2024 ACTIVITY REPORT

cea list

INSTITUT CARNOT CEA LIST

université PARIS-SACLAY

UGA Université Grenoble Alpes

cea list

CEA-List, an institute of the French Atomic Energy and Alternative Energies Commission (CEA), conducts research and development in the field of smart digital systems. With facilities on the CEA Paris-Saclay and CEA Grenoble campuses, CEA-List's activities span artificial intelligence, digital trust, and the industry of the future. The institute's R&D programs address a variety of use cases in service to a more competitive industrial sector. Guided by a human-centric approach and the values of social and environmental responsibility, CEA-List's team of 1,000 research engineers and technicians are committed to making progress on major societal and economic challenges through high-added-value technological innovations. In recognition of the quality of its research partnerships with businesses, CEA-List was renewed as a member of the Carnot Network in 2006—the fourth consecutive renewal since 2006.

list.cea.fr/en

Foreword

"Our people are committed to making scientific and technological advances in service to research and to society. It is their passion and determination, which, day after day, yielded remarkable results in 2024."

— **ALEXANDRE BOUNOUH**
DIRECTOR, CEA-LIST

The United States' sudden and radical policy changes—and the resulting shift in transatlantic relations—mark a turning point. There is no longer any question as to Europe's need to establish strategic sovereignty, especially in security and defense and in digital. And the issue extends well beyond European security and defense: our dependence on US technology has never been felt as strongly as now. Europe has been talking about sovereignty since the Covid-19 pandemic. However, not even in our wildest dreams would we have guessed that a threat, not from a virus, but from one of Europe's historic allies, would bring such a new and vital urgency. The year 2024 and, more specifically, CEA-List's results, which I encourage you to discover in the following pages, must be viewed through this new lens.

Our people are committed to making scientific and technological advances in service to research and to society. It is their passion and determination, which, day after day, yielded remarkable results in 2024. In AI, for example, the first open-source software platform for embedded AI, AIDGE, was released. Significant advances were also made in generative AI, a field in which our researchers successfully established their leadership in the space of just a few months, bringing home first prize in the French military procurement agency's LLM competition, and being selected by Thales as their trusted partner for the first-ever joint laboratory on Generative AI for defense.

Quantum computing is another area where our people drove advances. We made significant contributions to two major new programs that were launched last year: Q-Loop (a national *Grand Défi* project) on qubit control, and the *Maison du Quantique Île-de-France*, a multi-partner center for quantum, which we are coordinating. These programs are a testament to our people and their capacity to coordinate far-reaching technology projects and programs.

We also forged ahead with strategic projects this year, deploying, for example, new smart robotics resources at the Lab2Fab PRISM platform for the industry of the future, a unique research infrastructure that distills our value proposition by facilitating the transfer of CEA-List technologies to companies. The accelerated rollout of services through the AI-Matters Testing and Experimentation Facility and our reinforced position in data sharing and cloud computing provide further evidence of how CEA-List continues to gain traction.

CEA-List also continued its active participation in European projects, submitting a hundred proposals. Of the nearly 30 selected is the DECIDE project on the Chips for Europe Design Platform Coordination Team (PCT). DECIDE will lay the groundwork for the next stage in our semiconductor strategy, with Design Enablement Teams (DETs) to support companies' chip design projects.

In 2024, we put substantial time and effort into an assessment by France's higher education and research evaluator, HCERES, with the production of a self-assessment report. HCERES confirmed CEA-List's mission, "...from the key enabling technologies for digital through to use cases, addressed systemically from hardware and software and from early-stage research to use cases. CEA-List's positioning—a provider of early-stage research to support the economic competitiveness of industrial users—is unique in France." The evaluators concluded that "CEA-List powerfully links academic research to industrial end-users."

Another initiative we intend to pursue—this one societal—is the FRATHEA project on FLASH radiotherapy, which will revolutionize cancer treatment. The interplay between art and science is also something we aspire to. In 2024 a series of works by world-renowned artist Claude Mercier made their way into our collection, where they will spark conversations and open new doors into the world of our truth seekers—our scientists.

