing the same object. Filling colors represent different biases, namely easy-to-learn and spurious features that are highly correlated with the target objective but they actually do not characterize it. For instance, the anchor is characterized by a green bias. This means that all samples with the same bias might be closer in the representation space (thus considered as "more similar" by the method) than samples with a different bias (Fig 1). We proposed a new contrastive method that aims at increasing the minimal margin between positive and negative samples and at the same debias the representation learnt by the model, thus removing the effect of the bias (Fig. 2).

Reference:
11th International Conference on Learning Representations (ICLR), Kigali, Rwanda, 2023.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

BallMerge: High-quality Fast Surface Reconstruction via Voronoi Balls

Amal Dev Parakkat, Stefan Ohrhallinger, Elmar Eisemann and Pooran Memari

Computer Graphics Forum

We introduce a Delaunay-based algorithm for reconstructing the underlying surface of a given set of unstructured points in 3D. The implementation is very simple, and it is designed to work in a parameter-free manner. The solution builds upon the fact that in the continuous case, a closed surface separates the set of maximal empty balls (medial balls) into an interior and exterior. Based on discrete input samples, our reconstructed surface consists of the interface between Voronoi balls, which approximate the interior and exterior medial balls. An initial set of Voronoi balls is iteratively processed, merging Voronoi-ball pairs if they fulfil an overlapping error criterion. Our complete open-source reconstruction pipeline performs up to two quick linear-time passes on the Delaunay complex to output the surface, making it an order of magnitude faster than the state of the art while being competitive in memory usage and often superior in quality. We propose two variants (local and global), which are carefully designed to target two different reconstruction scenarios for watertight surfaces from accurate or noisy samples, as well as real-world scanned data sets, exhibiting noise, outliers, and large areas of missing data. The results of the global variant are, by definition, watertight, suitable for numerical analysis and various applications (e.g., 3D printing). Compared to classical Delaunay-based reconstruction techniques, our method is highly stable and robust to noise and outliers, evidenced via various experiments, including on real-world data with challenges such as scan shadows, outliers, and noise, even without additional preprocessing. •
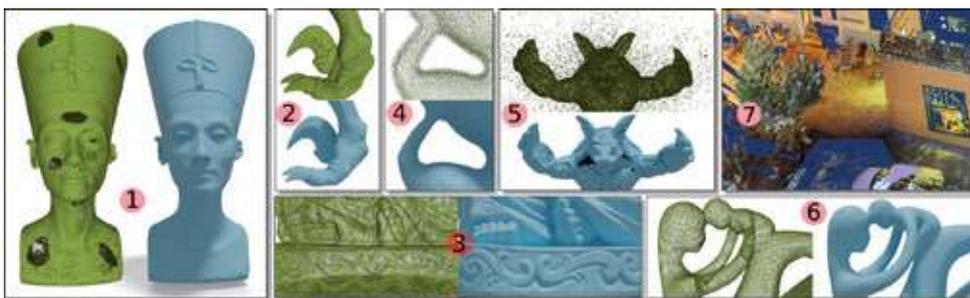
BallMerge is a Delaunay-based algorithm for reconstructing the underlying surface of a given set of unstructured points in 3D. The figure shows the 3D models reconstructed by BallMerge from inputs with different artifacts, namely synthetic holes (1), sharp and subtle features (2,3), noise (4), outliers (5), genus> 0 (6), and challenging real-world scans (7).

✧ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Robustness to Spatially Correlated Speckle in Plug-and-Play PolSAR Despeckling

Cristiano Ulondu Mendes, Loïc Denis, Charles Deledalle and Florence Tupin

IEEE Transactions on Geoscience and Remote Sensing

Synthetic aperture radar (SAR) provides valuable information about the Earth's surface in all-weather and day-and-night conditions. Due to the inherent presence of speckle phenomenon, a filtering step is often required to improve the performance of downstream tasks. In this article, we focus on dealing with the spatial correlations of speckle, which impacts negatively many of the existing speckle filters. Taking advantage of the flexibility of variational methods based on the plug-and-play (PnP) strategy, we propose to use a Gaussian denoiser trained to restore SAR scenes corrupted by colored Gaussian noise with correlation structures typical of a range of radar sensors. Our approach improves the robustness of PnP despeckling techniques. Experiments conducted on simulated and real polarimetric SAR images show that the proposed method removes speckle efficiently in the presence of spatial correlations without introducing artifacts, with a good level of detail preservation. Our method can be readily applied, without network re-training or fine-tuning, to filter SAR images from various sensors, acquisition modes (SAR, PolSAR, InSAR, PolInSAR), and spatial resolution. The code of the trained models is made freely available at: https://gitlab.telecom-paris.fr/ring/mulog-drunet. ●
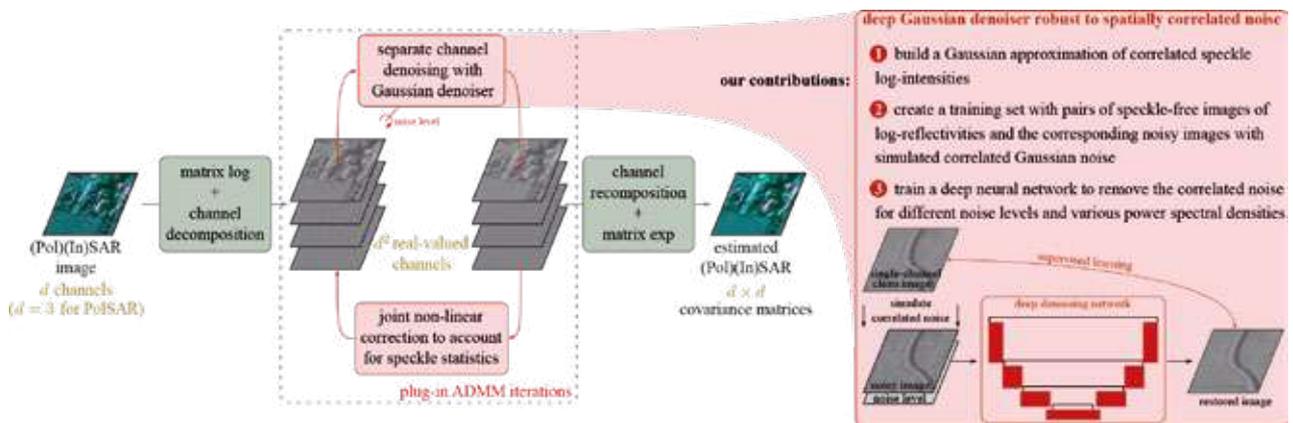
MuLoG despeckling framework.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Plug-and-Play image restoration with Stochastic deNOising REgularization

Marien Renaud, Jean Prost, Arthur Leclaire and Nicolas Papadakis

Proceedings of the 41st International Conference on Machine Learning (ICML'24)

Plug-and-Play (PnP) algorithms are a class of iterative algorithms that address image inverse problems by combining a physical model and a deep neural network for regularization. Even if they produce impressive image restoration results, these algorithms rely on a non-standard use of a denoiser on images that are less and less noisy along the iterations, which contrasts with recent algorithms based on Diffusion Models (DM), where the denoiser is applied only on re-noised images. We propose a new PnP framework, called Stochastic deNOising REgularization (SNORE), which applies the denoiser only on images with noise of the adequate level. It is based on an explicit stochastic regularization, which leads to a stochastic gradient descent algorithm to solve ill-posed inverse problems. A convergence analysis of this algorithm and its annealing extension is provided. Experimentally, we prove that SNORE is competitive with respect to state-of-the-art methods on deblurring and inpainting tasks, both quantitatively and qualitatively. ●
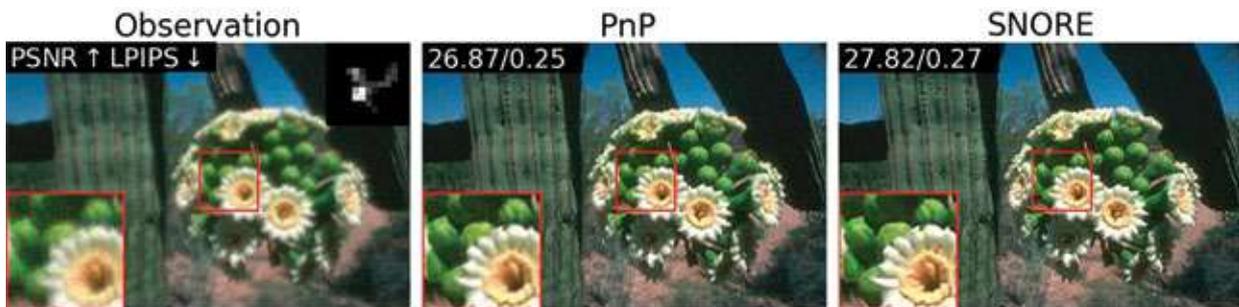
Several image restoration tasks (for example deblurring or super-resolution) can be formulated as ill-posed inverse problems. They can be solved by plug-and-play methods, which are iterative algorithms that rely on a regularizing function encoded by a denoiser. Since 2013, the performance of plug-and-play restoration was considerably improved thanks to the progress of denoising neural networks. But these deep methods raise important convergence and stability issues which deserve a dedicated study. In the PhD thesis of Marien Renaud[1], we work on the convergence of stochastic plug-and-play algorithms, where the iterates are renoised at each iteration. We proposed a regularization called SNORE that allows to design a provably convergent plug-and-play scheme based on stochastic gradient descent. This new algorithm improves restoration performance compared to deterministic plug-and-play, as can be seen on the deblurring example of the figure above. This work was later pursued with a study of other plug-and-play algorithms that will close the gap with methods based on recent generative AI techniques, for which there is a urging need of control and explainability.

[1] https://theses.fr/s367245

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Fully synthetic training for image restoration tasks

Raphaël Achddou, Yann Gousseau and Saïd Ladjal

Computer Vision and Image Understanding

In this work, we show that neural networks aimed at solving various image restoration tasks can be successfully trained on fully synthetic data. In order to do so, we rely on a generative model of images, the scaling dead leaves model, which is obtained by superimposing disks whose size distribution is scale-invariant. Pairs of clean and corrupted synthetic images can then be obtained by a careful simulation of the degradation process. We show on various restoration tasks that such a synthetic training yields results that are only slightly inferior to those obtained when the training is performed on large natural image databases. This implies that, for restoration tasks, the geometric contents of natural images can be nailed down to only a simple generative model and a few parameters. This prior can then be used to train neural networks for specific modality, without having to rely on demanding campaigns of natural images acquisition. We demonstrate the feasibility of this approach on difficult restoration tasks, including the denoising of smartphone RAW images and the full development of low-light images. ●

In this work, we show that various image restoration networks can be trained fully from synthetic, abstract images. These images are obtained from realisations of the dead leaves model (illustrated in the figure above), which from a very small number of parameters can mimic the statistics of natural images. Surprisingly, these networks yield restoration results that are similar to those obtained with networks trained using realistic photographs, for various tasks including RAW image denoising, super-resolution and low-light imaging.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Weighted Ensemble Models Are Strong Continual Learners

Imad Eddine Marouf, Subhankar Roy, Enzo Tartaglione and Stéphane Lathuilière

Proceedings of the 18th European Conference on Computer Vision (ECCV 2024)

In this work, we study the problem of continual learning (CL) where the goal is to learn a model on a sequence of tasks, under the assumption that the data from the previous tasks becomes unavailable while learning on the current task data. CL is essentially a balancing act between learning on the new task (i.e. plasticity) and maintaining the performance on the previously learned concepts (i.e. stability). To address the stability-plasticity trade-off, we propose to perform weight-ensembling of the model parameters of the previous and current tasks. This weighted-ensembled model, which we call Continual Model Averaging (or CoMA), attains high accuracy on the current task by leveraging plasticity, while not deviating too far from the previous weight configuration, ensuring stability. We also propose an improved variant of CoMA, named Continual Fisher-weighted Model Averaging (or CoFiMA), that selectively weighs each parameter in the weights ensemble by leveraging the Fisher information of the weights of the model. Both variants are conceptually simple, easy to implement, and effective in attaining state-of-the-art performance on several standard CL benchmarks. The code is available at: https://github.com/IemProg/CoFiMA. ●
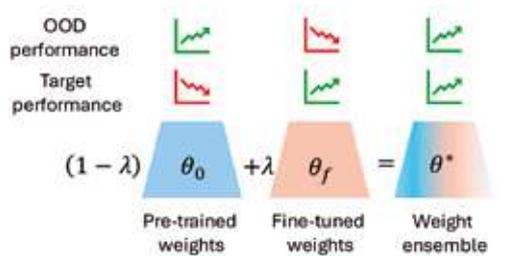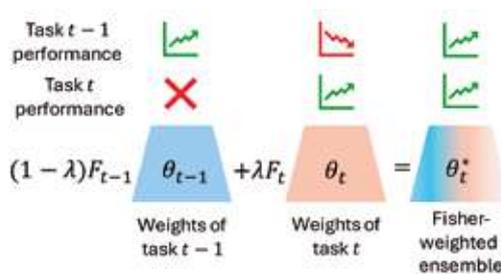
(a) Model averaging

(b) Continual Fisher-weighted Model Averaging (CoFiMA)

From general model averaging to continual learning with CoFiMA.
Panel (a) illustrates standard model averaging, where weights from pre-trained and fine-tuned models are combined to improve generalization. Panel (b) shows our proposed CoFiMA method, which extends this idea to continual learning by weighting parameters according to their task importance (via Fisher information). This enables models to adapt to new tasks while preserving performance on earlier ones.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

On the Trade-off between Over-smoothing and Over-squashing in Deep Graph Neural Networks

Jhony H. Giraldo, Konstantinos Skianis, Thierry Bouwmans and Fragkiskos D. Malliaros

Graph Neural Networks (GNNs) have succeeded in various computer science applications, yet deep GNNs underperform their shallow counterparts despite deep learning's success in other domains. Over-smoothing and over-squashing are key challenges when stacking graph convolutional layers, hindering deep representation learning and information propagation from distant nodes. Our work reveals that over-smoothing and over-squashing are intrinsically related to the spectral gap of the graph Laplacian, resulting in an inevitable trade-off between these two issues, as they cannot be alleviated simultaneously. To achieve a suitable compromise, we propose adding and removing edges as a viable approach. We introduce the Stochastic Jost and Liu Curvature Rewiring (SJLR) algorithm, which is computationally efficient and preserves fundamental properties compared to previous curvature-based methods. Unlike existing approaches, SJLR performs edge addition and removal during GNN training while maintaining the graph unchanged during testing. Comprehensive comparisons demonstrate SJLR's competitive performance in addressing over-smoothing and over-squashing. ●

[1] https://arxiv.org/pdf/2503.12919

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Since the publication of our work on over-smoothing and over-squashing in deep graph neural networks, we have extended this line of research to other geometric deep learning frameworks. In the article titled "Continuous Product Graph Neural Networks" (NeurIPS 2024 see next page ☞), we introduced a principled approach based on tensorial partial differential equations on product graphs, enabling robust and efficient learning from multidomain spatiotemporal data. This model provides theoretical guarantees on stability and alleviates over-smoothing while achieving state-of-the-art performance in traffic and weather forecasting. More recently, in the article titled "Continuous Simplicial Neural Networks" (NeurIPS 2025)[1], we generalized these ideas to simplicial complexes, capturing higher-order interactions beyond pairwise relations. This new model leverages continuous diffusion dynamics to control over-smoothing, enhance robustness to topological perturbations, and improve performance in applications such as trajectory prediction and mesh regression. Together, these works expand the scope of continuous geometric deep learning for complex, multi-relational data.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Continuous Product Graph Neural Networks

Aref Einizade, Fragkiskos D. Malliaros and Jhony H. Giraldo

Proceedings of the 38th Conference on Neural Information Processing Systems (NeurIPS 2024)

Processing multido-main data defined on multiple graphs holds significant potential in various practical applications in computer science. However, current methods are mostly limited to discrete graph filtering operations. Tensorial partial differential equations on graphs (TPDEGs) provide a principled framework for modeling structured data across multiple interacting graphs, addressing the limitations of the existing discrete methodologies. In this paper, we introduce Continuous Product Graph Neural Networks (CITRUS) that emerge as a natural solution to the TPDEG. CITRUS leverages the separability of continuous heat kernels from Cartesian graph products to efficiently implement graph spectral decomposition. We conduct thorough theoretical analyses of the stability and over-smoothing properties of CITRUS in response to domain-specific graph perturbations and graph spectra effects on the performance. We evaluate CITRUS on well-known traffic and weather spatiotemporal forecasting datasets, demonstrating superior performance over existing approaches. The implementation codes are available at this URL: https://github.com/ArefEinizade2/CITRUS. ●
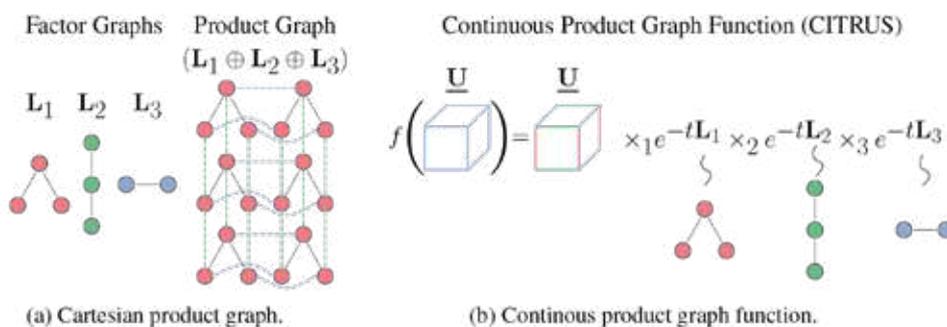
Illustration of key concepts of CITRUS. (a) Cartesian product between three-factor graphs. (b) Continous product graph function (CITRUS) operating on the multidomain graph data $\underline{U}$.

✧ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Debiasing Surgeon: Fantastic Weights and How to Find Them

Rémi Nahon, Ivan Luiz De Moura Matos, Van-Tam Nguyen and Enzo Tartaglione

Nowadays an ever-growing concerning phenomenon, the emergence of algorithmic biases that can lead to unfair models, emerges. Several debiasing approaches have been proposed in the realm of deep learning, employing more or less sophisticated approaches to discourage these models from massively employing these biases. However, a question emerges: is this extra complexity really necessary? Is a vanilla-trained model already embodying some "unbiased sub-networks" that can be used in isolation and propose a solution without relying on the algorithmic biases? In this work, we show that such a sub-network typically exists, and can be extracted from a vanilla-trained model without requiring additional fine-tuning of the pruned network. We further validate that such specific architecture is incapable of learning a specific bias, suggesting that there are possible architectural countermeasures to the problem of biases in deep neural networks. ●
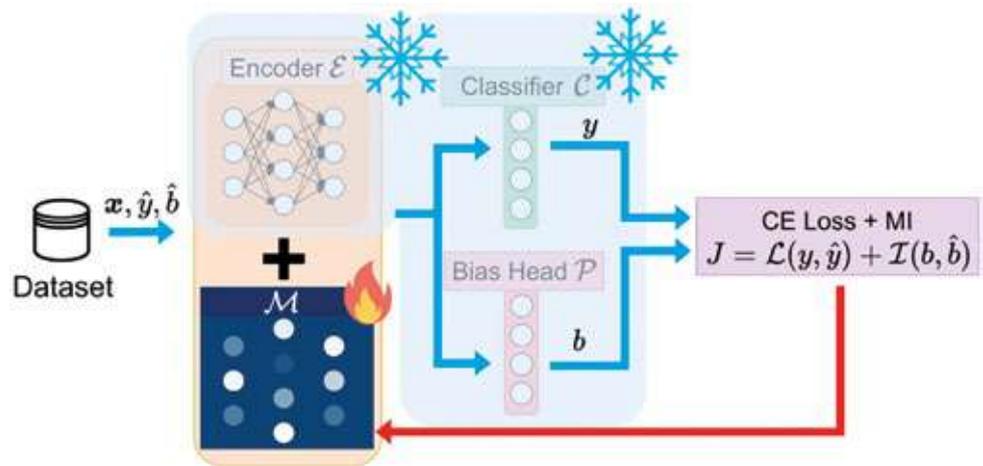
Pipeline for Debiasing Surgeon - only the mask selecting parameters/neurons to remove is learned, leaving the original architecture unchanged.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

DSD^2: Can We Dodge Sparse Double Descent and Compress the Neural Network Worry-Free?

Victor Quétu and Enzo Tartaglione

Neoteric works have shown that modern deep learning models can exhibit a sparse double descent phenomenon. Indeed, as the sparsity of the model increases, the test performance first worsens since the model is overfitting the training data; then, the overfitting reduces, leading to an improvement in performance, and finally, the model begins to forget critical information, resulting in underfitting. Such a behavior prevents using traditional early stop criteria. In this work, we have three key contributions. First, we propose a learning framework that avoids such a phenomenon and improves generalization. Second, we introduce an entropy measure providing more insights into the insurgence of this phenomenon and enabling the use of traditional stop criteria. Third, we provide a comprehensive quantitative analysis of contingent factors such as re-initialization methods, model width and depth, and dataset noise. The contributions are supported by empirical evidence in typical setups. Our code is available at https://github.com/VGCQ/DSD2.
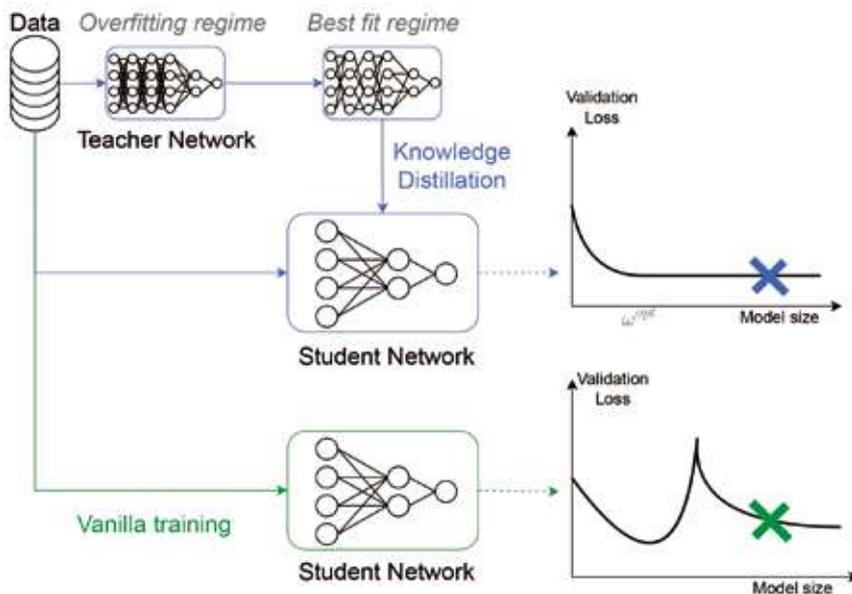
Reference:
Proceedings of the 38th AAAI Conference on Artificial Intelligence, 2024, 38(13), 14749-14757.

✧ **DATA SCIENCE AND ARTIFICIAL INTELLIGENCE**

Find the Lady: Permutation and Re-Synchronization of Deep Neural Networks

Carl De Sousa Trias, Mihai Petru Mitrea, Attilio Fiandrotti, Marco Cagnazzo, Sumanta Chaudhuri and Enzo Tartaglione

Proceedings of the 38th AAAI Conference on Artificial Intelligence (AAAI 2024)

Deep neural networks are characterized by multiple symmetrical, equi-loss solutions that are redundant. Thus, the order of neurons in a layer and feature maps can be given arbitrary permutations, without affecting (or minimally affecting) their output. If we shuffle these neurons, or if we apply to them some perturbations (like fine-tuning) can we put them back in the original order i.e. re-synchronize? Is there a possible corruption threat? Answering these questions is important for applications like neural network white-box watermarking for ownership tracking and integrity verification.

We advance a method to re-synchronize the order of permuted neurons. Our method is also effective if neurons are further altered by parameter pruning, quantization, and fine-tuning, showing robustness to integrity attacks. Additionally, we provide theoretical and practical evidence for the usual means to corrupt the integrity of the model, resulting in a solution to counter it. We test our approach on popular computer vision datasets and models, and we illustrate the threat and our countermeasure on a popular white-box watermarking method. ●

✧ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Statistical wave field theory

Roland Badeau

The Journal of the Acoustical Society of America (JASA)

In this paper, we introduce the foundations of the statistical wave field theory. This theory establishes the statistical laws of waves propagating in a closed bounded volume, that are mathematically implied by the boundary-value problem of the wave equation. These laws are derived from the Sturm-Liouville theory and the mathematical theory of dynamical billiards. They hold after many reflections on the boundary surface, and at high frequency. This is the first statistical theory of reverberation that provides the closed-form expression of the power distribution and the correlations of the wave field jointly over time, frequency, and space inside the bounded volume, in terms of the geometry and the specific admittance of its boundary surface. The statistical wave field theory may find applications in various science fields, including room acoustics, electromagnetic theory, and nuclear physics. ●

Particle / ray trajectory
in a classical billiard

Wave field
in a quantum billiard

Statistical wave field theory:
semi-classical approximation of
the wave field in a chaotic billiard
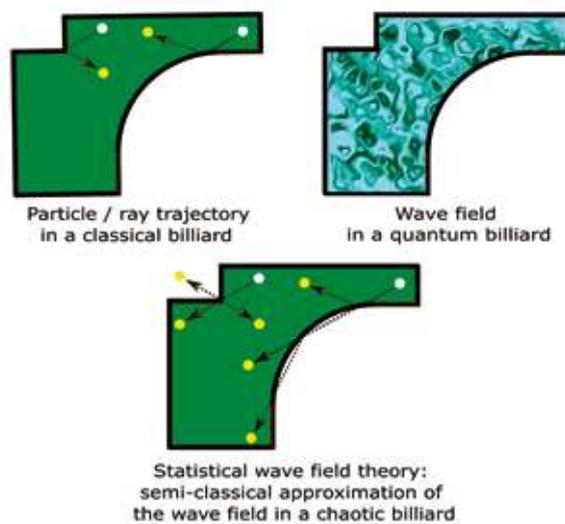
Compared to the abundant literature that covers a century of research in the fields of room acoustics, electromagnetic theory and quantum physics, the contributions of the statistical wave field theory are many:
- ➡ it provides a unified framework that encompasses all the previously known statistical properties of late reverberation, including the reverberation time;
- ➡ it provides a global description of the wave field that has been verified by experiment;
- ➡ it extends the original class of ergodic billiards to anisotropic wave fields;
- ➡ it is more accurate than the existing approaches based on classical billiards, thanks to the semiclassical approximation of quantum physics, which accounts for curvatures and edges;
- ➡ it reveals the existence of black holes, which behave like those of general relativity: a part of the incident wave energy is trapped forever in the vicinity of the domain's boundary.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Active Bipartite Ranking

James Cheshire, Vincent Laurent and Stephan Clémençon

Proceedings of the 37th Conference on Neural Information Processing Systems (NeurIPS 2023)

In this paper, we develop an active learning framework for the bipartite ranking problem. Motivated by numerous applications, ranging from supervised anomaly detection to credit-scoring through the design of medical diagnosis support systems, and usually formulated as the problem of optimizing (a scalar summary of) the ROC curve, bipartite ranking has been the subject of much attention in the passive context. Various dedicated algorithms have been recently proposed and studied by the machine-learning community. In contrast, active bipartite ranking rule is poorly documented in the literature. Due to its global nature, a strategy for labeling sequentially data points that are difficult to rank w.r.t. to the others is required. This learning task is much more complex than binary classification, for which many active algorithms have been designed. It is the goal of this article to provide a rigorous formulation of such a selective sampling approach. We propose a dedicated algorithm, referred to as active-rank, which aims to minimise the distance between the ROC curve of the ranking function built and the optimal one, w.r.t. the sup norm. We show that, for a fixed confidence level ϵ and probability δ, active-rank is PAC(ϵ,δ). In addition, we provide a problem dependent upper bound on the expected sampling time of active-rank and also demonstrate a problem dependent lower bound on the expected sampling time of any PAC(ϵ,δ) algorithm. Beyond the theoretical analysis carried out, numerical results are presented, providing strong empirical evidence of the performance of the algorithm proposed, which compares favorably with more naive approaches. ●

We prove our algortihm `active-rank` is PAC(ε, δ) under a ROC criterion for ranking the K armed bandit and provide the following **upper bound** on its expected stopping time of the order,

$$\sum_{i \in [K]} H_i \log(c H_i K^2/\delta), \quad \text{where } H_i := \max_{j \in [K]} \frac{1}{\text{kl}(\mu_j, \mu_j - \Delta_i)},$$

$$\Delta_i := \max \left\{ x > 0 : \sum_{i \neq j} x \mathbb{I}\big(|\mu_i - \mu_j| \leq x\big) < K \varepsilon p(1 - \mu_i) \right\}.$$

By proving a corresponding **lower bound** we demonstrate the above bound is tight up to log terms.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Deep Learning 101 for Audio-based MIR

Geoffroy Peeters, Gabriel Meseguer Brocal, Alain Riou and Stefan Lattner

Web book written for a tutorial session of the 25th International Society for Music Information Retrieval Conference (ISMIR 2024)

Audio-based MIR (MIR based on the processing of audio signals) covers a broad range of tasks, including analysis (pitch, chord, beats, tagging), similarity/cover identification, and processing/generation of samples or music fragments. A wide range of techniques can be employed for solving each of these tasks, spanning from conventional signal processing and machine learning algorithms to the whole zoo of deep learning techniques. This tutorial aims to review the various elements of this deep learning zoo commonly applied in Audio-based MIR tasks. We review typical audio front-ends (such as waveform, Log-Mel-Spectrogram, HCQT, SincNet, LEAF, quantization using VQ-VAE, RVQ), as well as projections (including 1D-Conv, 2D-Conv, Dilated-Conv, TCN, WaveNet, RNN, Transformer, Conformer, U-Net, VAE), and examine the various training paradigms (such as supervised, self-supervised, metric-learning, adversarial, encoder-decoder, diffusion). Rather than providing an exhaustive list of all of these elements, we illustrate their use within a subset of (commonly studied) Audio-based MIR tasks such as multi-pitch/chord-estimation, cover-detection, auto-tagging, source separation, music-translation or music generation. This subset of Audio-based MIR tasks is designed to encompass a wide range of deep learning elements. For each task we address a) the goal of the tasks, b) how it is evaluated, c) provide some popular datasets to train a system, and d) explain (using slides and pytorch code) how we can solve it using deep learning. The objective is to provide a 101 lecture (introductory lecture) on deep learning techniques for Audio-based MIR. It does not aim at being exhaustive in terms of Audio-based MIR tasks nor on deep learning techniques but to provide an overview for newcomers to Audio-Based MIR on how to solve the most common tasks using deep learning. It will provide a portfolio of codes (Colab notebooks and Jupyter book) to help newcomers achieve the various Audio-based MIR Tasks. This tutorial can be considered as a follow-up of the tutorial "Deep Learning for MIR" by Alexander Schindler, Thomas Lidy and Sebastian Böck, held at ISMIR-2018. ●
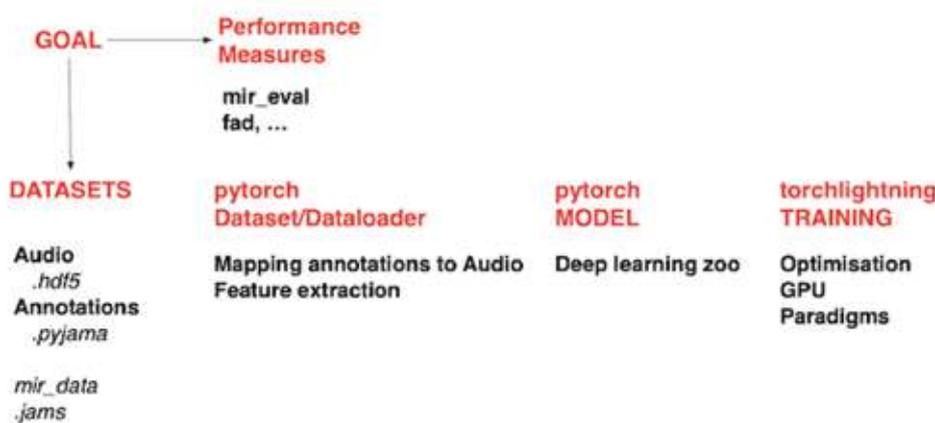
Overall description of tasks in terms of goal/evaluation/datasets/model.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Collaborating Foundation Models for Domain Generalized Semantic Segmentation

Yasser Benigmim, Subhankar Roy, Slim Essid, Vicky Kalogeiton and Stéphane Lathuilière

Domain Generalized Semantic Segmentation (DGSS) deals with training a model on a labeled source domain with the aim of generalizing to unseen domains during inference. Existing DGSS methods typically effectuate robust features by means of Domain Randomization (DR). Such an approach is often limited as it can only account for style diversification and not content. In this work we take an orthogonal approach to DGSS and propose to use an assembly of CoLlaborative FOUndation models for Domain Generalized Semantic Segmentation (CLOUDS). In detail CLOUDS is a framework that integrates Foundation Models of various kinds: (i) CLIP backbone for its robust feature representation (ii) Diffusion Model to diversify the content thereby covering various modes of the possible target distribution and (iii) Segment Anything Model (SAM) for iteratively refining the predictions of the segmentation model. Extensive experiments show that our CLOUDS excels in adapting from synthetic to real DGSS benchmarks and under varying weather conditions notably outperforming prior methods by 5.6% and 6.7% on averaged mIoU respectively. Our code is available at https://github.com/yasserben/CLOUDS. ●
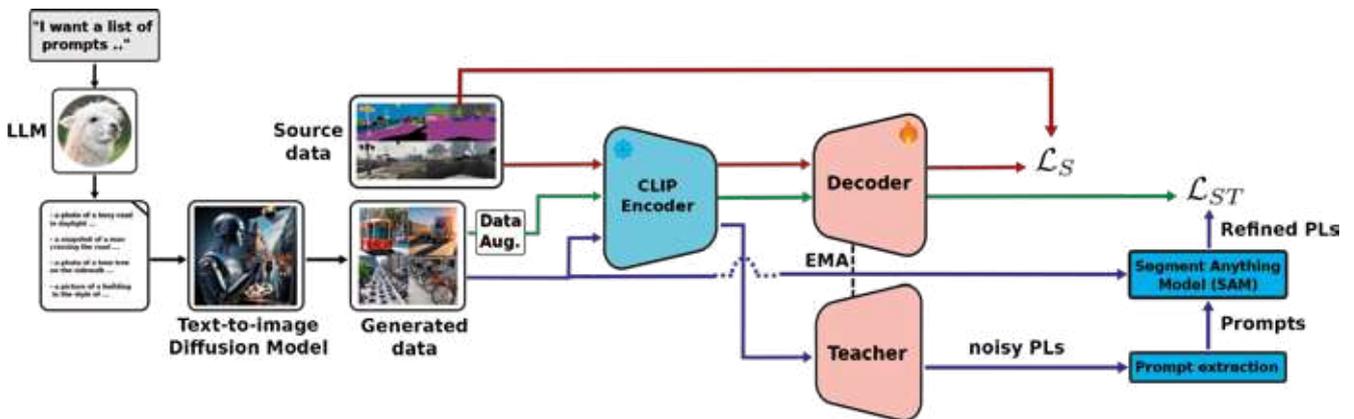
Training pipeline of CLOUDS: The model integrates a CLIP image encoder with a MaskFormer decoder. Our domain randomization strategy is based on a data generalization module that combines a Large Language Model with a text-to-image diffusion model to generate a varied dataset, representative of potential target datasets. This data is then employed in a Self-Training framework, where initial pseudo labels prompt the Segment Anything Model for refined pseudo labels, thereby fortifying the decoder's robustness.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

New Penalized Criteria for Smooth Non-Negative Tensor Factorization With Missing Entries

Amaury Durand, François Roueff, Jean-Marc Jicquel and Nicolas Paul

IEEE Transactions on Signal Processing

Tensor factorization models are widely used in many applied fields such as chemometrics, psychometrics, computer vision or communication networks. Real life data collection is often subject to errors, resulting in missing data. Here we focus in understanding how this issue should be dealt with for non-negative tensor factorization. We investigate several criteria used for non-negative tensor factorization in the case where some entries are missing. In particular we show how smoothness penalties can compensate the presence of missing values in order to ensure the existence of an optimum. This leads us to propose new criteria with efficient numerical optimization algorithms. Numerical experiments are conducted to support our claims. ●

EERE's Dataset : site activation.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Tackling Interpretability in Audio Classification Networks With Non-negative Matrix Factorization

Jayneel Parekh, Sanjeel Parekh, Pavlo Mozharovskyi, Gaël Richard and Florence d'Alché-Buc

This article tackles two major problem settings for interpretability of audio processing networks, post-hoc and by-design interpretation. For post-hoc interpretation, we aim to interpret decisions of a network in terms of high-level audio objects that are also listenable for the end-user. This is extended to present an inherently interpretable model with high performance. To this end, we propose a novel interpreter design that incorporates non-negative matrix factorization (NMF). In particular, an interpreter is trained to generate a regularized intermediate embedding from hidden layers of a target network, learnt as time-activations of a pre-learnt NMF dictionary. Our methodology allows us to generate intuitive audio-based interpretations that explicitly enhance parts of the input signal most relevant for a network's decision. We demonstrate our method's applicability on a variety of classification tasks, including multi-label data for real-world audio and music. ●
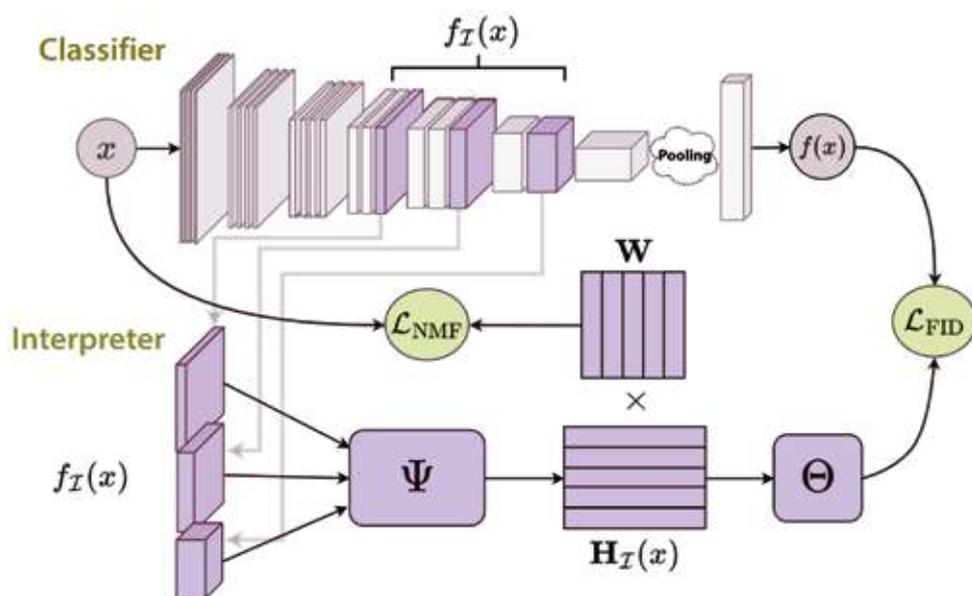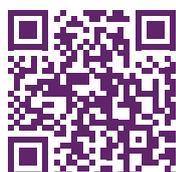
Overview of our common approach for both post-hoc and by-design interpretation. The interpreter (in purple) accesses hidden layer outputs of the classifier which are used to predict an intermediate encoding. This encoding is designed to both mimic the classifier's output and also serve as the time activations of a pre-learnt Non-Negative Matrix Factorization dictionary. The classifier is pre-trained and fixed for post-hoc interpretation, while for by-design interpretation both classifier and interpreter are trained jointly to make final predictions using output of the interpreter.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

The Factuality of Large Language Models in the Legal Domain

Rajaa El Hamdani, Thomas Bonald, Fragkiskos D. Malliaros, Nils Holzenberger and Fabian Suchanek

This paper investigates the factuality of large language models (LLMs) as knowledge bases in the legal domain, in a realistic usage scenario: we allow for acceptable variations in the answer, and let the model abstain from answering when uncertain. First, we design a dataset of diverse factual questions about case law and legislation. We then use the dataset to evaluate several LLMs under different evaluation methods, including exact, alias, and fuzzy matching. Our results show that the performance improves significantly under the alias and fuzzy matching methods. Further, we explore the impact of abstaining and in-context examples, finding that both strategies enhance precision. Finally, we demonstrate that additional pre-training on legal documents, as seen with SaulLM, further improves factual precision from 63% to 81%. ●
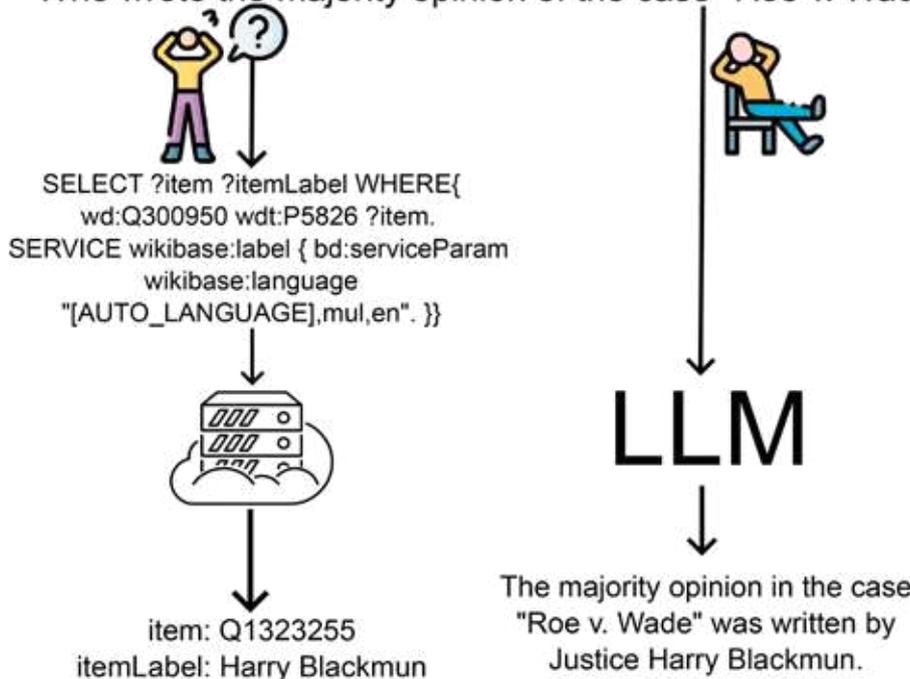
DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

PyClause – Simple and Efficient Rule Handling for Knowledge Graphs

Patrick Betz, Luis Galárraga, Simon Ott, Christian Meilicke, Fabian Suchanek and Heiner Stuckenschmidt

Proceedings of the 33rd International Joint Conference on Artificial Intelligence (IJCAI-24)

Rule mining finds patterns in structured data such as knowledge graphs. Rules can predict facts, help correct errors, and yield explainable insights about the data. However, existing rule mining implementations focus exclusively on mining rules – and not on their application. The PyClause library offers a rich toolkit for the application of the mined rules: from explaining facts to predicting links, scoring rules, and deducing query results. The library is easy to use and can handle substantial data loads. ●
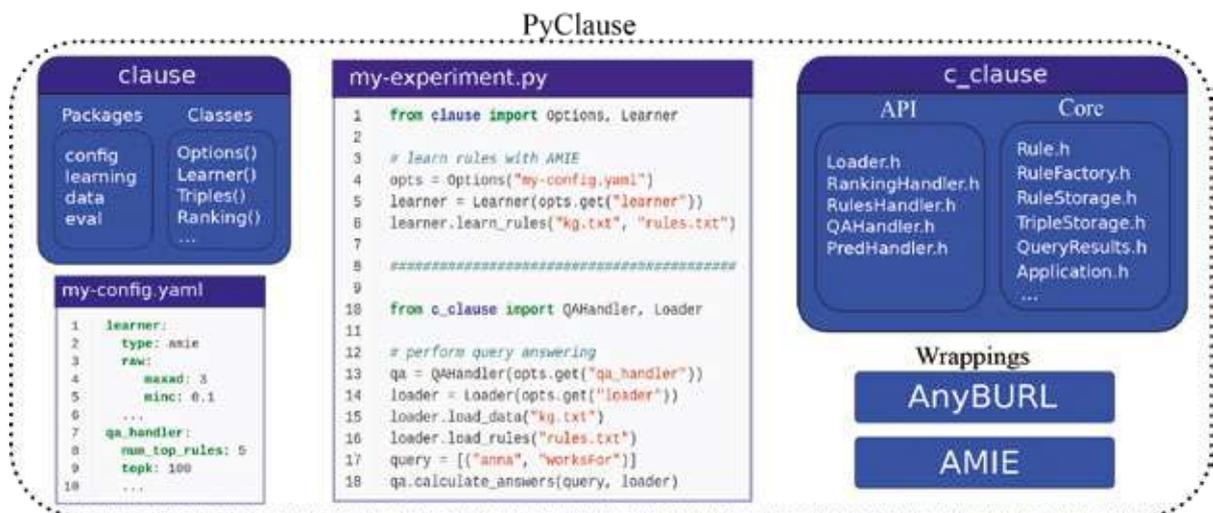
Usage-centric library overview. The example code mines rules with AMIE, which are used to predict the employer of a person.

DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Qiana: A First-Order Formalism to Quantify over Contexts and Formulas

Simon Coumes, Pierre-Henri Paris, François Schwarzentruber and Fabian M. Suchanek

Proceedings of the 21st International Conference on Principles of Knowledge Representation and Reasoning (KR 2024)

Best student paper

We introduce Qiana, a logic framework for reasoning on formulas that are true only in specific contexts. In Qiana, it is possible to quantify over both formulas and contexts to express, eg, that "everyone knows everything Alice says". Qiana also permits paraconsistent logics within contexts, so that contexts can contain contradictions. Furthermore, Qiana is based on first-order logic, and is finitely axiomatizable, so that Qiana theories are compatible with pre-existing first order logic theorem provers.

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Since this article was published, multiple extensions were added to Qiana and various development were done in the implementation. We notably wrote an extended journal version of this article with typing, temporality, and better notations. It is to be published soon in volume 83 of the Journal of Artificial Intelligence Research (JAIR) under the title: "Qiana: A First-Order Formalism to Quantify over Contexts and Formulas with Temporality". Please see our Github for more information: https://github.com/dig-team/Qiana.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Preventing Discriminatory Decision-making in Evolving Data Streams

Zichong Wang, Nripsuta Saxena, Tongjia Yu, Sneha Karki, Tyler Zetty, Israat Haque, Shan Zhou, Dukka Kc, Ian Stockwell, Xuyu Wang, Albert Bifet and Wenbin Zhang

Bias in machine learning has rightly received significant attention over the past decade. However, most fair machine learning (fair-ML) works to address bias in decision-making systems has focused solely on the offline setting. Despite the wide prevalence of online systems in the real world, work on identifying and correcting bias in the online setting is severely lacking. The unique challenges of the online environment make addressing bias more difficult than in the offline setting. First, Streaming Machine Learning (SML) algorithms must deal with the constantly evolving real-time data stream. Secondly, they need to adapt to changing data distributions (concept drift) to make accurate predictions on new incoming data. Incorporating fairness constraints into this already intricate task is not straightforward. In this work, we focus on the challenges of achieving fairness in biased data streams while accounting for the presence of concept drift, accessing one sample at a time. We present Fair Sampling over Stream (FS2), a novel fair rebalancing approach capable of being integrated with SML classification algorithms. Furthermore, we devise the first unified performance-fairness metric, Fairness Bonded Utility (FBU), to efficiently evaluate and compare the trade-offs between performance and fairness across various bias mitigation methods. FBU simplifies the comparison of fairness-performance trade-offs of multiple techniques through one unified and intuitive evaluation, allowing model designers to easily choose a technique. Overall, extensive evaluations show our measures surpass those of other fair online techniques previously reported in the literature. ●
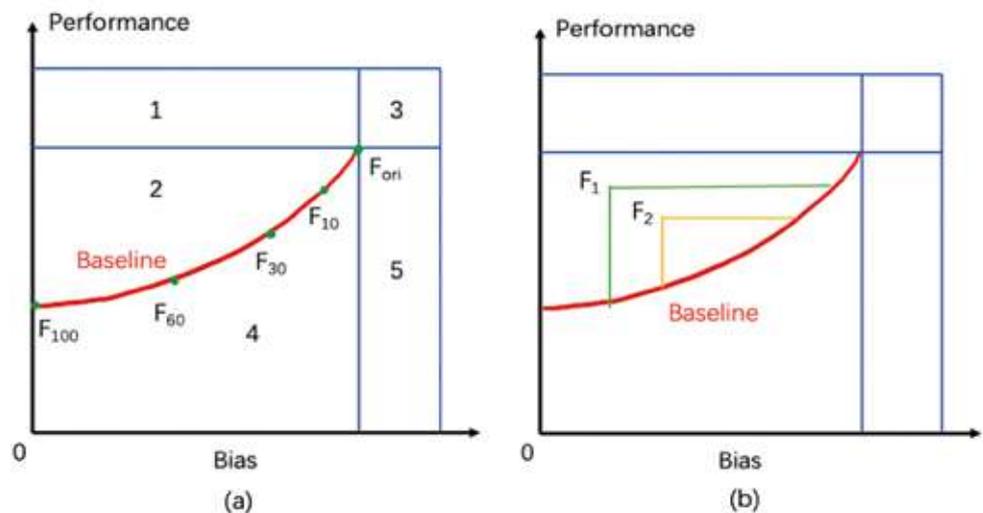
The FBU fairness-accuracy trade-off baseline is depicted by the original trade-off point (F_{ori}) and the points generated by the pseudo models ($F_{10},..., F_{100}$). A bias reduction method is considered effective if it shows a superior trade-off compared to the FBU baseline (i.e., it lies above the red line).

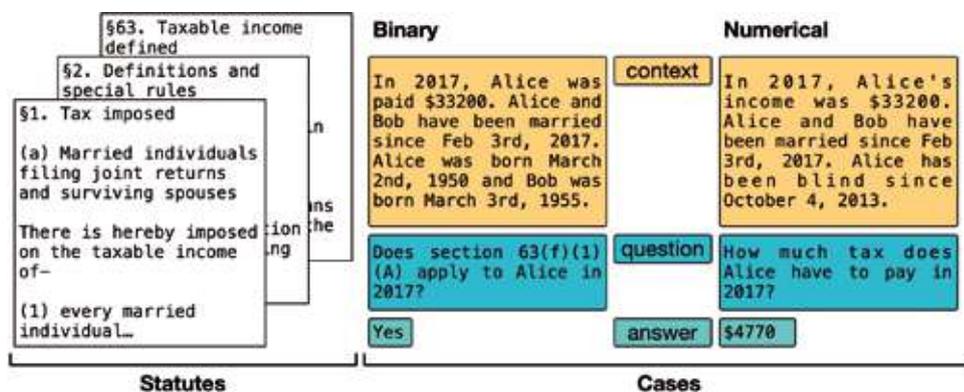## ✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

OpenAI Cribbed Our Tax Example, But Can GPT-4 Really Do Tax?

Andrew Blair-Stanek, Nils Holzenberger and Benjamin Van Durme

Tax Notes Federal

OpenAI introduced GPT-4 during a livestream on Youtube, on March 14, 2023. To showcase GPT-4's abilities, the presenter prompted GPT-4 to solve a tax-related problem: he provided the model with (1) legal statutes describing tax laws, and (2) a description of Alice and Bob, a married couple, their son Charlie, and their respective income. This problem was taken directly from the StAtutory Reasoning Assessment (SARA), a research dataset developed at Johns Hopkins University and published in 2020, with Nils Holzenberger (then-PhD student at JHU, now faculty at Télécom Paris) as one of the authors. The livestream prompted further discussion in the AI and law communities, with some lauding GPT-4's new ability to understand laws and compute taxes, and some explaining why GPT-4's response was incorrect. It was indeed incorrect under current American tax law, but correct under the statutes of the SARA dataset, which were a simplified form of actual tax statutes. Taking this demo as a starting point, we evaluated GPT-4 on the full SARA dataset, measuring its ability to predict the amount of taxes owed by a specific taxpayer for a specific taxable year. We found that GPT-4's correct answer during the livestream was not representative of the majority of its answers: it predicted the correct tax amount (within $1) in less than a third of cases. But its predictions were within 10% of the correct amount in 76% of cases, a notable departure from the limited performance of previous Natural Language Processing systems. We further emphasized that SARA is a semi-synthetic dataset, and relies on a deliberately simplified form of tax law. In practice, tax practitioners must deal with a much larger volume of information and must deploy more complex reasoning. Perfectly solving the SARA dataset does not imply one can "do tax". Since this paper was published, the research community has invented Large Language Models with the ability to reason, further pushing the performance boundaries on SARA-type tasks. ●

Sample cases from the SARA dataset. The questions can be answered by applying the rules contained in the statutes to the context.
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✦ **DATA SCIENCE AND ARTIFICIAL INTELLIGENCE**

Memory Manipulations in Extended Reality

Elise Bonnail, Wen-Jie Tseng, Mark Mcgill, Eric Lecolinet, Samuel Huron and Jan Gugenheimer

Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '23)

Human memory has notable limitations (e.g., forgetting) which have necessitated a variety of memory aids (e.g., calendars). As we grow closer to mass adoption of everyday Extended Reality (XR), which is frequently leveraging perceptual limitations (e.g., redirected walking), it becomes pertinent to consider how XR could leverage memory limitations (forgetting, distorting, persistence) to induce memory manipulations. As memories highly impact our self-perception, social interactions, and behaviors, there is a pressing need to understand XR Memory Manipulations (XRMMs). We ran three speculative design workshops (n=12), with XR and memory researchers creating 48 XRMM scenarios. Through thematic analysis, we define XRMMs, present a framework of their core components and reveal three classes (at encoding, pre-retrieval, at retrieval). Each class differs in terms of technology (AR, VR) and impact on memory (influencing quality of memories, inducing forgetting, distorting memories). We raise ethical concerns and discuss opportunities of perceptual and memory manipulations in XR. ●
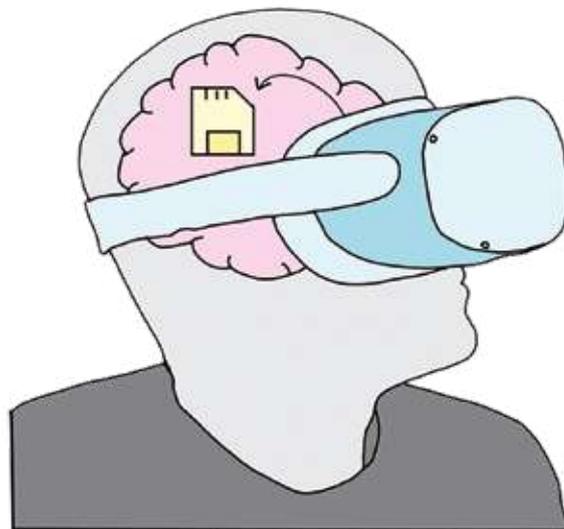
Memories of VR experiences could be later remembered as real, which could be a source of memory manipulations.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

Exploring User Placement for VR Remote Collaboration in a Constrained Passenger Space

Daniel Medeiros, Graham Wilson, Mauricio Sousa, Nadia Pantidi, Mark McGill, Diego Drago and Stephen Brewster

Proceedings of the 30th ACM Symposium on Virtual Reality Software and Technology (VRST '24)

Extended Reality (XR) offers the potential to transform the passenger experience by allowing users to inhabit varied virtual spaces for entertainment, work or social interaction, whilst escaping the constrained transit environment. XR allows remote collaborators to feel like they are together and enables them to perform complex 3D tasks. However, the social and physical constraints of the passenger space pose unique challenges to productive and socially acceptable collaboration. Using a collaborative VR puzzle task, we examined the effects of five different f-formations of collaborator placement and orientation in an interactive workspace on social presence, task workload, and implications for social acceptability. Our quantitative and qualitative results showed that face-to-face formations were preferred for tasks with a high need for verbal communication but may lead to social collisions, such as inadvertently staring at a neighbouring passenger, or physical intrusions, such as gesturing in another passenger's personal space. More restrictive f-formations, however, were preferred for passenger use as they caused fewer intrusions on other passengers' visual and physical space. ●

Our envisaged scenario, where a VR user sits in a constrained, shared transit environment such as a plane, and engages in remote collaboration.

✧ **DATA SCIENCE AND ARTIFICIAL INTELLIGENCE**

On Selective, Mutable and Dialogic XAI: a Review of What Users Say about Different Types of Interactive Explanations

Astrid Bertrand, Tiphaine Viard, Rafik Belloum, James R. Eagan and Winston Maxwell

Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '23)

Honorable mention

Explainability (XAI) has matured in recent years to provide more human-centered explanations of AI-based decision systems. While static explanations remain predominant, interactive XAI has gathered momentum to support the human cognitive process of explaining. However, the evidence regarding the benefits of interactive explanations is unclear. In this paper, we map existing findings by conducting a detailed scoping review of 48 empirical studies in which interactive explanations are evaluated with human users. We also create a classification of interactive techniques specific to XAI and group the resulting categories according to their role in the cognitive process of explanation: "selective", "mutable" or "dialogic". We identify the effects of interactivity on several user-based metrics. We find that interactive explanations improve perceived usefulness and performance of the human+AI team but take longer. We highlight conflicting results regarding cognitive load and overconfidence. Lastly, we describe underexplored areas including measuring curiosity or learning or perturbing outcomes. ●
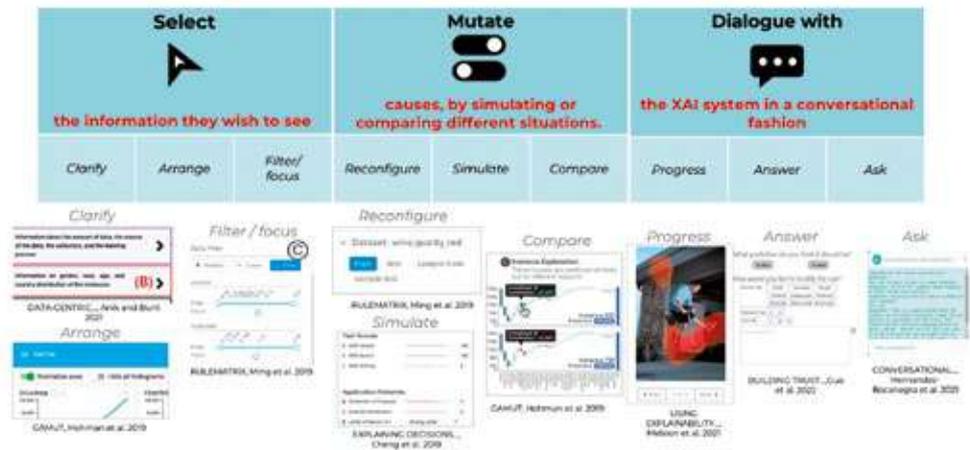
Illustration of the taxonomy of interaction in explainability.

✦ DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

MyWebstrates: Webstrates as Local-first Software

Clemens Nylandsted Klokmose, James R. Eagan and Peter van Hardenberg

Proceedings of the 37th Annual ACM Symposium on User Interface Software and Technology (UIST '24)

Webstrates are web substrates, a practical realization of shareable dynamic media under which distributability, shareability, and malleability are fundamental software principles. Webstrates blur the distinction between application and document in a way that enables users to share, repurpose, and refit software across a variety of domains, but its reliance on a central server constrains its use; it is at odds with personal and collective control of data; and limits applications to the web. We extend the fundamental principles to include interoperability and sovereignty over data and propose MyWebstrates, an implementation of Webstrates on top of a new, lower-level substrate for synchronization built around local-first software principles. MyWebstrates registers itself in the user's browser and function as a piece of local software that can selectively synchronise data over sync servers or peer-to-peer connections. We show how MyWebstrates extends Webstrates to enable offline collaborative use, interoperate between Webstrates on non-web technologies such as Unity, and maintain personal and collective sovereignty over data. We demonstrate how this enables new types of applications of Webstrates and discuss limitations of this approach and new challenges that it reveals. ●
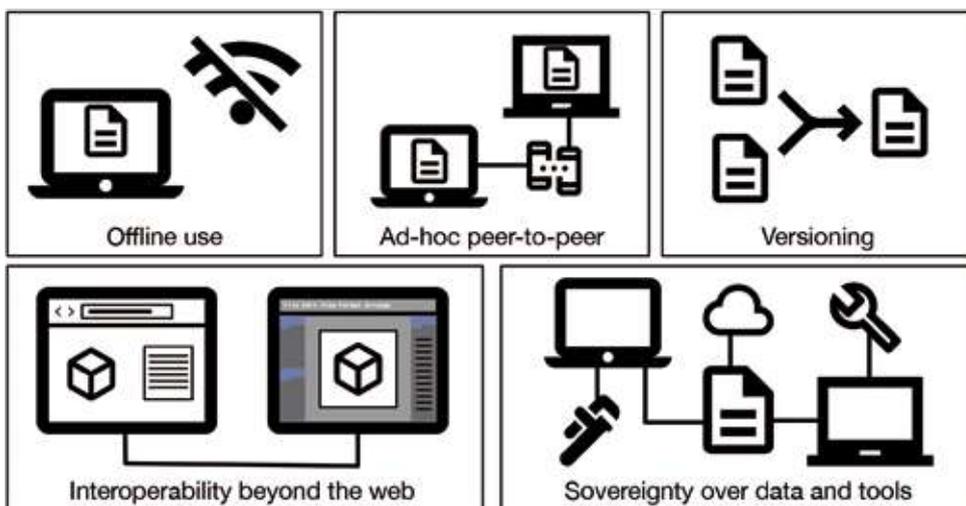
MyWebstrates is a local-first implementation of Webstrates enabling: ofline use; ad-hoc peer-to-peer collaboration without an internet connection; versioning including clone and merge; interoperability beyond the web with conventional desktop software; personal and collective sovereignty over how data and tools are stored and shared.
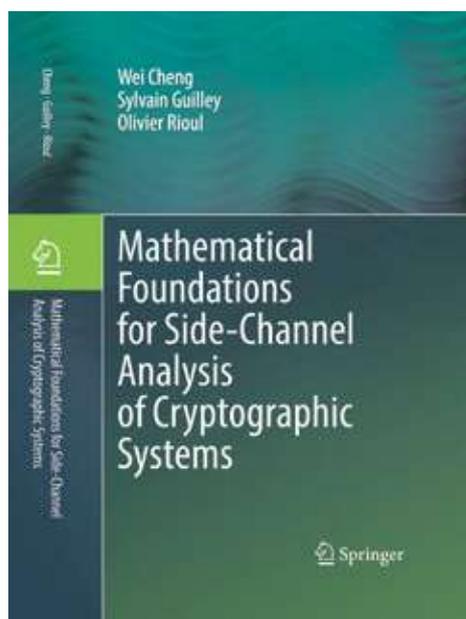
⬤ DIGITAL TRUST

Mathematical Foundations for Side-Channel Analysis of Cryptographic Systems

Wei Cheng , Sylvain Guilley and Olivier Rioul

Book

This book offers the reader a formalization, characterization and quantification of the real threat level posed by side-channel leaks from devices implementing cryptography. It exploits the best mathematical tools for quantifying information leakage and characterizing leakage-based attacks. The two possible approaches are described in detail. This includes the optimal attack strategy that can be derived (in specific contexts) or generic bounds regarding data complexity that can be computed. The tone of this book is essentially mathematical. It aims to establish formal foundations for techniques that are otherwise used as engineering recipes in industrial laboratories or empirical intuitions for deriving security levels from practical implementations. It is a systematization of knowledge and a compilation of relevant tools relating to the practice of side-channel analysis on embedded systems. This book provides an up-to-date and improved analysis and understanding of embedded devices that conceal secrets that can be extracted by an attacker. Typical attacks involve measuring the device's power consumption or radiated electromagnetic field. As a source of noisy information, this correlates it with secrets and enabling these secrets to be retrieved. The attacker in some cases, can purchase a blank device from the same series and learn about its leakage, particularly how it relates to the secrets. This book also covers how such information can enhance hardware attacks deployed on another device. ⬤

DIGITAL TRUST

AI-Driven Consistency of SysML Diagrams

Bastien Sultan and Ludovic Apvrille

Proceedings of the ACM/IEEE 27th International Conference on Model Driven Engineering Languages and Systems (MODELS '24)

Graphical modeling languages, expected to simplify systems analysis and design, present a challenge in maintaining consistency across their varied views. Traditional rule-based methods for ensuring consistency in languages like UML often fall short in addressing complex semantic dimensions. Moreover, the integration of Large Language Models (LLMs) into Model Driven Engineering (MDE) introduces additional consistency challenges, as LLM's limited output contexts requires the integration of responses.