Contents

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CEA-List had a front-row seat to major new national initiatives in 2024 targeting cybersecurity, artificial intelligence, the digital continuum, and quantum technologies. These initiatives resulted in a slate of new instruments to accelerate, high-risk research projects, programs in support of breakthrough innovations for the digital industry led by the National Program Agencies, and by the acceleration strategies in the national France 2030 economic revitalization platform. CEA-List's role is to transfer innovations rapidly and broadly at the European level, and our people responded by creating innovation platforms in a variety of fields like digital health, defense, semiconductors, and the factory of the future.

Our key initiatives in 2024


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Program Agencies

The national Program Agencies, set up in 2024, coordinate research nationally, bringing France's top research teams together around topics deemed strategic at the national level. Large-scale, operationally-oriented research programs with budgets ranging from €20 million to €40 million can be financed through the Program Agencies. CEA-List is co-coordinating (with Inria) the AI chip program under the CEA-led ASIC ("from components to digital systems and infrastructures") Program Agency, whose work spans components to systems to digital infrastructures. Finally, CEA-List is contributing to the Inria-led Digital ("algorithms, software, applications") Program Agency, coordinating research on AI evaluation and digital twins.

«Recherche à risque»

The CEA's moonshot program, *Audace!*, which has been allocated €40 million in government funding under the national France 2030 plan, targets high-risk but promising science and technology research. TwinSec, a key project led by CEA-List and CEA-Leti, focuses on secure-by-design SoCs. The researchers will model attackers' capabilities, analyze physical impacts on hardware, and apply formal methods to guarantee a high level of security. A holistic digital twin of the system and of attacks will be designed with a view to countering most vulnerabilities natively in the SoC design.

TwinSec
Hardware security

The first-ever holistic digital twin for secure-by-design SoCs

- Four-year capacity-building moonshot project
- Budget: €4 million
- Led by CEA-List and CEA-Leti
- 8 research teams from the CEA, Grenoble-Alpes University, Inria, CS, and MSE
- End-to-end attacker capacity modeling Formal methods to guarantee a high level of security
- Secure-by-design SoCs Creation of super-resilient islands of trust
- Nationally-strategic research

Research for the second quantum revolution

We are bringing our expertise in numerical calculation to deeper engagement with the second quantum revolution. We launched major capacity-building projects in quantum in 2024, including Quorum, *la Maison du quantique d'Île-de-France*, and IRT Nanoelec's Q-Loop. Our role is to serve as a crucial connector between academic research and real-world applications by developing and transferring quantum technologies. For the Quorum project, for example, we will be developing industrial use-cases and implementing the quantum algorithms developed under the HQI program.

Q-Loop
Scale up control and readout electronics for quantum computers

- €40 million in government funding through France 2030
  €25 million in private-sector funding
- 6 years
- 2 semiconductor manufacturers
  6 quantum startups
- 5 research organizations

Addressing strategic industries

Digital continuity

At the core of today's digital revolution, digital continuity is reshaping the way data is managed. The amount of industrial, energy, health, and other data collected in the field has mushroomed, pushing conventional centralized cloud solutions to their limits. Hybrid edge-to-cloud computing and storage, combined with AI and digital twins, can ensure efficient and secure data management and respond to industrial end-users' demands for real-time capabilities, trust, and sovereignty. Edge-to-cloud can help organizations be more productive, resilient, and competitive. OTPaaS and Data4Industry-X are two separate but complementary France 2030 projects that focus on OT/IT convergence for manufacturing optimization, and on data exchange between local and distant clouds. CEA-List is handling data security. The two-pronged approach embodied by these projects is also reflected in the creation of data spaces to build capacity through sovereign technologies in industries like aeronautics (DECAD-X) and energy.

OTPaaS

- 12 partners
- Budget: €50 million
- The right cloud for field digitization (OT/IT convergence)
- Replace siloed processing in the field with a native Gaia-X platform

Data4Industry-X

- 5 partners
- Budget €37 million
- Controlling data exchanges in manufacturing for productivity, competitiveness, and sovereignty
- Smart, low-cost solutions for managing federated data in heterogeneous information

Digital health

The purpose of the FRATHEA project, coordinated by Institut Curie, is to demonstrate the potential of FLASH radiotherapy (using very high-energy electrons) to improve outcomes in cancer patients with poor prognosis and reduce side effects. Implementing this new treatment modality in clinical settings poses unexplored technological challenges that will call for new dosimetry and modeling methods—challenges that align perfectly with CEA-List's expertise.