This paper presents a new framework that automates the detection and correction of inconsistencies across different views, leveraging formally defined rules and incorporating OpenAI's GPT, as implemented in TTool. Focusing on the consistency between use case and block diagrams, the framework is evaluated through its application to three case studies, highlighting its potential to significantly enhance consistency management in graphical modeling. ●

Distinguished paper
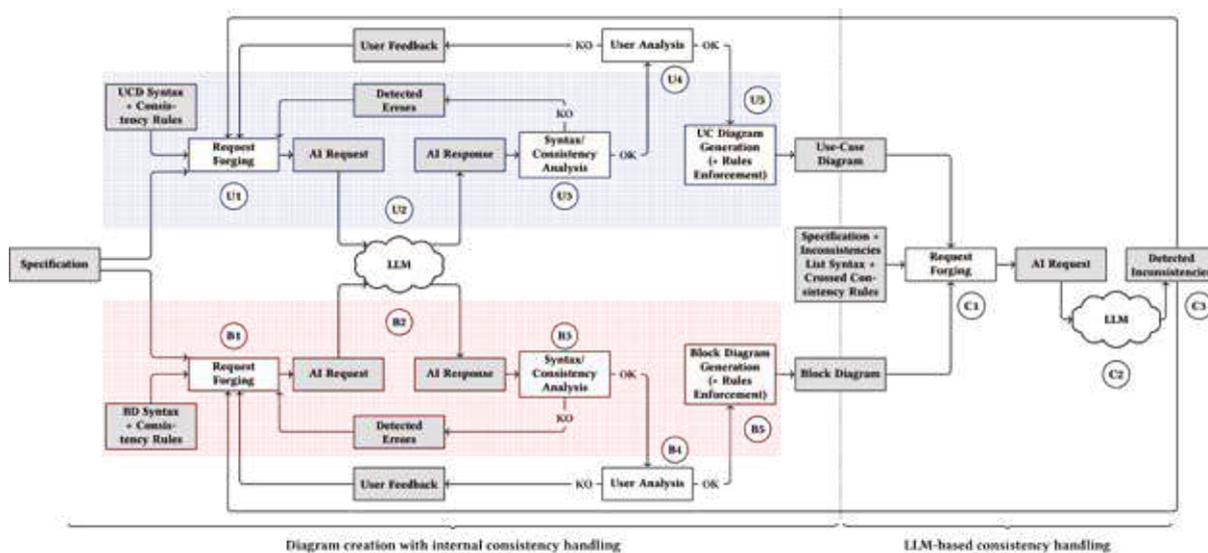
Functional architecture of the TTool-AI extension. Grey blocks denote data, while white blocks denote actions. /UCD/ and /BD/ refer to two SysML diagrams: Use Case Diagram and Block Diagram. The upper-left part of the figure illustrates the automated generation of a UCD, and the lower-left part illustrates the automated generation of a BD. Once both diagrams have been produced, the AI analyzes potential semantic inconsistencies between them (right side of the figure). These inconsistencies can then be reinjected into the UCD and BD generation process, allowing both diagrams to be automatically and consistently updated, until users validate the AI-generated diagrams.

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This article addresses the study of consistency between models produced using the SysML language. While these models are usually created manually, based on the engineer's experience and the system specification to be modeled, the advent of LLMs makes it possible to provide assistance for carrying out time-consuming, lower-value tasks: generating initial models (requirements, use cases, classes, or blocks), ensuring consistency across multiple views. This work opens several perspectives, including the notion of a continuous assistant that can monitor the modeling process as the models are being built. Another perspective concerns support for model verification, such as generating properties to be checked (from a system specification and/or requirements) or producing test sequences.

DIGITAL TRUST

Compositional equivalences based on open pNets

Rabéa Ameur-Boulifa, Ludovic Henrio and Eric Madelaine

Establishing equivalences between programs is crucial both for verifying correctness of programs and for justifying optimisations and program transformations. There exist several equivalence relations for programs, and bisimulations are among the most versatile of these equivalences. Among bisimulations one distinguishes strong bisimulation that requires that each action of a program is simulated by a single action of the equivalent program, and weak bisimulation that allows some of the actions to be invisible, and thus not simulated. pNet is a generalisation of automata that model open systems. They feature variables and hierarchical composition. Open pNets are pNets with holes, i.e. placeholders that can be filled later by sub-systems. However, there is no standard tool for defining the semantics of an open system in this context. This article first defines open automata that are labelled transition systems with parameters and holes. Relying on open automata, it then defines bisimilarity relations for the comparison of systems specified as pNets. We first present a strong bisimilarity for open pNets called FH-bisimilarity. Next we offer an equivalence relation similar to the classical weak bisimulation equivalence, and study its properties. Among these properties we are interested in compositionality: if two systems are proven equivalent they will be indistinguishable by their context, and they will also be indistinguishable when their holes are filled with equivalent systems. We identify sufficient conditions to ensure compositionality of strong and weak bisimulation. The contributions of this article are illustrated using a transport protocol as running example. ●

This article provides the theoretical groundwork for developing new algorithms for the compositional verification of programs and systems. The formalism presented supports an incremental verification approach through refinement. Ongoing implementation of these algorithms is expected to give rise to a new generation of model-checking tools, with the potential to significantly improve the scalability and applicability of verification in complex or safety-critical systems.
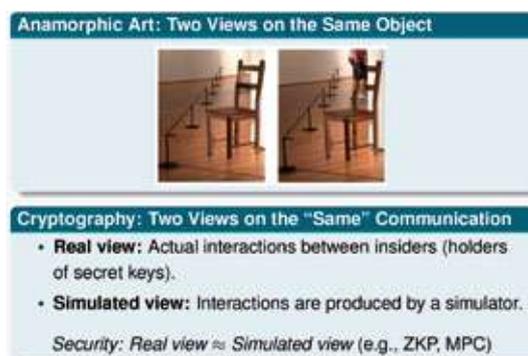
DIGITAL TRUST

Public-Key Anamorphism in (CCA-Secure) Public-Key Encryption and Beyond

Giuseppe Persiano, Duong Hieu Phan and Moti Yung

The notion of (Receiver-) Anamorphic Encryption was put forth recently to show that a dictator (i.e., an overreaching government), which demands to get the receiver's private key and even dictates messages to the sender, cannot prevent the receiver from getting an additional covert anamorphic message from a sender. The model required an initial private collaboration to share some secret. There may be settings though where an initial collaboration may be impossible or performance-wise prohibitive, or cases when we need an immediate message to be sent without private key generation (e.g., by any casual sender in need). This situation, to date, somewhat limits the applicability of anamorphic encryption. To overcome this, in this work, we put forth the new notion of "public-key anamorphic encryption", where, without any initialization, any sender that has not coordinated in any shape or form with the receiver, can nevertheless, under the dictator control of the receiver's private key, send the receiver an additional anamorphic secret message hidden from the dictator. We define the new notion with its unique new properties, and then prove that, quite interestingly, the known CCA-secure Koppula-Waters (KW)

system is, in fact, public-key anamorphic. We then describe how a public-key anamorphic scheme can support a new hybrid anamorphic encapsulation mode (KDEM) where the public-key anamorphic part serves a bootstrapping mechanism to activate regular anamorphic messages in the same ciphertext, thus together increasing the anamorphic channel capacity. Looking at the state of research thus far, we observe that the initial system (Eurocrypt'22) that was shown to have regular anamorphic properties is the CCA-secure Naor-Yung (and other related schemes). Here we identify that the KW CCA-secure scheme also provides a new type of anamorphism. Thus, this situation is hinting that there may be a connection between some types of CCA-secure schemes and some type of anamorphic schemes (in spite of the fact that the goals of the two primitives are fundamentally different); this question is foundational in nature. Given this, we identify a sufficient condition for a "CCA-secure scheme which is black-box reduced from a CPA secure scheme" to directly give rise to an "anamorphic encryption scheme!" Furthermore, we identify one extra property of the reduction, that yields a public-key anamorphic scheme as defined here. ●

Anamorphic Art: Two Views on the Same Object

Cryptography: Two Views on the "Same" Communication

- **Real view:** Actual interactions between insiders (holders of secret keys).
- **Simulated view:** Interactions are produced by a simulator.

Security: Real view ≈ Simulated view (e.g., ZKP, MPC)

Anamorphic Cryptography, invented by Persiano, Phan and Yung at Eurocrypt 2022, and developed since then by more than ten research groups worldwide, combines the two-view principle from anamorphic art with the two-view principle from cryptography to provide both functionality and security. Functionality: an anamorphic ciphertext supports two decryption views: with the normal key, it reveals the regular message; with the double key, it reveals the anamorphic message. About the security: everything must look like an ordinary ciphertext to a powerful adversary—that we call a dictator.

⬤ **DIGITAL TRUST**

Computational Differential Privacy for Encrypted Databases Supporting Linear Queries

Ferran Alborch Escobar, Sébastien Canard, Fabien Laguillaumie and Duong Hieu Phan

Proceedings on the 24th Privacy Enhancing Technologies Symposium (PETS 2024)

Differential privacy is a fundamental concept for protecting individual privacy in databases while enabling data analysis. Conceptually, it is assumed that the adversary has no direct access to the database, and therefore, encryption is not necessary. However, with the emergence of cloud computing and the "on-cloud" storage of vast databases potentially contributed by multiple parties, it is becoming increasingly necessary to consider the possibility of the adversary having (at least partial) access to sensitive databases. A consequence is that, to protect the on-line database, it is now necessary to employ encryption. At PoPETs'19, it was the first time that the notion of differential privacy was considered for encrypted databases, but only for a limited type of query, namely histograms. Subsequently, a new type of query, summation, was considered at CODASPY'22. These works achieve statistical differential privacy, by still assuming that the adversary has no access to the encrypted database. In this paper, we take an essential step further by assuming that the adversary can eventually access the encrypted data, making it impossible to achieve statistical differential privacy because the security of encryption (beyond the one-time pad) relies on computational assumptions. Therefore, the appropriate privacy notion for encrypted databases that we target is computational differential privacy, which was introduced by Beimel et al. at CRYPTO '08. In our work, we focus on the case of functional encryption, which is an extensively studied primitive permitting some authorized computation over encrypted data. Technically, we show that any randomized functional encryption scheme that satisfies simulation-based security and differential privacy of the output can achieve computational differential privacy for multiple queries to one database. Our work also extends the summation query to a much broader range of queries, specifically linear queries, by utilizing inner-product functional encryption. Hence, we provide an instantiation for inner-product functionalities by proving its simulation soundness and present a concrete randomized inner-product functional encryption with computational differential privacy against multiple queries. In terms of efficiency, our protocol is almost as practical as the underlying inner product functional encryption scheme. As evidence, we provide a full benchmark, based on our concrete implementation for databases with up to 1 000 000 entries. Our work can be considered as a step towards achieving privacy-preserving encrypted databases for a wide range of query types and considering the involvement of multiple database owners. ●

DIGITAL TRUST
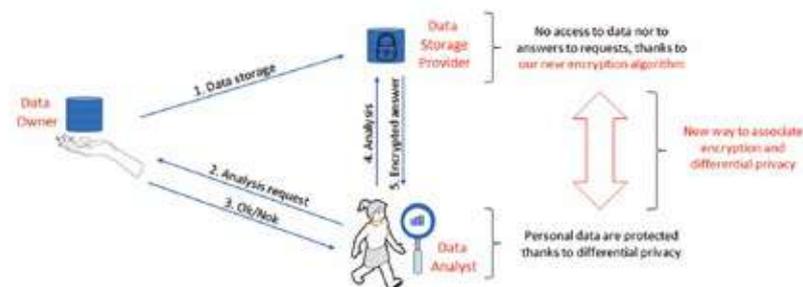
Horst Meets Fluid -SPN: Griffin for Zero-Knowledge Applications

Lorenzo Grassi, Yonglin Hao, Christian Rechberger, Markus Schofnegger, Roman Walch and Qingju Wang

Zero-knowledge (ZK) applications form a large group of use cases in modern cryptography, and recently gained in popularity due to novel proof systems. For many of these applications, cryptographic hash functions are used as the main building blocks, and they often dominate the overall performance and cost of these approaches. Therefore, in the last years several new hash functions were built in order to reduce the cost in these scenarios, including Poseidon and Rescue among others. These hash functions often look very different from more classical designs such as AES or SHA-2. For example, they work natively over prime fields rather than binary ones. At the same time, for example. Poseidon and Rescue share some common features, such as being SPN schemes and instantiating the nonlinear layer with invertible power maps. While this allows the designers to provide simple and strong arguments for establishing their security, it also introduces crucial limitations in the design, which may affect the performance in the target applications. In this paper, we propose the Horst construction, in which the addition in a Feistel scheme $(x, y) \mapsto (y + F(x), x)$ is extended via a multiplication, i.e., $(x, y) \mapsto (y \times G(x) + F(x), x)$. By carefully analyzing the performance metrics in SNARK and STARK protocols, we show how to combine an expanding Horst scheme with a Rescue-like SPN scheme in order to provide security and better efficiency in the target applications. We provide an extensive security analysis for our new design Griffin and a comparison with all current competitors. ●
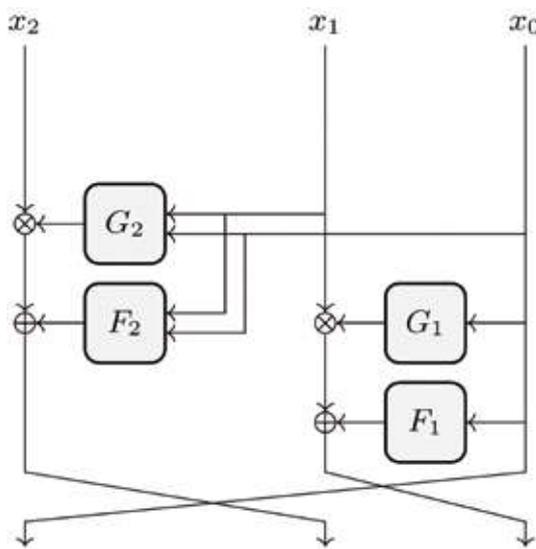
Generalized Horst over $\mathbb{F}_q^3$.

Reference:
Advances in Cryptology – CRYPTO 2023, 43rd Annual International Cryptology Conference, CRYPTO 2023, Santa Barbara, CA, USA, August 20–24, 2023, In: Handschuh, H., Lysyanskaya, A. (eds) Advances in Cryptology – CRYPTO 2023. CRYPTO 2023. Lecture Notes in Computer Science, vol 14083.

⬤ DIGITAL TRUST

Detecting DDoS attacks using adversarial neural network

Ali Mustapha, Rida Khatoun, Sherali Zeadally, Fadlallah Chbib, Ahmad Fadlallah, Walid Fahs and Ali El Attar

Computers & Security

In a Distributed Denial of Service (DDoS) attack, a network of compromised devices is used to overwhelm a target with a flood of requests, making it unable to serve legitimate requests. The detection of these attacks is a challenging issue in cybersecurity, which has been addressed using Machine Learning (ML) and Deep Learning (DL) algorithms. Although ML/DL can improve the detection accuracy, they can still be evaded - ironically - through the use of ML/DL techniques in the generation of the attack traffic. In particular, Generative Adversarial Networks (GAN) have proven their efficiency in mimicking legitimate data. We address the above aspects of ML/DL-based DDoS detection and anti-detection techniques. First, we propose a DDoS detection method based on the Long Short-Term Memory (LSTM) model, which is a type of Recurrent Neural Networks (RNNs) capable of learning long-term dependencies. The detection scheme yields a high accuracy level in detecting DDoS attacks. Second, we tested the same technique against different types of adversarial DDoS attacks generated using GAN. The results show the inefficiency of the LSTM-based detection scheme. Finally, we demonstrate how to enhance this scheme to detect adversarial DDoS attacks. Our experimental results show that our detection model is efficient and accurate in identifying GAN-generated adversarial DDoS traffic with a detection ratio ranging between 91.75% and 100%. ⬤
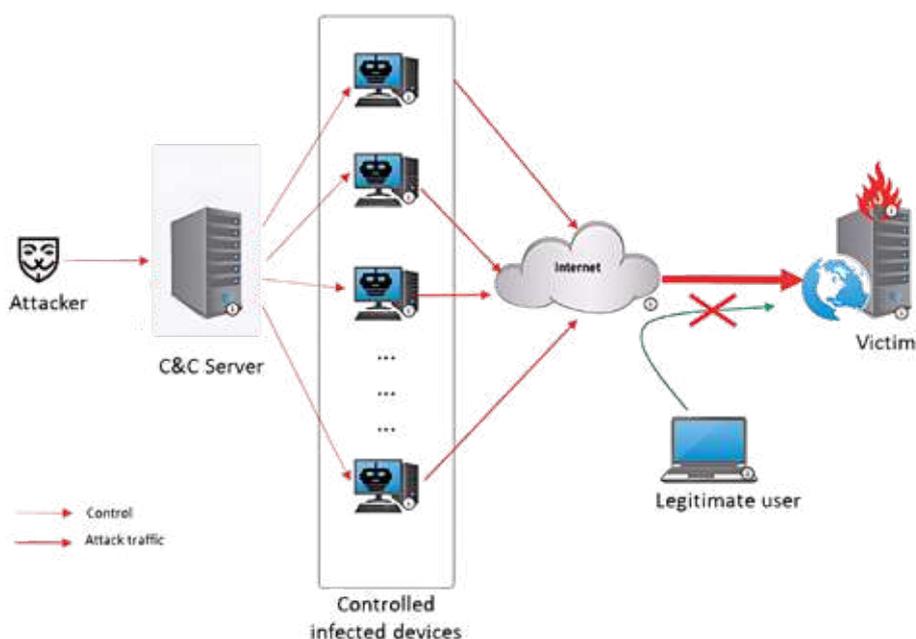
Distributed Denial of Service (DDoS) Attack.

DIGITAL TRUST

Assessing the Threat Level of Software Supply Chains with the Log Model

Luís Soeiro, Thomas Robert and Stefano Zacchiroli

Proceedings of the IEEE International Conference on Big Data (BigData 2023)

The use of free and open source software (FOSS) components in all software systems is estimated to be above 90%. With such high usage and because of the heterogeneity of FOSS tools, repositories, developers and ecosystem, the level of complexity of managing software development has also increased. This has amplified both the attack surface for malicious actors and the difficulty of making sure that the software products are free from threats. The rise of security incidents involving high profile attacks is evidence that there is still much to be done to safeguard software products and the FOSS supply chain.

Software Composition Analysis (SCA) tools and the study of attack trees help with improving security. However, they still lack the ability to comprehensively address how interactions within the software supply chain may impact security. This work presents a novel approach of assessing threat levels in FOSS supply chains with the log model. This model provides information capture and threat propagation analysis that not only account for security risks that may be caused by attacks and the usage of vulnerable software, but also how they interact with the other elements to affect the threat level for any element in the model. ●
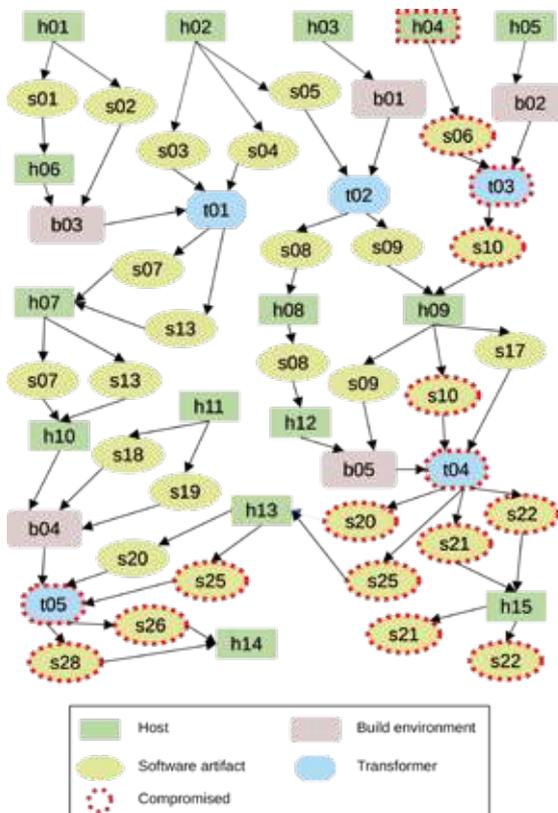
Threat propagation in the software supply chain: the "compromised" state originates at host h04 and spreads along directed supply chain edges according to the Log Model.

⚪ **DIGITAL TRUST**

CryptoConcurrency: (Almost) Consensusless Asset Transfer with Shared Accounts

Andrei Tonkikh, Pavel Ponomarev, Petr Kuznetsov and Yvonne-Anne Pignolet

A typical blockchain protocol uses consensus to make sure that mutually mistrusting users agree on the order in which their operations on shared data are executed. However, it is known that asset transfer systems, by far the most popular application of blockchains, can be implemented without consensus. Assuming that no account can be accessed concurrently and every account belongs to a single owner, one can efficiently implement an asset transfer system in a purely asynchronous, consensus-free manner. It has also been shown that implementing asset transfer with shared accounts is impossible without consensus. In this paper, we propose CryptoConcurrency, an asset transfer protocol that allows concurrent accesses to be processed in parallel, without involving consensus, whenever possible. More precisely, if concurrent transfer operations on a given account do not lead to overspending, i.e. can all be applied without the account balance going below zero, they proceed in parallel. Otherwise, the account's owners may have to access an external consensus object. Notably, we avoid relying on a central, universally-trusted, consensus mechanism and allow each account to use its own consensus implementation, which only the owners of this account trust. This provides greater decentralization and flexibility. 🟡
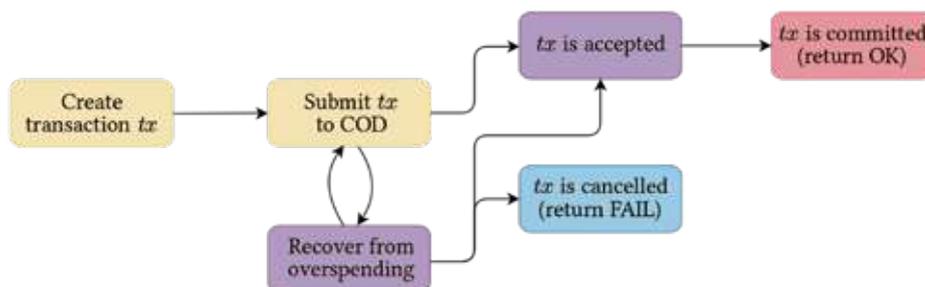
Transaction lifecycle in CryptoConcurrency.

Reference:
Proceedings of the 2023 ACM SIGSAC Conference on Computer and Communications Security (CCS '23). Association for Computing Machinery, New York, NY, USA, 1556–1570.

DIGITAL TRUST

An abstraction-refinement framework for verifying strategic properties in multi-agent systems with imperfect information

Francesco Belardinelli, Angelo Ferrando and Vadim Malvone

Artificial Intelligence

We investigate the verification of Multi-Agent Systems against strategic properties expressed in Alternating-time Temporal Logic under the assumptions of imperfect information and perfect recall. To this end, we develop a three-valued semantics for concurrent game structures upon which we define an abstraction method. We prove that concurrent game structures with imperfect information admit perfect information abstractions that preserve three-valued satisfaction. Furthermore, to deal with cases in which the value of a specification is undefined, we develop a novel automata-theoretic technique for the linear-time logic (LTL), then apply it to finding "failure" states. The latter can then be fed into a refinement procedure, thus providing a sound, albeit incomplete, verification method. We illustrate the overall procedure in a variant of the Train Gate Controller scenario and a simple voting protocol under imperfect information and perfect recall. We also present an implementation of our procedure and provide preliminary experimental results. ●
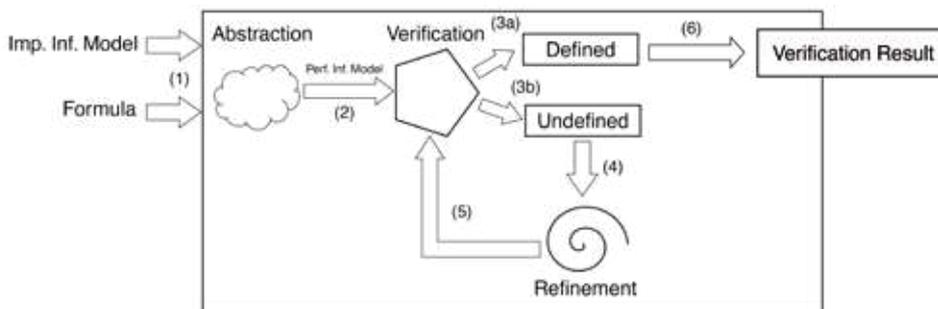
Given a model with imperfect information and a formula (1), the first step is to generate an abstract model with perfect information and verify the truth value of the formula. If it is defined (3a)—that is, either true or false— we can return the truth value (6) and terminate. If it is undefined (3b), a refinement process (4) on the model must be carried out. On the refined model, the truth value of the formula is verified again (4). As before, if it is defined (3a), we can return the truth value (6) and terminate. If it remains undefined (3b), a new refinement process (4) on the model must be performed. Since the problem is, in general, undecidable, the refinement process does not guarantee a result for all given models and formulas.

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Following the publication of this work, we have continued to pursue this line of research in search of new decidable fragments. Through sustained effort, we introduced novel abstraction methods applied to the formula presented at AAMAS[1]. In addition, a hybrid approach combining runtime verification and model checking was published in the Journal of Artificial Intelligence Research (JAIR)[2]. Building on these results, a promising future direction is to define a taxonomy of decidability in the context of agents operating under imperfect information. Another major challenge for making this approach applicable to real-world problems lies in developing a verification tool for multi-agent systems capable of handling large-scale data efficiently. In response to this need, we developed the tool VITAMIN, which has been presented at leading venues such as AAMAS[3,4].

[1] Angelo Ferrando, Vadim Malvone: Towards the Verification of Strategic Properties in Multi-Agent Systems with Imperfect Information. AAMAS 2023: 793-801.

[2] Davide Catta, Angelo Ferrando, Vadim Malvone: Reasoning about Decidability of Strategic Logics with Imperfect Information and Perfect Recall Strategies. J. Artif. Intell. Res. 82: 777-817 (2025).

[3] Angelo Ferrando, Vadim Malvone: VITAMIN: VerIficaTion of A MultI ageNt system. AAMAS 2025: 3023-3025.

[4] Angelo Ferrando, Vadim Malvone: VITAMIN: A Compositional Framework for Model Checking of Multi-Agent Systems. ICAART (1) 2025: 648-655.

DIGITAL TRUST

Decoding Attack Behaviors by Analyzing Patterns in Instruction-Based Attacks using gem5

Muhammad Awais, Maria Mushtaq, Lirida Naviner, Florent Bruguier, Jawad Haj Yahya and Pascal Benoit

Proceedings of the International Workshop on Rapid System Prototyping (RSP 2024)

The diversity of Instruction Set Architectures (ISAs), each with its unique constraints and optimization strategies, presents significant opportunities and challenges in processor design. Modern processor vendors exploit these ISAs to enhance security, reliability, and performance. Recent security vulnerabilities, notably Spectre and Meltdown, have highlighted the critical need for robust hardware security measures. In this paper, we employ gem5, a state-of-the-art cycle-accurate simulation tool, to simulate the Spectre attack. We developed and modified scripts for both x86 and ARM architectures to ensure compatibility with gem5 version 23.1. Our simulation setup involved running attack scenarios under various configurations to gather comprehensive data on cache misses, cache hits, mispredicted branches, and level 2 cache hits and misses. In the simulation, we analyzed the trace files generated by gem5, utilizing a range of debug flags such as Exec for disassembly (dasm) insights. By detailed analysis of cache and branch prediction using detailed debug data revealed by gem5 traces, we identify some specific attack patterns that are useful for automating the detection of the attacks. Our future work aims to expand this analysis to include additional attack vectors and find more attack patterns, thereby strengthening our attack pattern recognition capabilities. ●

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Building on this work, we have extended the gem5-based simulation framework to support RISC-V microarchitectures and integrated machine learning modules for automated classification of instruction-level attack patterns. The enhanced framework embeds pre-trained detection models for Flush+Reload, Prime+Probe, and Speculative Execution attacks directly into the gem5 trace analysis pipeline, enabling adaptive identification and explainability of attack behaviors. Ongoing collaborative efforts within the SCAMA project (Secure-by-Design Computing Against Microarchitectural Attacks, funded by the French National Research Agency (ANR)) are scaling this framework toward hardware accelerators and extended cache hierarchies, producing a unified dataset for AI-driven microarchitectural threat modeling and defense evaluation.

Reference:

**COMMUNICATION SYSTEMS AND NETWORKS**

Spectral Structure Analysis of FFT-based Digital Predistortion for Wideband 5G Applications

Tayeb H. C. Bouazza, Dang-Kièn Germain Pham, Reda Mohellebi and Patricia Desgreys

In this paper, a spectral structure analysis for the FFT-based subband digital predistortion is performed. This analysis consists in investigating whether the spectrum of the signal at the output of the power amplifier (PA) shows any particular structuring of the information. Various scenarios are investigated by simulation and validated by experiments, on a real PA. It is found that some spectral zones are more critical than others to maintain good linearization, which makes possible to reduce the requirements of the feedback path. ●
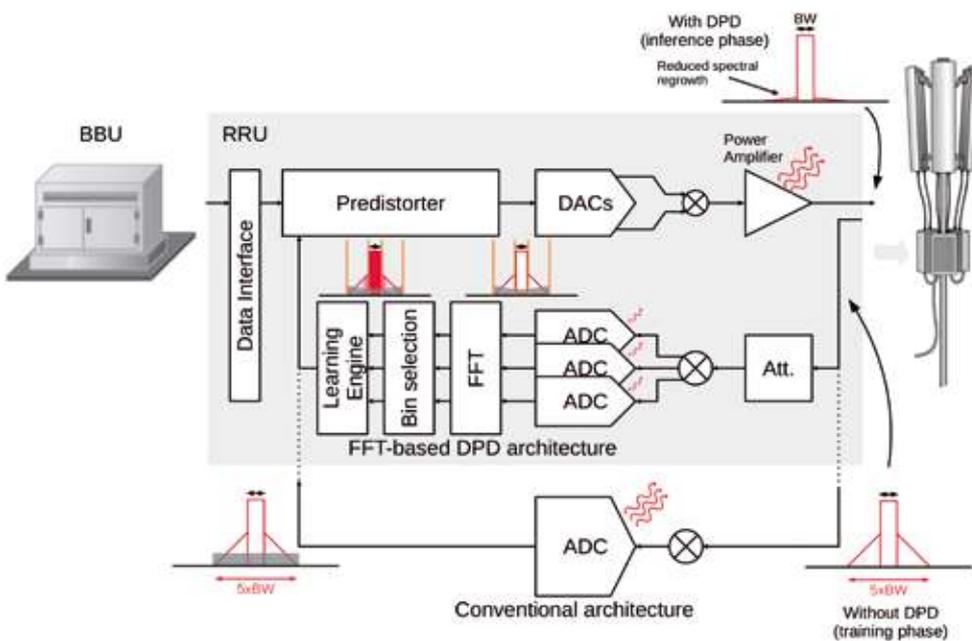
Visual comparison between conventional fullband DPD and FFT-based subband DPD.
Conventional approaches rely on wideband ADCs and fullband processing, leading to high sampling rates and computational complexity. In contrast, the FFT-based method uses subband ADCs with relaxed performances and only a subset of critical frequency bins for predistortion, enabling reduced feedback bandwidth, lower computational cost, and improved efficiency without sacrificing linearization performance.

COMMUNICATION SYSTEMS AND NETWORKS

An Information Theoretic Condition for Perfect Reconstruction

Idris Delsol, Olivier Rioul, Julien Béguinot, Victor Rabiet and Antoine Souloumiac

Entropy

A new information theoretic condition is presented for reconstructing a discrete random variable X based on the knowledge of a set of discrete functions of X. The reconstruction condition is derived from Shannon's 1953 lattice theory with two entropic metrics of Shannon and Rajski. Because such a theoretical material is relatively unknown and appears quite dispersed in different references, we first provide a synthetic description (with complete proofs) of its concepts, such as total, common, and complementary information. The definitions and properties of the two entropic metrics are also fully detailed and shown to be compatible with the lattice structure. A new geometric interpretation of such a lattice structure is then investigated, which leads to a necessary (and sometimes sufficient) condition for reconstructing the discrete random variable X given a set $\{X_1, \ldots, X_n\}$ of elements in the lattice generated by X. Intuitively, the components $X_1, \ldots, X_n$ of the original source of information X should not be globally "too far away" from X in the entropic distance in order that X is reconstructable. In other words, these components should not overall have too low of a dependence on X; otherwise, reconstruction is impossible. These geometric considerations constitute a starting point for a possible novel "perfect reconstruction theory", which needs to be further investigated and improved along these lines. Finally, this condition is illustrated in five specific examples of perfect reconstruction problems: the reconstruction of a symmetric random variable from the knowledge of its sign and absolute value, the reconstruction of a word from a set of linear combinations, the reconstruction of an integer from its prime signature (fundamental theorem of arithmetic) and from its remainders modulo a set of coprime integers (Chinese remainder theorem), and the reconstruction of the sorting permutation of a list from a minimal set of pairwise comparisons. ●
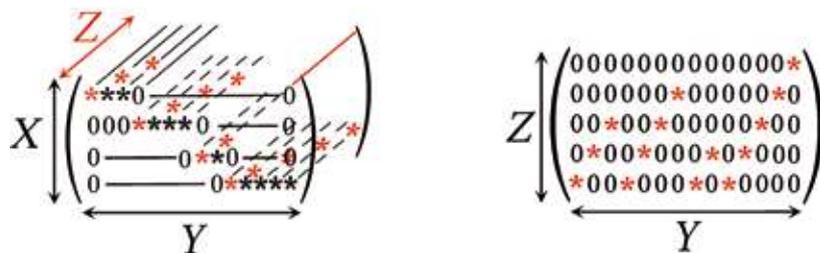
Construction of the complementary information Z allowing passing from X to Y. The stochastic tensor of (X, Y, Z) representing $\mathbb{P}_{X,Y,Z}$ has non-zero entries marked in red. The distribution $\mathbb{P}_Z$ of Z is obtained by marginalizing the tensor on the Z-axis.

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Quite remarkably, this work is the result of a research project conducted by a second-year student (Idris Delsol) at Télécom Paris. It suggests that perfect recovery of data from a set of deterministic transformations of it ("components") is possible only if its components collectively maintain strong informational closeness according to the lattice geometry. While theoretical frameworks drawn from lattice-based reconstruction remain largely unexplored in empirical domains, the emerging advancements in entropy estimation and compression suggest promising practical avenues for applying the perfect reconstruction theory in communications, learning, and signal recovery.

COMMUNICATION SYSTEMS AND NETWORKS

Statistical Modeling of Scenario-Based Indoor WBAN Channels

Badre Youssef, Christophe Roblin and Alain Sibille

This article presents a parametric statistical path loss (PL) model for wireless body area network (WBAN) communications in the context of a scenario-based approach for indoor environments. One of the specificities of WBANs is their numerous sources of variability (subject motion and morphology, antennas, local environment, and so on). We focus here on the influence of the environment, in the case of empty rooms. The model, developed for the first ultra wide band (UWB) sub-band ($B = [3.1, 4.8]$ GHz), takes into account the sizes of the rooms (assumed to be parallelepipedic and empty) and the wall characteristics (via an average reflectivity coefficient). They also involve an elaborate categorization of environments. The following methodology was implemented, to avoid time-consuming and complex experimental campaigns while still having a relatively representative and sufficient number of statistical samples: first, a simplified ray tracing (RT) code enabled a large number of different rooms to be sampled at moderate computational cost; second, part of these simulations was supported by anechoic chamber measurements; and third, the simulations were carried out using elaborate experimental designs (EDs), based on a categorization of environments and a fairly comprehensive study of building industry data. The parametric PL models obtained significantly reduce their variance. ●
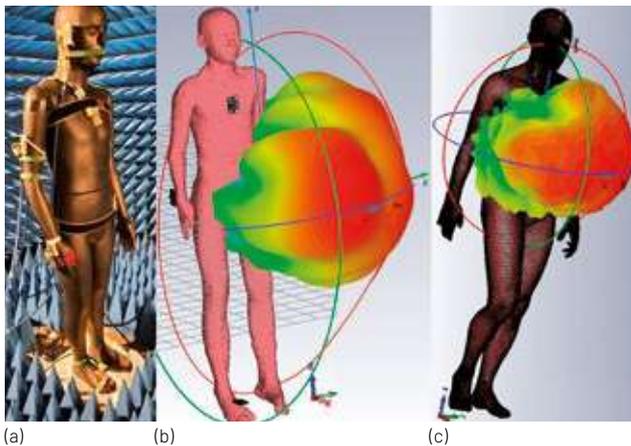
(a) Measurement setup on whole body homogeneous real phantom (*Kevin*), (b) Simulation with a realistic non homogeneous numerical phantom from MRI (*Louis*, from Virtual Population Suite®, *IT'IS Foundation – ETHZ*) and (c) Simplified homogeneous phantom (from common image processing freeware DAZ Studio®).

(a)   (b)   (c)

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The work in progress on this research topic is to develop a *local* statistical model in which the subject's position, orientation, and movement will be explicitly taken into account as input variables, in addition to those characterizing the room variability. The ultimate goal is to integrate this model into a comprehensive model that takes into account almost all sources of variability: subject's posture, position, movement, gender, and morphology (models related to this and to room variability have been published), as well as variability due to antennas (types, position, and distance from the body) and frequency, in addition to the influence of indoor environments. Related work concerns the design of small antennas that are *resilient* to body-proximity effects (the human body being a strong EM scatterer).

COMMUNICATION SYSTEMS AND NETWORKS

Taming Fabry–Pérot resonances in a dual-metasurface multiband antenna with beam steering in one of the bands

Rafael Gonçalves Licursi de Mello, Anne Claire Lepage and Xavier Begaud

Scientific Reports

Metasurfaces are artificial materials that can provide properties not readily available in nature for the interaction with acoustic, elastodynamic, or electromagnetic waves. In Electromagnetics, metasurfaces allow particular functionalities to antennas, which in turn lately have been increasingly pushed to a multiband operation. To fully exploit metasurfaces' capabilities, the use of a metasurface reflector and a metasurface superstrate surrounding a radiating element in multiband antennas is interesting. However, such topology generally creates multiple reflections inside the formed cavity, known as Fabry–Pérot resonances. Here we show that one should tame this phenomenon to use two parallel metasurfaces surrounding a planar radiating element. We present the conditions to obtain directive, multiband antennas under such circumstances. The concepts are validated with a compact device for 5G/4G/Wi-Fi 2.4/5/6E performing a beam steering in the 5G without disturbing the radiation patterns of the other bands. This device demonstrates that the functionalities of two metasurfaces may be exploited in a single design if the presented conditions are respected. We also anticipate our work to be a starting point for other studies in the wave domain. For example, compact, multiband, beam-steerable microphones or sonar transducers with two parallel metasurfaces could be investigated in the future. ●
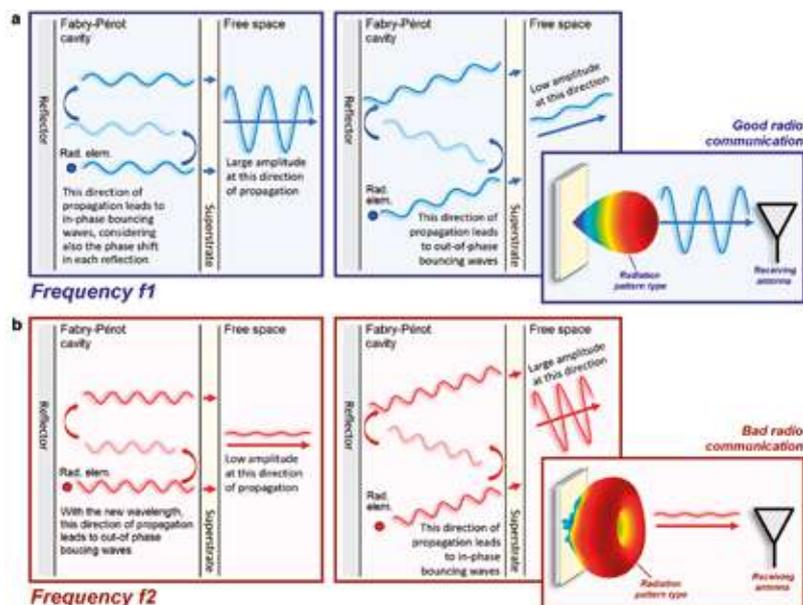
Outside the Fabry–Pérot cavity, waves interfere either constructively or destructively at each angle depending on the path travelled inside the cavity and the phase shift due to reflections on the reflector and the superstrate. (a) Constructive interferences occur at the broadside direction at the frequency $f = f1$. (b) Destructive interferences occur at the broadside direction at the frequency $f = f2$.

COMMUNICATION SYSTEMS AND NETWORKS

Joint Metrics for EMF Exposure and Coverage in Real-World Homogeneous and Inhomogeneous Cellular Networks

Quentin Gontier, Charles Wiame, Shanshan Wang, Marco Di Renzo, Joe Wiart, François Horlin, Christo Tsigros, Claude Oestges and Philippe De Doncker

This paper evaluates the downlink performance of cellular networks in terms of coverage and electromagnetic field exposure (EMFE), in the framework of stochastic geometry. The model is constructed based on datasets for sub-6 GHz macro cellular networks but it is general enough to be applicable to millimeter-wave networks as well. On the one hand, performance metrics are calculated for β-Ginibre point processes which are shown to faithfully model a large number of motion-invariant networks. On the other hand, performance metrics are derived for inhomogeneous Poisson point processes with a radial intensity measure, which are shown to be a good approximation for motion-variant networks. For both cases, joint and marginal distributions of the EMFE and the coverage, and the first moments of the EMFE are provided and validated by Monte Carlo simulations using realistic sets of parameters from two sub-6 GHz macro urban cellular networks, i.e., 5G NR 2100 (Paris, France) and LTE 1800 (Brussels, Belgium) datasets. In addition, this paper includes the analysis of the impact of the network parameters and discusses the achievable trade-off between coverage and EMFE. ●
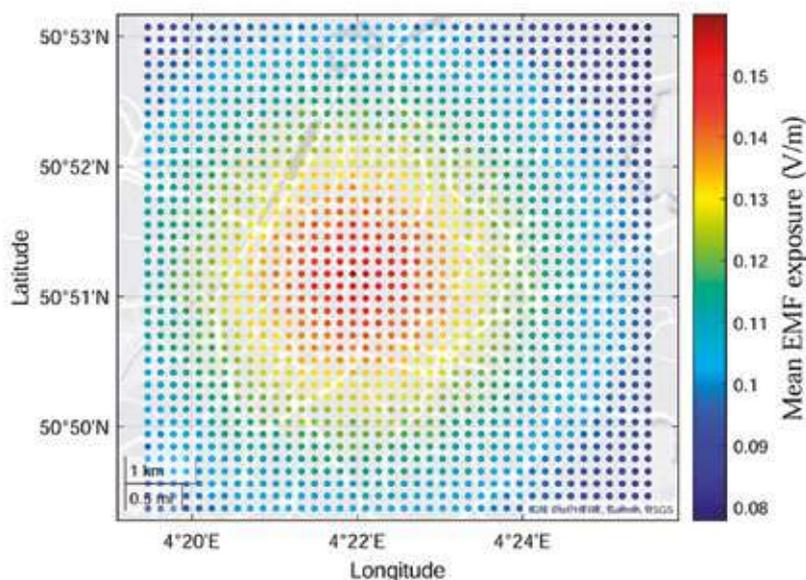
Mean EMFE (electromagnetic field exposure) from the considered LTE 1800 network at 2500 locations in the center of Brussels.
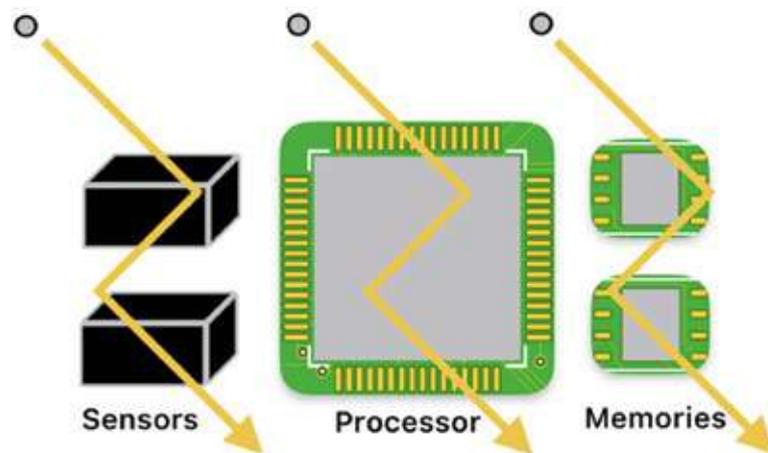
COMMUNICATION SYSTEMS AND NETWORKS

Impact of Scaling Up the Sensor Sampling Frequency on the Reliability of Edge Processing Systems in Tolerating Soft Errors Caused by Neutrons

Matheus Minelli de Carvalho, Luiz Henrique Laurini, Emmanuel Atukpor, Lirida Naviner and Rodrigo Possamai Bastos

IEEE Sensors Letters

In this letter, we reveal the impact of increasing the sensor sampling frequency on the reliability of a typical edge processing system operating under the effects of 14-MeV neutrons and thermal neutrons. The results of two types of accelerated radiation tests indicate the rates of failures induced by soft errors caused by 14-MeV and thermal neutrons grow as a function of the sensor sampling frequency. The rate of failures caused by 14-MeV neutrons rose by factor of 2.2 by shifting the sensor sampling frequency from around 140 to 430 Hz. The results also suggest that the design and calibration of edge processing systems should consider the sensor sampling frequency as a parameter to finely tradeoff the computing speed of the system for improving the reliability in tolerating soft errors caused by neutrons. ●

Experimental CubeSat satellite electronics components for low Earth orbit radiation-induced soft error investigation.