FRATHEA
Flash RAdiation THerapy Electron Acceleration

institut Curie

FRATHEA
A new FLASH radiotherapy demonstrator – application of very high-energy electrons

- 3 partners: Institut Curie, CEA, private-sector partner
- €37 million - 2024 to 2028: France 2030 and Île-de-France regional government

Digital for defense

We translate strategic defense needs into technological innovations, developing operational digital solutions to challenges like threats, intelligence, decision support, secure defense infrastructures, and military equipment maintenance. CEA-List draws on a solid reputation in European R&D to contribute to key defense projects like StarLight and build partnerships with defense contractors like MBDA and Thales.


© Gorodenkoff/Adobestock

Serving industry

Our technology transfer activities ramped up significantly in 2024, with three long-term capacity-building partnerships emblematic of our mission. We are developing trusted generative AI for intelligence and command with Thales (CortAIx Lab). We are working with Aubert & Duval to make metallurgical products safer through innovation in non-destructive testing. Finally, our partnership with Dawex on industrial data spaces is driving innovation for sustainable and resilient ecosystems thanks to smart contracts and semantic hub technologies.

European infrastructures

Europe

The purpose of the DECIDE project, part of the European Chips Act to bolster Europe's semiconductor industry, is to create a European Design Platform. This virtual IC design platform is being developed by the CEA, Imec, Fraunhofer, and Chips-IT. DECIDE will help European startups, SMEs, and research institutes innovate and become more competitive in alignment with European Green Deal objectives. The platform will feature a marketplace, design centers, and customized access to electronic design automation tools, component models, and pilot lines.

DECIDE
Virtual design environment

- €25 million, 4 years
- 12 partners, 11 Member States: 4 national research organizations, 8 universities
- 4 pilot lines
- Integrated circuits, Photonics, quantum states, open source
- Support for startups and SMEs
- Europractice representative

Our innovation platforms

Companies can come to PRISM to innovate and receive support deploying industry of the future technologies. In 2025, PRISM will have a 600 sq. m smart interactive robotics testing lab, R2I. This agile and flexible facility is designed for testing industrial scenarios involving CEA-List's and partners' robotic technologies.

In 2022, the CEA's digital task force created the DeepLab collaborative systems and software engineering platform, offering requirements management, systems architecture, verification, and sharing tools. DeepLab, available in-house CEA-wide and on a collaborative site for our partners, will soon include digital user assistance agents.

PRISM

matters

PRISM Platform
Industry of the future

Capacity building
- €2.5 million invested in 2024

Ecosystems and projects
- Services for SMEs. 5 new services in 2024
- Projects under development

DeepLab
Collaborative engineering platform

- Development: 5 CEA units
- Requirements, design, IVV Complex software and systems
- 4 pilot use cases
- > 15 services rolled out
- Rollout across all CEA operational departments Q1 2025
- Open source

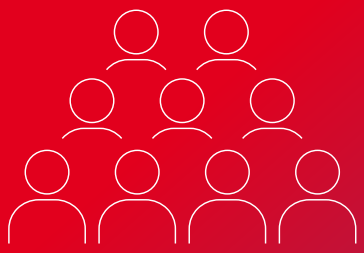
Objectives

- Support European startups and SMEs to increase chip design activities and maintain sovereignty in key areas;
- Build a pioneering virtual design environment that democratizes access to cutting-edge semiconductor design technologies;
- Foster a robust ecosystem of IC design houses across Europe to stimulate innovation, improve competitiveness, and support the rapid development and deployment of next-generation semiconductor technologies;
- Serve as a catalyst for cultivating a thriving chip design industry in Europe, making a significant contribution to the EU's digital and ecological agendas.