This publication investigated the impact of scaling up the sensor sampling frequency on the reliability of edge processing systems in tolerating soft errors caused by neutrons. It motivated the development of an experimental CubeSat satellite electronics project focused on characterizing radiation-induced soft errors in commercial of-the-shelf sensors, their interface circuitry, and associated signal processor and support memories, as depicted in the figure above.

COMMUNICATION SYSTEMS AND NETWORKS

The Long Road to Sobriety: Estimating the Operational Power Consumption of Cellular Base Stations in France

Arsalan Ahmed and Marceau Coupechoux

Proceedings of the International Conference on ICT for Sustainability (ICT4S 2023)

As the Information and Communication Technology (ICT) sector represents 1.8% to 3.9% of the global Green House Gas (GHG) emissions, it is of upmost importance to know how much energy is spent annually in mobile networks and how this consumption is evolving. It is quite likely that the huge energy efficiency gains achieved by technology evolution have at least been compensated by the surge in data traffic. Therefore, in this paper, we estimate the operational power consumption of cellular Base Stations (BSs) deployed in France from 2015 to 2022. However, unfortunately, the lack of openly available data hinders the estimation process. In order to work around this issue, we rely on a public dataset on radio electric installations, on widely adopted power consumption models and on a set of assumptions backed by the scientific literature. We demonstrate that, over the considered period, the numbers of BSs and transceivers have grown at a sustained Compound Annual Growth Rate (CAGR) of 7.55% and 18.27%, respectively. Within the same period, the average BS power consumption has increased at a CAGR of 9.89% while the total operational power consumption of BSs has grown at a CAGR of 18.18%. We further show that the introduction of 5G has accelerated this trend despite the recent decommissioning of 2G and 3G transceivers. These alarming figures advocate for proactive digital sobriety policies. ●
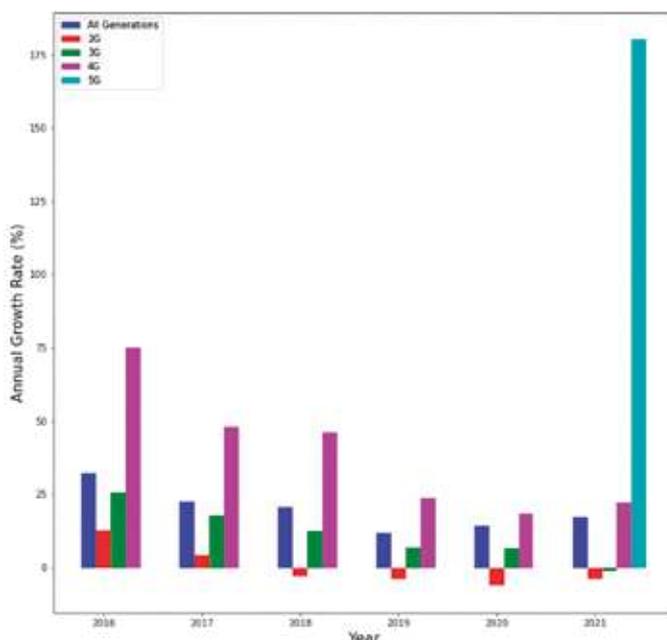
Annual growth rate of transceivers in France (2016 - 2021).

Reference:
Proceedings of the 2023 International Conference on ICT for Sustainability (ICT4S), Rennes, France, 2023, pp. 188-196.

COMMUNICATION SYSTEMS AND NETWORKS

Modeling UAV Swarm Deployment Based on Sibuya Process

Bin Liu, Haifeng Hu, Laurent Decreusefond and Haitao Zhao

Utilizing Unmanned Aerial Vehicles (UAVs) to provide coverage service has a variety of advantages over terrestrial cellular networks. A typical one is that multiple adjacent UAVs can form swarms dynamically to provide stable connection for high populated areas. Due to the random location feature, stochastic geometry tool is used to evaluate their coverage performance. Prior work leveraged Poisson/Binomial and Poisson cluster processes to characterize single-swarm and multi-swarm respectively. These models simplify the analytical procedure at the price of failing to capture heavy-tailed property of UAV numbers in swarms inspired by population density. This leads to underestimated interference impact, inaccurate performance evaluation and insufficient UAV deployments. For this reason, for the first time, we leverage Sibuya and discrete α–stable processes to characterize single–swarm and multi-swarm networks respectively. These two processes have tractable probability generation functionals and capture heavy tail property as well. In addition, we derive the coverage probability under the maximal instantaneous signal-to-interference ratio association policy for both deployments. Finally, simulation results validate our analytical models. ●

For events such as concerts and sports competitions, drones can offer a cost-effective and adaptable solution to enhance wireless coverage. However, predicting their efficacy necessitates the utilization of new stochastic models. This presents a novel challenge, as we must establish point processes where points can be exceptionally close to one another, a characteristic precisely suited to the design of Sibuya processes.

COMMUNICATION SYSTEMS AND NETWORKS

LUVI: Lightweight UWB-VIO based relative positioning for AR-IoT applications

Hong-Beom Choi, Keun-Woo Lim and Young-Bae Ko

Ad Hoc Networks

In this paper, we propose LUVI, Lightweight UWB-VIO relative positioning method for indoor localization. Recent designs of handheld and embedded devices feature various technologies which have the means to enhance localization performance in indoor environments. These include visual odometry based on cameras and augmented reality, and communication hardware such as UWB. Integration of such technologies to exploit their advantages allows us to compensate for each other's errors in measurement. This improves the overall function of future services, such as visual representation of sensing information from sensors in areas that are not physically visible. However, existing work cannot fully exploit these technologies to high extent, often inducing high errors or wasted resources. LUVI is a novel localization method which estimates the location of a target object using relative coordinates of estimator devices without the aid of definitive coordinates. LUVI focuses on utilization of lightweight management of virtual anchors for localization, with functions that reduce the computing and communication complexity while maintaining the accuracy and improving energy efficiency of the localization. Our work has been fully implemented and tested in several indoor environments, showing robustness to NLOS while significantly reducing computational complexity, and up to 30% lower average error. ●
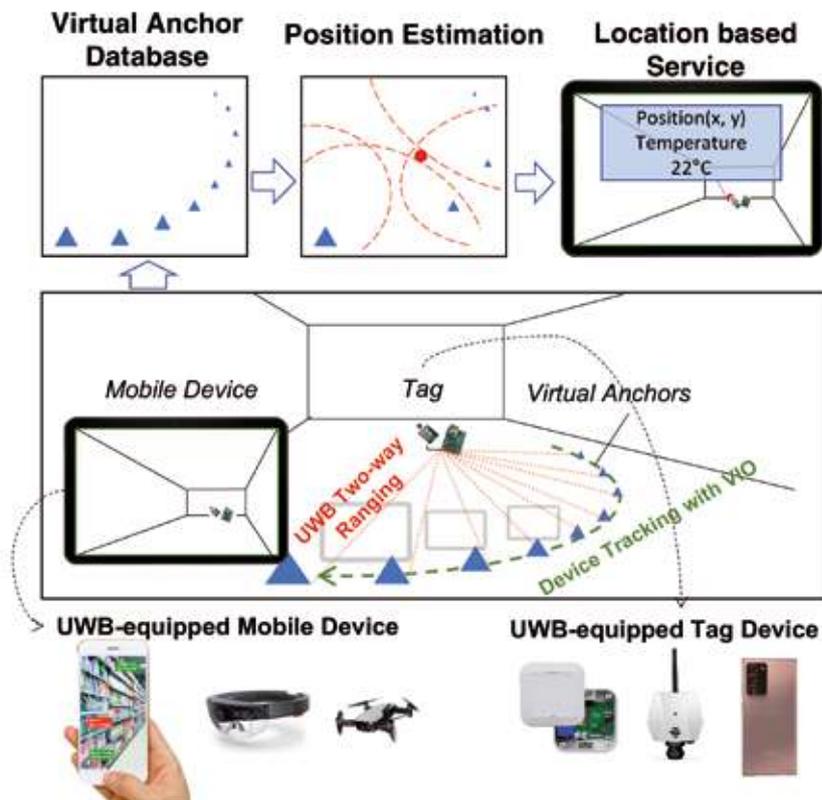
Illustration of Virtual Anchor based Relative Positioning system.
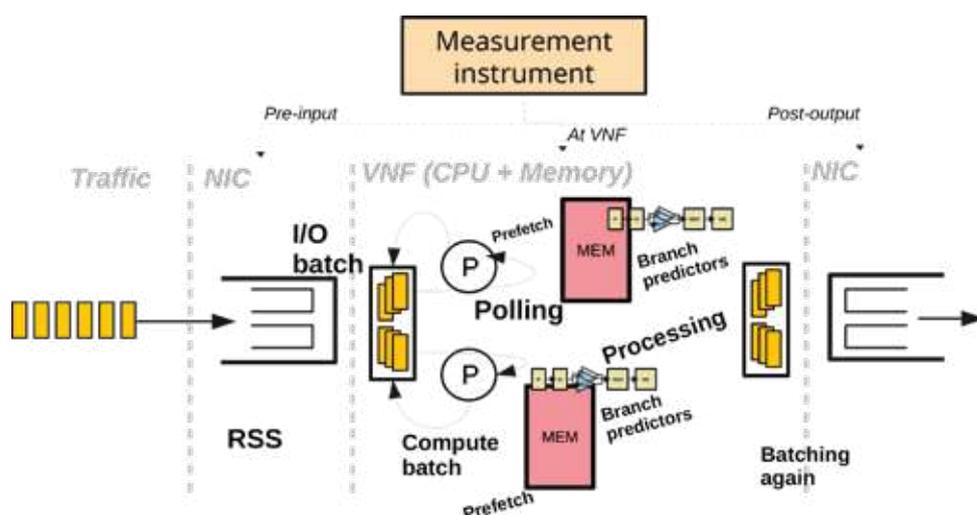
COMMUNICATION SYSTEMS AND NETWORKS

Non-invasive performance prediction of high-speed softwarized network services with limited knowledge

Qiong Liu, Tianzhu Zhang and Leonardo Linguaglossa

Modern telco networks have experienced a significant paradigm shift in the past decade, thanks to the proliferation of network softwarization. Despite the benefits of softwarized networks, the constituent software data planes cannot always guarantee predictable performance due to resource contentions in the underlying shared infrastructure. Performance predictions are thus paramount for network operators to fulfill Service-Level Agreements (SLAs), especially in high-speed regimes (e.g., Gigabit or Terabit Ethernet). Existing solutions heavily rely on in-band feature collection, which imposes non-trivial engineering and data-path overhead. This paper proposes a non-invasive performance prediction approach, which complements state-of-the-art solutions by measuring and analyzing low-level features ubiquitously available in the network infrastructure. Accessing these features does not hamper the packet data path. Our approach does not rely on prior knowledge of the input traffic, VNFs' internals, and system details. We show that (i) low-level hardware features exposed by the NFV infrastructure can be collected and interpreted for performance issues, (ii) predictive models can be derived with classical ML algorithms, (iii) and can be used to predict performance impairments in real NFV systems accurately. Our code and datasets are publicly available: https://github.com/evesiphus/onvm. ●

In our research, we aim at developing non-invasive analytical approaches for virtualized network systems, by determining i) how a measurement instrument retrieves data from a real system and ii) how data are processed in order to perform the required prediction or classification task. Since modern software routers are complex systems, with several stages of batching, polling and CPU instruction execution, any measurement equipment will inevitably alter the state of the system itself, thus originating the data uncertainty principle. However, as network functions and software routers are ultimately pieces of code executed on commercial general-purpose CPUs, we have developed a methodology, based on AI, that links the high-level state of the system with low-level features ubiquitously available in the network infrastructure. Accessing these features does not rely on prior knowledge of the input traffic, network's internals, and system details. Our methodology has been effectively implemented and applied to real system to perform performance prediction and traffic classification.

COMMUNICATION SYSTEMS AND NETWORKS

Metamaterial unipolar quantum optoelectronics for mid-infrared free-space optics

Thomas Bonazzi, Hamza Dely, Pierre Didier, Djamal Gacemi, Baptiste Fix, Mattias Beck, Jerome Faist, Abdelmounaim Harouri, Isabelle Sagnes, Frédéric Grillot, Angela Vasanelli and Carlo Sirtori

APL Photonics

Free-space optical communications in the mid-infrared transparency windows (4–5 and 8–14 μm wavelength regions) is emerging as a viable solution for high bitrate data transmission. Unipolar quantum optoelectronics is the technology of choice for data communication in this wavelength region, thanks to the high frequency response of detectors and modulators. In this work, it is demonstrated that the performances of these devices can be substantially enhanced by embedding them into metamaterials. It is also shown that metamaterials have to be engineered differently in detectors than in modulators, as the role of light–matter interaction must be tuned adequately in the two devices. Metamaterial-enhanced performances allow the realization of data transmission with a record rate of 68 Gbit/s, while ensuring robustness and consistency, as it should be for real-world applications. These findings underscore the promising role of metamaterial-enhanced unipolar devices in advancing free-space optical communication systems. ●
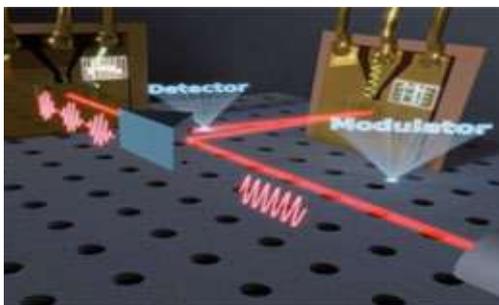
Communication system including a quantum cascade laser as well as a detector and a modulator made of metamaterial. The operating wavelength is 10 µm, corresponding to the long-wavelength infrared range.
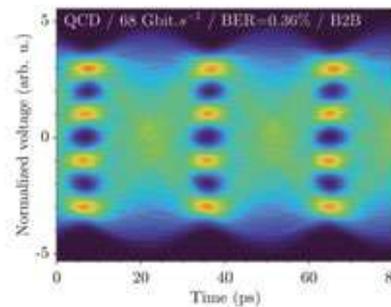
Eye diagram illustrating the performance of the 10 µm communication system with a throughput close to 70 gigabits per second (PAM-4 modulation).

Free-space optical communications in the mid-infrared windows (4–5 and 8–14 µm) are emerging as a powerful solution for ultra-high-bitrate data transmission in applications such as secure defense links, satellite-to-ground connections, and long-range terrestrial networks. In this spectral region, unipolar quantum optoelectronic devices including semiconductor lasers, modulators, and detectors based on quantum cascade technology offer the most suitable platform thanks to their high-frequency response. This work demonstrates that embedding such devices into carefully engineered metamaterials substantially boosts their performance. Leveraging these improvements, record data transmission rates approaching 70 Gbit/s are achieved at a wavelength of 10 µm with robustness and stability, underscoring the transformative potential of metamaterial-enhanced unipolar devices for advancing free-space optical communication systems into high-speed, reliable, and application-ready technologies.

COMMUNICATION SYSTEMS AND NETWORKS

Sequence Selection with Dispersion-Aware Metric for Long-Haul Transmission Systems

Jingtian Liu, Élie Awwad, Hartmut Hafermann and Yves Jaouën

Sequence selection (SS) potentially offers a pragmatic way to unlock nonlinear shaping gains in coherent optical fiber communications beyond those offered by probabilistic constellation shaping (PCS). We introduce a novel sign-dependent metric: the energy dispersion index (EDI) of sequences that endured chromatic dispersion, denoted as D-EDI, which exhibits more accurate opposite variations with the transmission performance compared to the standard EDI metric. Then, by applying D-EDI and EDI to the SS process, we present two signaling approaches denoted as D-SS and E-SS respectively. These approaches are designed to minimize rate loss and enhance transmission performance in nonlinear optical fiber transmission systems, catering to both short-distance and long-haul scenarios. With enumerative sphere shaping (ESS) as distribution matcher (DM), our simulation results reveal significant performance gains over ESS without SS, with improvements up to 0.4 bits/4D-symbol. These improvements were observed over a 205-km single-span standard single mode fiber link in wavelength-division multiplexing (WDM) transmission, with five dual-polarization channels, each operating at a net rate of 400 Gbit/s. Furthermore, we demonstrate that D-SS surpasses ESS without SS by 0.03 bits/4D-symbol in achievable information rate over a 30×80 km link in a single-wavelength, with 8 discrete multi-band (DMB) transmission, and an 880 Gbit/s net rate. Notably, our proposed D-SS scheme achieves similar performance to a sequence selection based on a full split-step Fourier method (SSFM) simulation and it consistently delivers throughput enhancements across various block lengths and selected sequence lengths. ●
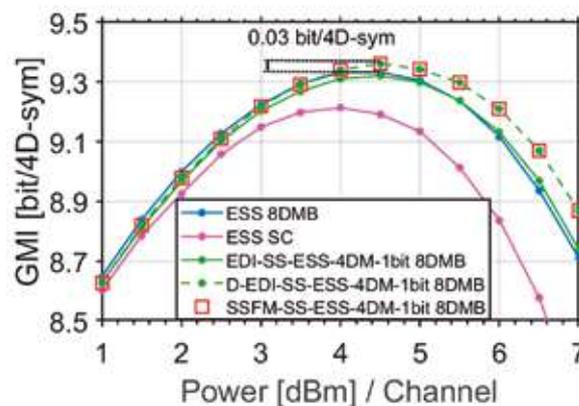
The plot shows the achieved information rate expressed as a generalized mutual information (GMI) in [bits/4D symbol] versus the optical power per wavelength channel for two state-of-the-art non-linear shaping schemes (enumerative sphere shaping (ESS) using a single-carrier transmission (SC) or 8 digital-multi-band transmission (8DMB)) and two of our proposed low-complexity sequence-selection (SS) schemes (EDI-SS-ESS and D-EDI-SS-ESS over an 8DMB transmission). EDI and D-EDI stand for the two metrics that we employ for sequence selection: EDI is the energy dispersion index of a sequence and D-EDI is the dispersion-aware energy dispersion index. Our novel scheme, the D-EDI-SS-ESS, can achieve the same performance as the high-complexity sequence-selection scheme (SSFM-SS 8DMB) that is used as an upper-bound of sequence-selection-based non-linear shaping methods. The simulated scenario is a single-channel 110 GBaud transmission (880 Gbit/s net rate) over a 30 x 80 km fiber link.

📖 **QUANTUM INFORMATION PROCESSING AND COMMUNICATION**

Semidefinite programming relaxations for quantum correlations

Armin Tavakoli, Alejandro Pozas-Kerstjens, Peter Brown and Mateus Araújo

Reviews of Modern Physics

Semidefinite programs are convex optimization problems involving a linear objective function and a domain of positive-semidefinite matrices. Over the past two decades, they have become an indispensable tool in quantum information science. Many otherwise intractable fundamental and applied problems can be successfully approached by means of relaxation to a semidefinite program. This methodology is reviewed here in the context of quantum correlations. The manner in which the core idea of semidefinite relaxations can be adapted is discussed for a variety of research topics in quantum correlations, including nonlocality, quantum communication, quantum networks, entanglement, and quantum cryptography. ●

$$p \in \mathcal{Q}_k$$

$$\text{iff}$$

$$\Gamma_k \succeq 0$$

+
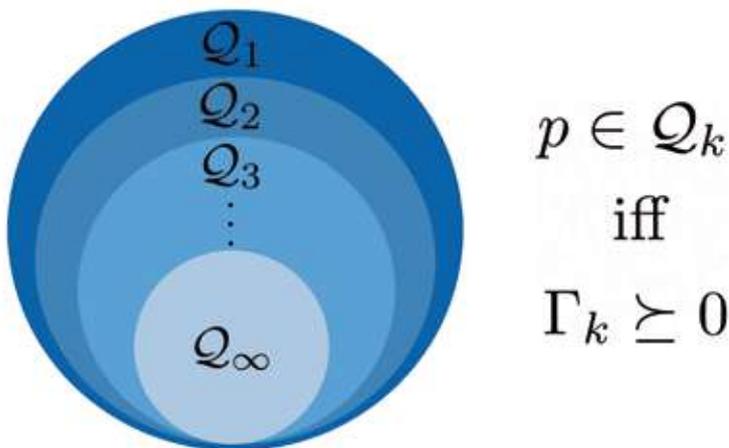
The scope of applications of semidefinite programming relaxations continues to expand within quantum information science. Recently, we developed new tools to approximate and optimize entropic quantities using these techniques [Quantum 8, 1445 (2024), arXiv:2408.12313], providing state-of-the-art methods for computing secret key rates in quantum cryptography. These advances boost the performance of cryptographic protocols and help push them closer to practical implementation.

📖 **QUANTUM INFORMATION PROCESSING AND COMMUNICATION**

Superselection Rules and Bosonic Quantum Computational Resources

Eloi Descamps, Nicolas Fabre, Astghik Saharyan, Arne Keller and Pérola Milman

Physical Review Letter

We present a method to systematically identify and classify quantum optical nonclassical states as classical or nonclassical based on the resources they create on a bosonic quantum computer. This is achieved by converting arbitrary bosonic states into multiple modes, each occupied by a single photon, thereby defining qubits of a bosonic quantum computer. Starting from a bosonic classical-like state in a representation that explicitly respects particle number superselection rules, we apply universal gates to create arbitrary superpositions of states with the same total particle number. The nonclassicality of the corresponding states can then be associated with the operations they induce in the quantum computer. We also provide a correspondence between the adopted representation and the more conventional one in quantum optics, where superpositions of Fock states describe quantum optical states, and we identify how multimode states can lead to quantum advantage. Our work contributes to establish a seamless transition from continuous to discrete properties of quantum optics while laying the grounds for a description of nonclassicality and quantum computational advantage that is applicable to spin systems as well. ●

$$|\Psi\rangle = \sum_{n=0}^{N} c_n \, |n\rangle_{\mathbf{A}} \, |N-n\rangle_{\mathbf{R}}, \qquad \begin{aligned} \hat{J}_x &= \frac{1}{2}\left(\hat{a}_A^\dagger \hat{a}_R + \hat{a}_R^\dagger \hat{a}_A\right) \\[4pt] \hat{J}_y &= \frac{i}{2}\left(\hat{a}_A^\dagger \hat{a}_R - \hat{a}_R^\dagger \hat{a}_A\right) \\[4pt] \hat{J}_z &= \frac{1}{2}\left(\hat{a}_A^\dagger \hat{a}_A - \hat{a}_R^\dagger \hat{a}_R\right) \end{aligned}$$

The particle-number superselection rule-compliant description of quantum states consists of incorporating a phase reference, that permits its unambiguous definition and the evaluation of its resourcefulness in quantum information.

📖 **QUANTUM INFORMATION PROCESSING AND COMMUNICATION**

Efficient learning of ground and thermal states within phases of matter

Cambyse Rouzé, Daniel Stilck França, Emilio Onorati and James D. Watson

Nature Communications

We consider two related tasks: (a) estimating a parameterisation of a given Gibbs state and expectation values of Lipschitz observables on this state; (b) learning the expectation values of local observables within a thermal or quantum phase of matter. In both cases, we present sample-efficient ways to learn these properties to high precision. For the first task, we develop techniques to learn parameterisations of classes of systems, including quantum Gibbs states for classes of non-commuting Hamiltonians. We then give methods to sample-efficiently infer expectation values of extensive properties of the state, including quasi-local observables and entropies. For the second task, we exploit the locality of Hamiltonians to show that M local observables can be learned with probability $1 - \delta$ and precision ε using $N = \mathcal{O}\left(\log\left(\frac{M}{\delta}\right)e^{\mathrm{polylog}(\varepsilon^{-1})}\right)$ samples — exponentially improving previous bounds. Our results apply to both families of ground states of Hamiltonians displaying local topological quantum order, and thermal phases of matter with exponentially decaying correlations. ●
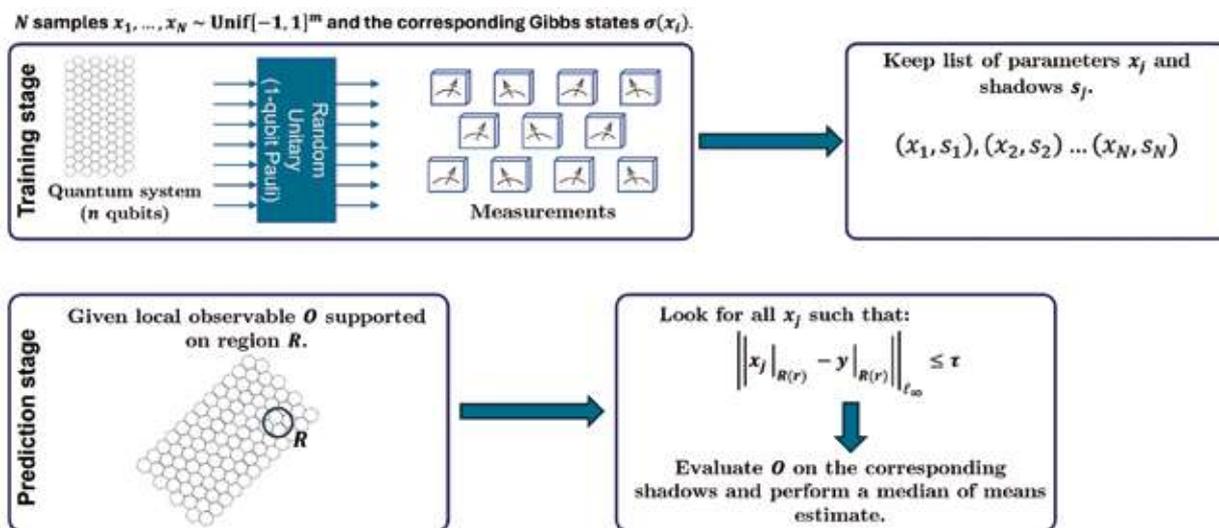
Schematic representation of our algorithm to learn phases of matter. The training stage just consists of collecting shadows corresponding to various parameters. In the prediction stage, given an observable O and corresponding parameter y supported on a region R, we search for parameters xi we sampled that have parameters close to y on an enlarged region, $R(r)$ around R and compute the expectation value of O on the corresponding shadows. The prediction is then a median of means estimate on the values. Note that no machine learning techniques are required for the estimate.

📖 **QUANTUM INFORMATION PROCESSING AND COMMUNICATION**

Limitations of local update recovery in stabilizer-GKP codes: a quantum optimal transport approach

Robert König and Cambyse Rouzé

International conference on Quantum Information Processing (QIP 2024)

Local update recovery seeks to maintain quantum information by applying local correction maps alternating with and compensating for the action of noise. Motivated by recent constructions based on quantum LDPC codes in the finite-dimensional setting, we establish an analytic upper bound on the fault-tolerance threshold for concatenated GKP-stabilizer codes with local update recovery. Our bound applies to noise channels that are tensor products of one-mode beamsplitters with arbitrary environment states, capturing, in particular, photon loss occurring independently in each mode. It shows that for loss rates above a threshold given explicitly as a function of the locality of the recovery maps, encoded information is lost at an exponential rate. This extends an early result by Razborov from discrete to continuous variable (CV) quantum systems. To prove our result, we study a metric on bosonic states akin to the Wasserstein distance between two CV density functions, which we call the bosonic Wasserstein distance. It can be thought of as a CV extension of a quantum Wasserstein distance of order 1 recently introduced by De Palma et al. in the context of qudit systems, in the sense that it captures the notion of locality in a CV setting. We establish several basic properties, including a relation to the trace distance and diameter bounds for states with finite average photon number. We then study its contraction properties under quantum channels, including tensorization, locality and strict contraction under beamsplitter-type noise channels. Due to the simplicity of its formulation, and the established wide applicability of its finite-dimensional counterpart, we believe that the bosonic Wasserstein distance will become a versatile tool in the study of CV quantum systems. ●
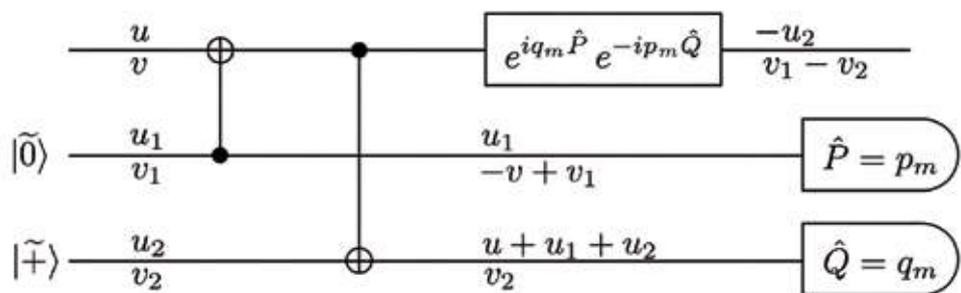
Illustration of Steane's error correction circuit. The labels $\{u, v\}$ next to a rail indicate a general displacement error $e^{-iu\hat{P}} e^{iv\hat{Q}}$ and the diagram indicates how the incoming errors propagate through the circuit. The two measurements are of the $\hat{P}$ and $\hat{Q}$ quadratures of the GKP code, respectively. For the correction shifts, we use the measurement outcomes modulo lattice spacing $\sqrt{\pi}$. Here, the approximate GKP state $|\tilde{+}\rangle$ corresponds to the logical $|+\rangle$ state.

🔲 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

How to Detect and Measure Labor Market Collusion?

Louis-Daniel Pape

17th International Conference on Competition and Regulation (CRESSE 2023)

With the aim of expanding the set of tools available to antitrust practitioners, this paper develops two new econometric methods to detect and measure the effects of labor market cartels. The first method is reduced form and aims to estimate wage loss. It exploits the inter-percentile difference between high earners and low earners within a difference-in-differences framework. This approach is simple to implement, can easily be explained to non-economists, measures heterogeneous effects, and requires no additional data compared to that necessary for a before-after analysis. The method is illustrated by revisiting the 1986-8 case of collusion in Major League Baseball, measuring an average yearly income loss of 26%. Second, this paper develops a structural model of labor market competition for the purpose of detecting collusive behavior. Applied to the data, it reveals that at the beginning of the cartel, there were heightened barriers to mobility across firms, rising profits, and a decreasing labor share of income. Surprisingly, these patterns sustain past the end date of the cartel, suggesting important and underestimated long-run effects. Finally, the structural model is used to simulate counter-factual wages, revealing that the yearly average wage should have been at least 30% higher. 🟡
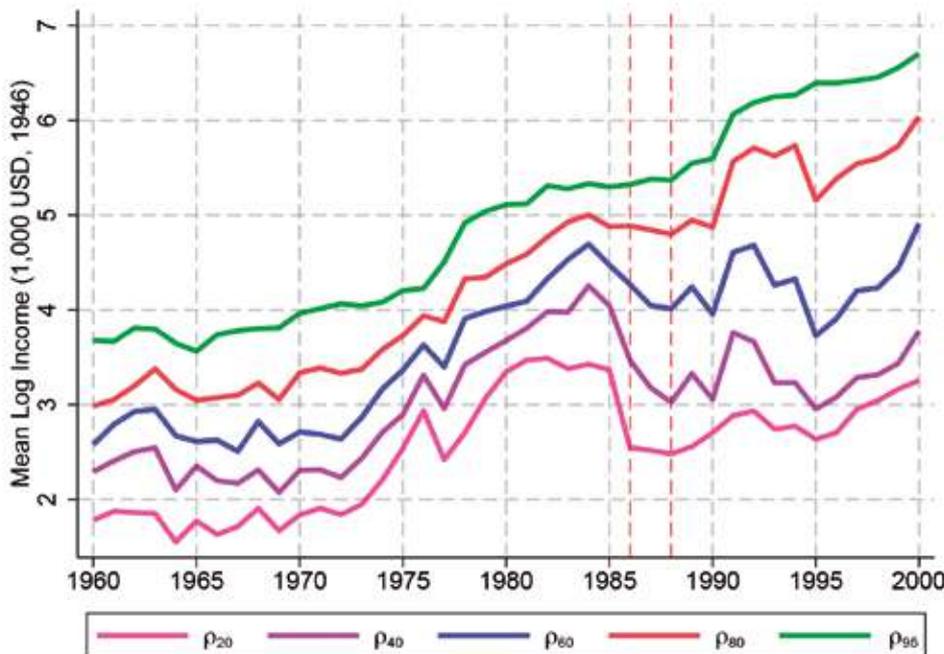
CRESSE-CPI
Best Paper Award 2023

Illustration of loss of earnings due to collusion.

📄 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

Competition and Reputation in an Online Marketplace: Evidence from Airbnb

Michelangelo Rossi

Management Science

This paper studies how competition affects the role of reputation in encouraging sellers to exert effort. More competition disciplines sellers, but, at the same time, it erodes reputational premia. This paper identifies whether one effect dominates the other using data from Airbnb. I exploit the introduction of a short-term rental regulation effective in San Francisco in 2017, that halved the number of short-term listings on the platform. I focus on hosts who are present on the platform before and after the regulation and I identify a negative causal effect of the number of competitors on ratings about hosts' effort. I extend this result with two other measures of effort: hosts' response rate and response time. I confirm that hosts exert less effort when the number of competitors increases. The rate of responses within 24 hours decreases, and response time increases. ●

🔲 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

Link Prediction Without Learning

Simon Delarue, Thomas Bonald and Tiphaine Viard

Proceedings of the 27th European Conference on Artificial Intelligence (ECAI 2024)

Link prediction is a fundamental task in machine learning for graphs. Recently, Graph Neural Networks (GNNs) have gained in popularity and have become the default approach for solving this type of task. Despite the considerable interest for these methods, simple topological heuristics persistently emerge as competitive alternatives to GNNs. In this study, we show that this phenomenon is not an exception and that GNNs do not consistently establish a performance standard for link prediction on graphs. For this purpose, we identify several limitations in the current GNN evaluation methodology, such as the lack of variety in benchmark dataset characteristics and the limited use of diverse baselines outside of neural methods. In particular, we highlight that integrating feature information into topological heuristics remains a little-explored path. In line with this observation, we propose a simple non-neural model that leverages local structure, node feature, and graph feature information within a weighted combination. Experiments conducted on large variety of networks indicate that the proposed approach outperforms existing state-of-the-art GNNs and increases generalisation ability. Contrasting with GNNs, our approach does not rely on any learning process and therefore achieves superior results without sacrificing efficiency, showcasing a reduction of one to three orders of magnitude in computation time. ●
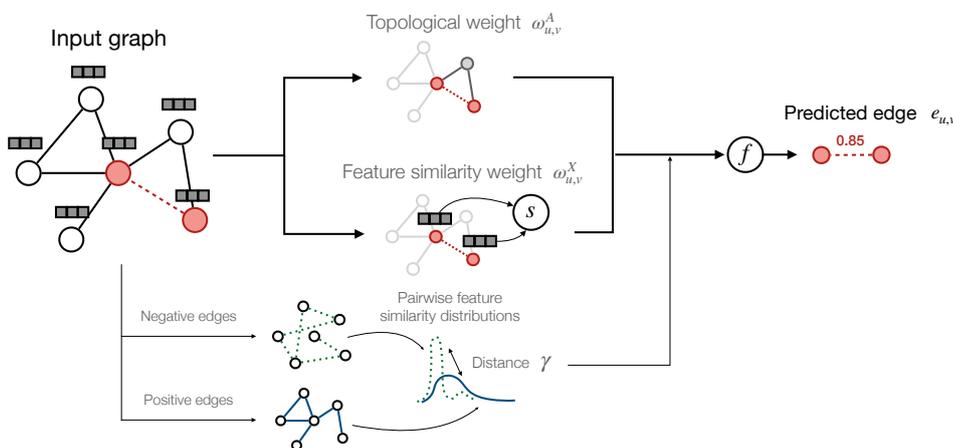
Enhanced topological heuristic for link prediction. For each target link, we compute a node-level topological weight, and a node-level feature similarity weight using a similarity metric s. Additionally, we measure graph-level feature similarity as the distance γ between pairwise feature similarity distributions for positive and negative edges in the graph. Finally, we predict the existence of a link using a linear combination f of both the topological and feature weights and using γ as a controlling parameter.

🗔 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

Why Reinvent the Wheel? Materializing multiplicity to resist reification in alternative organizations

Genevieve Shanahan, Stéphane Jaumier, Alban Ouahab and Thibault Daudigeos

Organization Studies

Often we unconsciously take for granted that there is not *really* an alternative to how we currently organize society – we tend to *reify* existing social order, misperceiving the way things are now as the way things must be. Such reification constrains our agency by discouraging the thought that we could do better. Alternative organizations undermine this reification by manifesting the real possibility of organizing differently. Such *dereification* is valuable in itself insofar as it lifts constraints on agency, facilitating intentional choice regarding the social systems we (re)produce. A case study of this dereification is offered by the Réseau Alimentaire Local (RAL), a network of French "solidarity groceries" unified by the pursuit of more just and sustainable alternatives to the dominant model. Groups within the RAL develop their own software to manage these novel alternatives. We were struck, however, by some groups' efforts to reify their own solutions, disparaging other approaches as mere attempts to "reinvent the wheel". The case thus raised a tricky question: can alternative organizations dereify existing social order without at the same time reifying their proposal, thereby reimposing constraints on agency? Our exploration through the RAL case grounds two contributions. First, conceptualizing reification in terms of materializing abstract ideas, we demonstrate how any given organizational configuration contributes to the materialization of multiple ideas simultaneously. We identify two forms of such multiplicity: *vertical multiplicity*, where nested relational networks materialize coherent ideas that differ only in their degree of specificity; and *horizontal multiplicity*, where intersecting relational networks materialize divergent ideas of the same degree of specificity. We argue that failure to recognize this multiplicity accounts for a great deal of materiality's reifying capacity, while its recognition can facilitate new ways of approaching the dereification challenge. Our second contribution is therefore a strategy for resisting reification: *materializing multiplicity*. ●

🗔 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

Waiting for Robots.
The Hired Hands of Automation

Antonio A. Casilli

Book

An essential investigation that pulls back the curtain on automation, like AI, to show human workers' hidden labor.

Artificial Intelligence fuels both enthusiasm and panic. Technologists are inclined to give their creations leeway, pretend they are animated beings, and consider them efficient. As users, we may complain when these technologies do not obey, or worry about their influence on our choices and our livelihoods. And yet, we also yearn for their convenience, see ourselves reflected in them, and treat them as something entirely new. But when we overestimate the automation of these tools, award-winning author Antonio A. Casilli argues, we fail to recognize how our fellow humans are essential to their efficiency. The danger is not that robots will take our jobs, but that humans will have to do theirs.

In this bracing and powerful book, Casilli uses up-to-the-minute research to show how today's technologies, including AI, continue to exploit human labor—even ours. He connects the diverse activities of today's tech laborers: platform workers, like Uber drivers and Airbnb hosts; "micro workers", including those performing atomized tasks like data entry on Amazon Mechanical Turk; and the rest of us, as we evaluate text or images to show we are not robots, react to Facebook posts, or approve or improve the output of generative AI. As Casilli shows us, algorithms, search engines, and voice assistants would not function without unpaid or underpaid human contributions. Further, he warns that if we fail to recognize this human work, we risk a dark future for all human labor.

Waiting for Robots urges us to move beyond the simplistic notion that machines are intelligent and autonomous. As the proverbial Godot, robots are the bearers of a messianic promise that is always postponed. Instead of bringing prosperity for all, they discipline the workforce, so we do not dream of a world without drudgery and exploitation. Casilli's eye-opening book makes clear that most "automation" requires human labor—and likely always will—shedding new light on today's consequences and tomorrow's threats of failing to recognize and compensate the "click workers" of today. 🟡

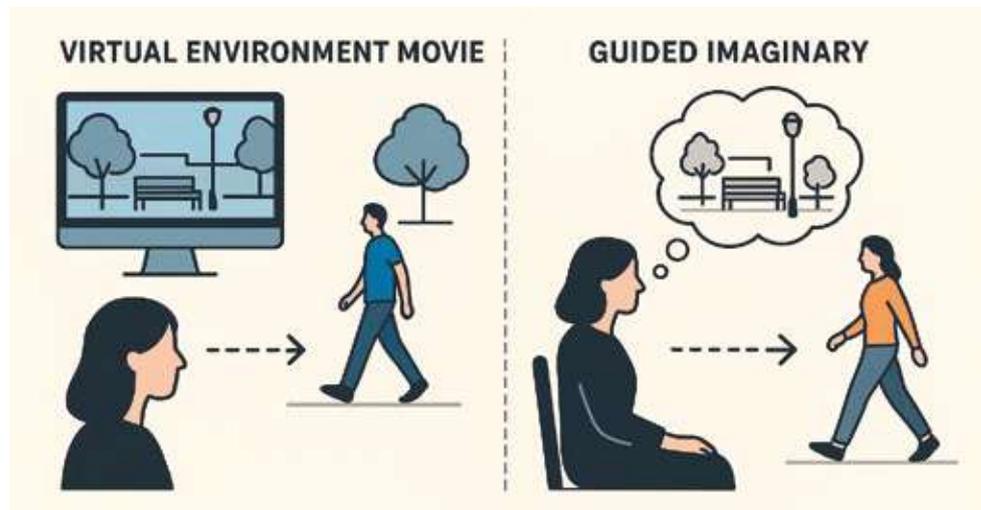## 🗂 DIGITAL INNOVATION, ECONOMICS AND REGULATION

How to catch prospective use? A comparative study of virtual environment movie and guided imaginary for projecting future users in a public space

Élodie Maniga, Sonia Adelé and Béatrice Cahour

Ergonomics

Focusing on the design of a public space, we propose a methodological contribution to integrate possible future users to studies in prospective ergonomics. Our objective is to establish a rigorous protocol for comparing two methods of projecting potential usage. First, a projection interview based on a virtual environment movie and second, a Guided Imaginary Projection interview. We sought to determine to what extent these two methods provide participants with the ability to live a "quasi-experience" of the space. This "quasi-experience" is measured by a questionnaire inspired by the concepts of presence and absorption and by the analysis of the embodiment level of the discourse produced during the interviews, from embodied to general discourse. The results show that while the two methods produce similar results in terms of the level of projection experience, the virtual environment movie projection produces significantly more general discourse. ●

DIGITAL INNOVATION, ECONOMICS AND REGULATION

Input Visualization: Collecting and Modifying Data with Visual Representations

Nathalie Bressa, Jordan Louis, Wesley Willett and Samuel Huron

Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24)

We examine input visualizations, visual representations that are designed to collect (and represent) new data rather than encode preexisting datasets. Information visualization is commonly used to reveal insights and stories within existing data. As a result, most contemporary visualization approaches assume existing datasets as the starting point for design, through which that data is mapped to visual encodings. Meanwhile, the implications of visualizations as inputs and as data sources have received little attention—despite the existence of visual and physical examples stretching back centuries. In this paper, we present a design space of 50 input visualizations analyzing their visual representation, data, artifact, context, and input. Based on this, we identify input modalities, purposes of input visualizations, and a set of design considerations. Finally, we discuss the relationship between input visualization and traditional visualization design and suggest opportunities for future research to better understand these visual representations and their potential. ●

The six input modalities, with input data represented in pink. Virtual and physical variants of all input modalities are possible. CC BY figure at: https://osf.io/bw3gp.