Budget
- €25M (4 years)

Consortium
- 12 partners
- 11 Member States
- 4 RTOs, 8 universities
- 4 pilot lines representatives
- Europractice representative
- IC, PIC, Quantum, Open source
- 76 support letters

2024 at a glance



Headcount

1,000
employees

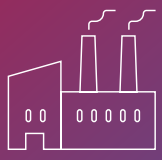
41 state-licensed research directors
3 senior fellows
(artificial intelligence, computing architectures, systems engineering)
12 fellows
61 senior experts
3 technical experts
110 experts
31 research directors
153 PhD students

Scientific output

300
A-rank publications

2,122
patents

80
new patents in 2024



Tech transfer

110
licensing agreements

29
startups created since 2003

200
corporate R&D partners per year

Partnerships

450
projects per year

€130M+
annual operating budget

80%+
of our external funding

Awards and distinctions

The COLIBRI proof program solver won first prize in three categories of the nineteenth SMT-COMP international equation satisfiability competition at CAV2024, the Computer Aided Verification conference, in July 2024 in Montreal, Canada.
https://smt-comp.github.io/2024/results/qf_abvfplra-single-query/
https://smt-comp.github.io/2024/results/qf_fplra-single-query/

CEA-List came in first in the EvalLLM 2024 competition, organized by the French Ministerial Agency for AI and Defense (*AMIAD*). The challenge, held at the JEPTALN2024 conference in July 2024 in Toulouse, France, was on the few-shot extraction of information from texts written in French using limited training data.
https://www.linkedin.com/posts/amiad-minarm_jeptaln2024-toulouse-llm-activity-7224338219838943234-fYR5/?originalSubdomain=fr

PyRAT won second prize for AI proof-of-reliability tools at the fifth VNN-Comp international neural network verification competition at CAV2024, the Computer Aided Verification conference, in July 2024 in Montreal, Canada.
https://arxiv.org/pdf/2412.19985

Jean-Marc Bordy won the 2024 *Prix LNE* for his major scientific contribution to the field of ionizing radiation metrology and, especially, dose metrology.
https://www.lne.fr/fr/recherche-et-developpement/prix-lne-recherche/laureats-2024

The Best Demo Award at the 2024 APCCAS conference in Taiwan went to our NeuroCorgi circuit, and, specifically, a paper by Ivan Miro-Panades et al titled "A 772µJ/frame ImageNet Feature Extractor Accelerator on HD Images at 30FPS."
https://www.linkedin.com/posts/cealist_iaembarqu%C3%A9e-neurocorgi-apccas-activity-7264940576322547712-c9Z8/

The SOFIA AI-enabled predictive maintenance solution (CEA-List, Socotec, and Sanef) won an award in the operations and maintenance category at Tech Show for Construction (organized by *Le Moniteur* and *Les Cahiers techniques du bâtiment*) in June 2024 in Paris, France.
https://www.cahiers-techniques-batiment.fr/article/palmares-tech-show-2024.71588

Social Dream won an Innovation Award in the Digital Health category for its DREAMSENS headset at CES 2024 in January 2024 in Las Vegas, Nevada, US. This virtual reality headset leverages CEA-List's interactive simulation technologies, adapting to the wearer's emotions for an immersive sensory experience.
https://www.ces.tech/ces-innovation-awards/2024/dreamsens/

CEA-List startup Snowpack won Startup of the Year at Forum Incyber Europe 2024 (formerly FIC) in March 2024 in Lille, France.
https://www.cea.fr/Pages/innovation-industrie/start-up/snowpack-anonymisation-securisation-donnees.aspx

Snowpack also won an Innovation Award at the 2024 *Assises de la Cybersécurité* in October 2024 in Monaco.
https://www.lesassisesdelacybersecurite.com/fr-FR/presse-media-asso/actualites-et-communique-de-presse/cp1-lesassises-2024, https://snowpack.eu/fr/quand-linvisible-devient-visible/

A Best Work-in-Progress (WIP) Award (honorable mention) went to E. Madoux and C. Hudin for their paper "Refreshable Braille display using wave focusing and bistable pins" at the EuroHaptics conference in July 2024 in Lille, France.

A Best Poster Award went to Marine Poret for her poster "Lab-around-fiber for detecting biological threats" at the 6th International Conference on CBRNE Research and Innovation in March 2024 in Strasbourg, France.

Hanane Slimani, PhD student, won a Best Student Paper Award for her paper "Detection, localization and characterization of fault in cable *via* machine learning approach based on compressed sensing time-domain reflectometry" at the IEEE Automatic Test Conference – AUTOTESTCON 2024 in August 2024 in National Harbor, Maryland, US. [DOI:10.1109/AUTOTESTCON47465.2024.10697515]
https://ieeexplore.ieee.org/author/625308984352659

PhD student Matilde Sosa Marti won a Best Paper Award for her paper "Point-by-point femtosecond fiber Bragg gratings behavior at high temperatures" at the Advanced Photonics Bragg Gratings, Photosensitivity and Poling in Optical Materials and Waveguides (BGPP) conference (AP/BGPP 2024) in July 2024 in Québec City, Québec, Canada. [DOI: 10.1364/BGPP.2024.BTu2A.3]

Vincent Fu, Lilia Zaourar, Alix Munier, and Marc Duranton won a Best Paper Prize for "Design Space Exploration of HPC Systems with Random Forest-based Bayesian Optimization" at the RAPIDO24 workshop at HiPEAC in Munich, Germany in 2024.
https://www.linkedin.com/posts/lilia-zaourar-koutchoukali_rapido24-munich-hipeac-activity-7155174425733058560-pvyW/

Hana Krichene and Rohit Prasad won Best Paper Hardware & Circuits for "A dataflow architecture with distributed control for DNN acceleration" at MECO'2024 & CPSIoT'2024 in June 2024 in Montenegro. [DOI : 10.1109/MECO62516.2024.10577802]
https://mecoconference.me/meco2024-cpsiot2024-conference-the-best-papers-awards/

A closer look inside the science

At CEA-List, our mission is to accelerate the digital transition for the benefit of society. Whether we are uncovering the next breakthrough or building innovative solutions, our research spans the physical and virtual worlds.

Our research programs

Our research programs, which focus on mitigating the environmental impacts of digital and on supporting French and European sovereignty, are designed to respond to the needs of the companies that partner with us. We strive to ensure that our programs keep pace with each scientific advance and adapt to a changing environment. Our researchers chart the technological course that guides the development of our ecosystem around ambitious projects and major infrastructure.

Our long-term vision of research translates into close cooperation with the academic community in leading France's national cloud, AI, and cybersecurity priority research programs and in the quest to overcome the scientific and technological barriers to quantum computing. We also run bold, high-risk research projects integrating approaches to cybersecurity addressing both hardware and software, the orchestration of distributed systems, generative AI for robotics, AI hardware accelerators, advanced instrumentation, and non-destructive testing.

Our mission of transferring new technologies to the market also includes monitoring and analyzing emerging needs and key challenges for applications in industries like defense, digital health, nuclear, and the factory of the future. Our eco-innovation activities, discussed in the chapter "Supporting societal transitions" of this report, support this mission. Together, these multiple perspectives create a fertile environment for synergies and cross-disciplinary cooperation between our teams and ensure our most innovative research is connected to the concrete and immediate needs of industry.

This chapter outlines our four research themes and zooms in on a selection of outstanding results. The following chapter is more centered on industrial innovations with additional examples.

AI-augmented non-destructive testing.

2024 advances

1 Systems engineering and digital twins

This research, which aims to speed up the development of reliable digital systems, is fundamental to the digital transition. Specifically, we are addressing software and complex systems engineering tools; safety and security assessment; and reliability, with approaches that integrate hardware behavior.
Precise modeling of software and systems architectures and their functional behaviors supports our research in this area. The resulting functional digital twins can accurately simulate complex systems and their software. Ultimately, these digital twins will make optimization and testing more efficient and provide formal proof of key safety and security properties.