Reference:
Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24). Association for Computing Machinery, New York, NY, USA, Article 499, 1–18.
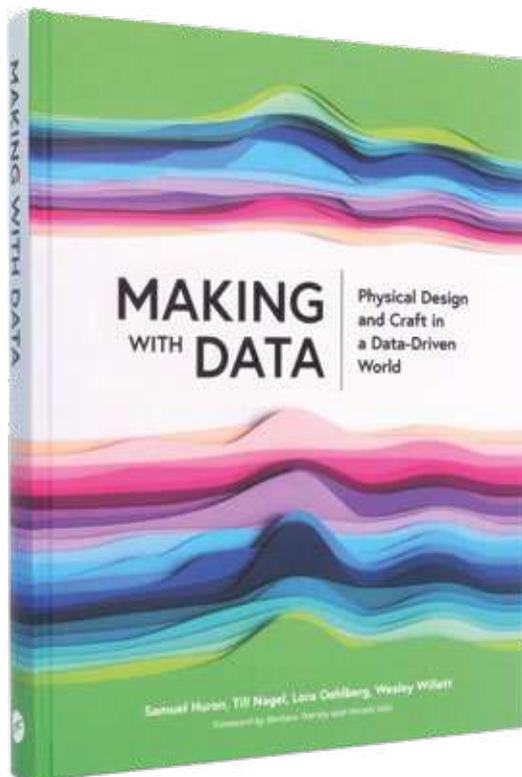
📑 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

Making with Data: Physical Design and Craft in a Data-Driven World

Samuel Huron, Till Nagel, Lora Oehlberg and Wesley Willett

Book

How can we give data physical form? And how might those creations change the ways we experience data and the stories it can tell?

Making with Data: Physical Design and Craft in a Data-Driven World provides a snapshot of the diverse practices contemporary creators are using to produce objects, spaces, and experiences imbued with data. Across 25+ beautifully-illustrated chapters, international artists, designers, and scientists each explain the process of creating a specific data-driven piece—illustrating their practice with candid sketches, photos, and design artifacts from their own studios. Featuring influential voices in computer science, data science, graphic design, art, craft, and architecture, Making with Data is accessible and inspiring for enthusiasts and experts alike. ●

🔲 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

"I know what it is". An interactional study of sex discovery in prenatal ultrasound examinations

Christian Licoppe, Nicolas Rollet and Luca Greco

Discourse Studies

One of the most exciting moments in a prenatal ultrasound session is learning the sex of the baby. Following a conversation analysis perspective, we present a multimodal analysis of sequences of interaction between patient and practitioner at the time the foetus' sex is the focus of attention. Based on video data collected from maternity wards and private practitioners, we report on two types of sequences, which illustrate the different ways of responding to the perceptually-occasioned formulation of the foetus' sex: as a telling or as a noticing (in which case participants orient towards jointly seeing). While the possibility of both response is inherent to the sequential properties of noticing-based claims in general, we will discuss how the production of both types of sequences is sensitive and articulated to the distribution of epistemic authority as a practical achievement in this medical setting, along two dimensions: expert versus ordinary knowledge, and professional vision versus lay gaze. ●

the femur (0.5) there these are the thighs

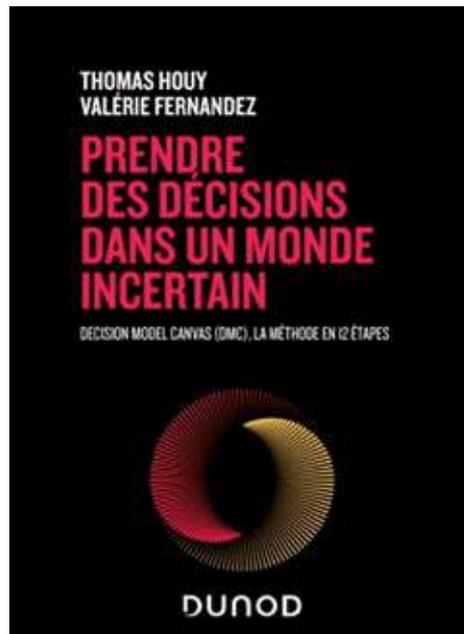Embodied perception and joint cognition: verbalizing the body parts of the foetus as they are made to appear on screen.

📖 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

Decision-making in uncertain environments

Valérie Fernandez and Thomas Houy

Book

Valérie Fernandez and Thomas Houy are developing their research around the now essential issue of decision-making in uncertain environments. Their work has been recognised and awarded several times in 2023 and 2024. Valérie Fernandez and Thomas Houy are developing an open-source, freely accessible tool to aid decision-making in uncertain situations, called the "Decision Model Canvas" (DMC). This tool enables professionals to make informed decisions when their companies or projects are operating in highly unpredictable contexts. Indeed, the immense challenges we face (climatic, digital, cyber, geopolitical, etc.) are causing upheaval in all disciplines of the social sciences. The conditions under which we make decisions are profoundly altered by the now uncertain nature of our environment.

Several foundations of management science have been weakened as a result. In their book entitled "Decision Making in an Uncertain World - Decision Model Canvas (DMC), the 12-step method" published in October 2024, Valérie Fernandez and Thomas Houy seek to understand this paradigm shift for the economic and social sciences and aim to help professionals cope with it. The DMC received the Foundation for Excellence in Management Education and Research (FNEGE) award for the best educational programme in the digital age 2023 and the 2023 educational innovation award from the Academy of Entrepreneurship and Innovation (AEI). In 2024, Valérie Fernandez and Thomas Houy were selected as winners for their DMC project in the IP Paris Prematuration Call for Projects, a key initiative to support innovative research and transform ideas from laboratories into concrete solutions. ●

Watch the video to learn more about the DMC

🔲 **DIGITAL INNOVATION, ECONOMICS AND REGULATION**

"My Disability Is Something We Use as a Strength" — Hero or Not Hero: Revisiting Critical Studies about Entrepreneurship

Julien Billion, Catherine Lejealle, Olivier Fournout and Claire Doussard

International Review of Entrepreneurship

Critical perspectives challenge the figure of the hero. Meanwhile, the scientific debate lacks a conceptual framework to define the hero characteristics. The objectives of this research are to present and extend the hero-matrix, to use entrepreneurs with disabilities (EWD) as a means to test the matrix empirically, and to shed light on what defines a hero in our current post-modernist context. To do so, we interviewed 20 EWD twice over the course of a year. Our results show that a hero is someone who successfully copes with seven injunctions relating both to himself or herself as a person, and to someone who interacts with others. Disability seems to increase the intensity of each criterion. 🟡

Maria Nowak Institute
Best Paper Award 2025
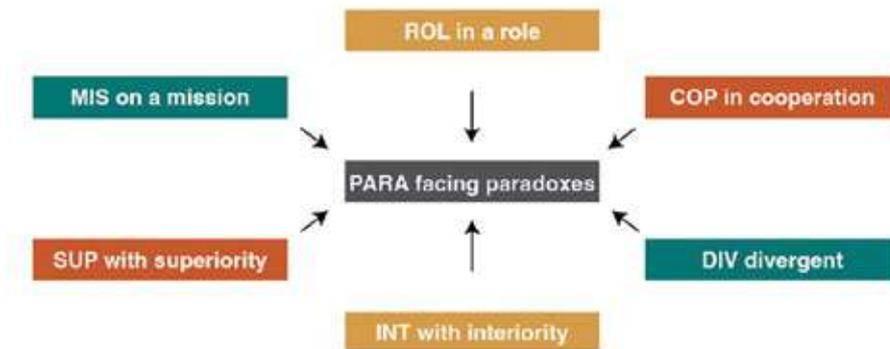
The seven features of the hero-matrix. Source: Fournout (2022).

08

AWARDS *and Distinctions*

Researchers are seldom motivated by the pursuit of distinctions, but they are always pleased to receive recognition from their peers. Congratulations to the recipients from our laboratories for their prizes and accolades, whether they are doctoral students or experienced scientists.
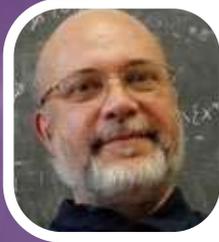
Francois Baccelli

Francois Baccelli, invited Professor at Télécom Paris (LTCI) and leader of the ERC advanced NEMO on the dynamics of large networks, was the winner of the 2024 Blackwell Prize awarded at the Informs conference held October 20-23, 2024 in Seattle, USA.

Isabelle Bloch

Isabelle Bloch, invited Professor at Télécom Paris (LTCI) and Professor at Sorbonne University (LIP6). In 2024, the French Academy of Sciences awarded her the Medal for Mechanical and Computer Sciences, and she received the Galien Prize in the "Research" category.

Antonio A. Casilli

Antonio A. Casilli, Professor at Télécom Paris (I³, NOS).
In February 2024, Antonio A. Casilli was honored to be elected as a French Government By-Fellow at Churchill College, University of Cambridge.

Frédéric Grillot

Frédéric Grillot, Professor at Télécom Paris (LTCI, GTO) was awarded the Ampère Medal by the SEE (Société de l'Électricité, de l'Électronique et des TIC) in 2024 for his pioneering work on optoelectronics in the mid-infrared and quantum dot lasers for silicon photonics. He also has been named Optica Fellow 2024.

Thomas Le Goff

Thomas Le Goff, Associate Professor at Télécom Paris (I³, NOS), received the 2024 Data Ring Thesis Award for his earlier doctoral dissertation entitled "Legal Issues Surrounding the Use of Artificial Intelligence in the Electricity Sector." His thesis highlights the potential impact of AI on the production and distribution of electrical energy.
He has also been appointed Research Fellow at the Centre on Regulation in Europe (CERRE).

Ghaya Rekaya-Ben Othman

In December 2023, Ghaya Rekaya-Ben Othman, Professor at Télécom Paris (LTCI, MIC) won the "Créatrices d'Avenir 2023" Grand Prize and received the DeepTech Category Award for her innovative start-up Mimopt Technology.
In 2024, she was awarded a Women TechEU grant, a European programme that recognises a strong commitment to a more diverse and inclusive technology ecosystem.

Florence Tupin

In 2024, Florence Tupin, Professor at Télécom Paris (LTCI, IMAGES) was appointed co-chair of the GRETSI conference branch.

Michèle Wigger

After receiving an ERC Starting Grant in 2017, Michèle Wigger, Professor at Télécom Paris (LTCI, MIC) has been awarded a European ERC Consolidator Grant in 2023 for her project on the fundamental limits of sensing systems.

THESIS AWARDS

Enrick Arnaud-Joufray (CREST, ECO), *The Economics of Digital Markets: Essays in Theoretical and Empirical Industrial Organization*, Concurrences Thesis Award 2023.

Youssouf Camara (CREST, ECO), *Four Essays on Empirical Economics in the Era of High-Frequency Data*, Institut Polytechnique de Paris Thesis Award 2023.

Sterenn Guerrier (LTCI, GTO), *High bandwidth detection of mechanical stress in optical fibre using coherent detection of Rayleigh scattering*, Institut Polytechnique de Paris Thesis Award 2023.

Elie Kadoche (LTCI, S²A), *Development of control algorithms based on multi-agent reinforcement learning for the optimization of large-scale wind farms*, third prize in the national "My Thesis in 180 Seconds" 2024 competition.

Guillaume Thébaudin (CREST, ECO), *Regulation of Digital Platforms: Essays in Industrial Organization*, Concurrences Thesis Award 2024.

09

NEW
joiners

In this section, we present all the faculty members who joined us in 2023–2024.

Data science and Artificial Intelligence

Nathalie **Bressa**

**Assistant Professor
at Télécom Paris, LTCI, DIVA**

Nathalie Bressa conducts research in human-computer interaction, information visualisation, situated visualisation and participatory design. She obtained her PhD in computer science from Aarhus University (Denmark) under the supervision of Susanne Bødker and Jo Vermeulen in 2021. She was a postdoctoral researcher in I^3 before joining the LTCI.

Maria **Boritchev**

**Assistant Professor
at Télécom Paris, LTCI, S^{2}A**

After studying computer science at ENS Lyon, Maria completed her PhD at LORIA, part of the University of Lorraine and Inria Nancy Grand-Est. She then worked as a postdoctoral researcher at the Institute of Mathematics of the Polish Academy of Sciences in Warsaw. She continued her research on the explainability of neural models at Orange Innovation in Lannion, where she worked more specifically on multilingual semantic analysers. Her main area of research is natural language processing.

Daniel **Pires de Sá Medeiros**

Associate Professor
at Télécom Paris, LTCI, DIVA

Daniel comes from the University of Glasgow, where he was a postdoctoral researcher in the field of human-computer interaction. His research focuses on the design and evaluation of new interaction techniques in virtual, augmented and mixed reality, with applications in a variety of fields. He studied the manipulation of virtual objects for medical applications during his doctoral research at the University of Lisbon. At Victoria University of Wellington, he contributed to the design of interfaces for asymmetric collaboration in virtual reality. At the University of Glasgow, he studied movement techniques to reduce the effects of "cyber sickness", as well as methods of interaction in constrained environments, such as public transport.

Enzo **Tartaglione**

Full Professor
at Télécom Paris, LTCI, MM

Enzo is head of the Multimedia team and holder of a Hi!Paris chair. He is also a member of ELLIS (a pan-European AI network of Excellence), a senior member of the IEEE, and deputy editor-in-chief of the IEEE Transactions on Neural Networks and Learning Systems journal and the EURASIP journal on image and video processing.

His main areas of interest are compression and responsible (frugal) AI, privacy-preserving learning, data debiasing, and regulation for deep learning.

Shanshan **Wang**

Assistant Professor
at Télécom Paris, LTCI, RFM[2]

Shanshan holds a Master of Science degree in Wireless Communications and Signal Processing from the University of Bristol and a PhD from Paris-Saclay University (L2S, CentraleSupelec) under the supervision of Marco Di Renzo. Her research focuses on stochastic geometry-based modelling for wireless networks and monitoring exposure to radiofrequency electromagnetic fields using statistical learning and AI techniques.
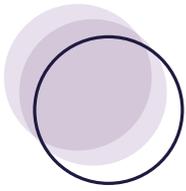
Digital trust

Sébastien **Canard**

Full Professor
at Télécom Paris, LTCI, C²

Sébastien is a cryptography researcher specialising in cybersecurity with 20 years' experience at Orange. After completing his PhD in 2003 on cryptography for anonymity and accountability, his research interests gradually broadened to encompass data protection and privacy. Whether for individuals' private data (particularly in relation to the GDPR) or for sensitive data belonging to companies or institutions, he works on designing cryptographic techniques (encryption, authentication, and standard and advanced signatures) that can be adapted to everyday needs. Sébastien obtained his HDR (Habilitation à Diriger des Recherches) in 2009 on the subject of "Cryptography for the protection of privacy" and has supervised more than 14 theses.

Victor **Dyseryn**

Associate Professor
at Télécom Paris, LTCI, C²
Responsible for digital training
**at the Corps des Mines**

Victor completed a PhD in post-quantum cryptography at the XLIM laboratory of the University of Limoges in early 2024. His research focuses mainly on encryption and signature primitives based on error-correcting codes. He took part in three applications for the latest NIST standardisation competition for post-quantum signatures. Victor is an engineer of the Corps des Mines and a former student of the École polytechnique.

Qingju **Wang**

Associate Professor
at Télécom Paris, LTCI, C²

Qingju comes from the University of Luxembourg, where she was a postdoctoral researcher. She previously obtained her PhD from KU Leuven and completed a one-year postdoctoral fellowship at DTU (Denmark Technical University). Her research focuses on symmetric cryptography and cryptanalysis with the aim of creating efficient and secure encryption algorithms, both from a theoretical and practical point of view. Her designs for authenticated encryption primitives have contributed to cryptography competitions, notably the NIST standardisation process on Lightweight Crypto.
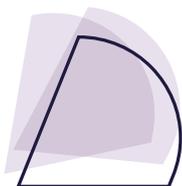
Communication Systems and Networks

Pavel **Chuprikov**

Assistant Professor
at Télécom Paris, LTCI, ACES

Pavel works primarily on the optimisation and specification of networked and distributed systems. After completing his PhD at the IMDEA Networks Institute and the Saint Petersburg Institute of Mathematics, Pavel joined the SWYSTEMS group at the Università della Svizzera italiana as a postdoctoral researcher, where he expanded his expertise from networks to distributed systems more generally. More recently, Pavel has begun exploring the emerging field of quantum network specification and verification, which promises to bring unprecedented levels of communication security and form the backbone of distributed quantum computing.

Nils **Holzenberger**

Assistant Professor
at Télécom Paris, LTCI, DIG

Nils graduated from Mines Paris - PSL in 2017. He has spent time at MIT, IBM Watson, Carnegie Mellon University, ENS PSL, and Mila research institute. Nils began his PhD at Johns Hopkins University in 2017, working with Professors Benjamin Van Durme and Raman Arora, and defended his thesis in 2022. His main scientific contributions are in representation learning for language, information extraction, and legal language processing. Together with Benjamin Van Durme and Andrew Blair-Stanek, Nils obtained funding from the NSF (National Science Foundation).

Xhevahire **Tërnava**

Assistant Professor
at Télécom Paris, LTCI, ACES

Xhevahire obtained her PhD in Computer Engineering in 2017 from Université Côte d'Azur in Nice. She subsequently spent two years as a postdoctoral researcher at Sorbonne Université in Paris. She spent three years as a postdoctoral researcher at Université de Rennes.

Xhevahire's research has focused on advancing software engineering, particularly in areas such as software variability, highly-configurable software systems, software product lines, and software reuse. She has made significant contributions through empirical studies and the development of innovative approaches and tools for managing, reverse engineering, visualizing, enhancing the build process, and reducing the bloat of variability in real highly-configurable software systems. Her current research interests are primarily in improving software quality by eliminating unnecessary variability from software systems.

Quantum information processing and communication

Juan Rafael **Alvarez Velasquez**

**Assistant Professor
at Télécom Paris, LTCI, GTO**

Juan Rafael is an expert in quantum mechanics and quantum information processing using light. He has pursued an international academic career in France, the United Kingdom, Spain and his native Colombia. He obtained his PhD in experimental physics from the University of Oxford in March 2023, Atom-Photon Connection group, before completing a post-doctorate at the University of Paris-Saclay.

Cambyse **Rouzé**

**Inria researcher, Associate Professor at Télécom Paris, LTCI, QTY**

Cambyse comes from the Technical University of Munich (TUM), where he was doing postdoctoral research. He previously obtained his PhD from the University of Cambridge. His research focuses on quantum information and computation theory and their interaction with the physics of complex quantum systems. More recently, he has been interested in the speed of convergence of chains of quantum Gibbs state sampling algorithms and its algorithmic consequences, as well as in the preparation of noise-robust quantum memories. Cambyse is also working on the design of algorithms for tomography and learning the physical states of matter, such as the fundamental and thermal states of local Hamiltonians modelling the interactions between neighbouring particles in a network of spins or quantum bosons.

Augustin **Vanrietvelde**

**Assistant Professor
at Télécom Paris, LTCI, QTY**

Augustin completed his PhD at the Quantum Group at the University of Oxford, followed by a postdoctoral position in the Inria QuaCS team at the Formal Methods Laboratory at ENS Paris-Saclay. He works on quantum information and computing. One of his areas of research focuses on the study of innovative computing architectures enabled by quantum theory, in which quantum logic gates are applied in a superimposed order; he has developed formal frameworks for writing and manipulating these architectures. He also works more generally on the notion of causal influence in quantum theory and on different ways of formalising it, in order to use it to better understand the information processing capabilities enabled by this theory.
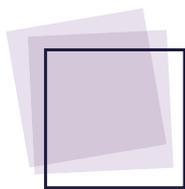
Digital innovation, economics and regulation

Michele **Fabi**

**Assistant Professor
at Télécom Paris, CREST, ECO**

After obtaining his PhD in 2021 as part of the IDEA-UAB doctoral programme (Universitat Autònoma de Barcelona), Michele was a postdoctoral researcher at École polytechnique within the Blockchain@polytechnique academic chair.

Michele is also affiliated with the Center for Research in Economics and Statistics (CREST) at the Institut Polytechnique de Paris.

His main areas of research are financial economics and microeconomics. He is interested in topics such as platforms, decentralised finance and start-ups, energy markets, blockchain and the digitisation of currency and markets.

Thomas **Le Goff**

**Associate Professor
at Télécom Paris, I³, NOS**

Thomas graduated from University Paris Cité (PhD in law).

His research focuses on the links between AI and sustainability, from a legal and policy perspective. Before joining Télécom Paris, he worked as a legal advisor at Électricité de France (EDF), where he was responsible for expertise in data protection and digital regulation.

Louis **Pape**

**Assistant Professor
at Télécom Paris, CREST, ECO**

Louis studied economics at the University of Cambridge and philosophy at the London School of Economics.

Louis obtained his PhD from École polytechnique, focusing on the economics of the digital economy, competition, and the labour market. In particular, he studied the extent to which French labour markets are competitive. He developed econometric methods to measure the impact on wages of mobility restrictions linked to collusion between several employers, and modelled the financial impact of creating video games adapted to players' abilities.
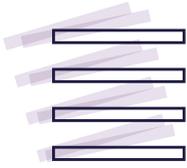
Mathematical modeling

Radu **Dragomir**

Assistant Professor
at Télécom Paris, LTCI, S²A

Radu's work focuses on optimization methods used in machine learning and signal processing.

Radu's PhD was co-supervised by Toulouse Capitole University and the SIERRA team at ENS - PSL. He followed this up with a two-year postdoctoral position at UCLouvain in Belgium, then at EPFL in Switzerland.

His research focuses on the theoretical understanding of optimization methods, in terms of both efficiency and reliability. He worked on problems with non-Euclidean and non-convex geometries. Applications include matrix factorization, manifold learning and inverse problems with non-Gaussian noise.

Radu holds a Hi! Paris chair in Optimization for Frugal Learning. His research project aims to improve the efficiency and robustness of methods used to solve very large problems.

Arthur **Leclaire**

Full Professor
at Télécom Paris, LTCI, IMAGES

After studying at the University of Nancy, ENS PSL and then ENS Paris-Saclay, Arthur obtained his PhD in applied mathematics for image processing in 2015, prepared at the MAP5 laboratory at Paris Cité University. He continued his career as an Agrégé-préparateur at ENS Paris -Saclay between 2014 and 2018, then as an Associate Professor at the Bordeaux Institute of Mathematics from 2018 to 2023.

His research focuses on the study of mathematical models for image restoration and synthesis. He has contributed to the development of new plug-and-play image restoration methods that exploit the performance of deep denoising networks while maintaining good theoretical guarantees. His research project aims to extend the use of these methods to other imaging processes and to combine them with sampling and Bayesian statistical tools in order to quantify the uncertainty of restoration.

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