2 Responsible artificial intelligence

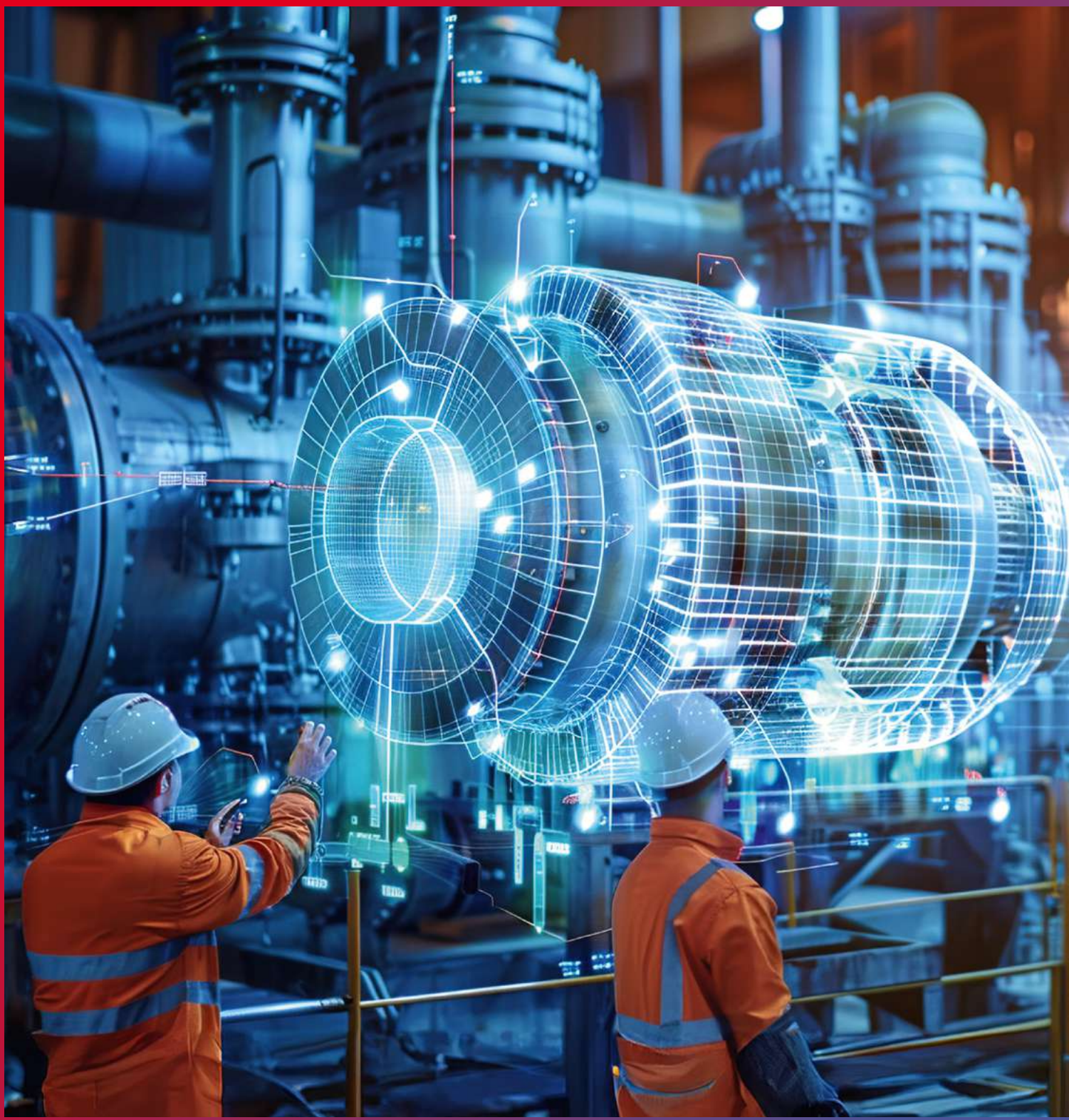
AI, which plays a vital role in many innovations, raises important questions around trustworthiness and frugality. Appropriate machine learning methods and algorithms will need to be developed, as will reliable theoretical frameworks for analysis. With the advent of large-scale foundation models like generative AI and their many potential uses, we must circle back to these issues now if we are to promote responsible machine learning that integrates this technological aspect of AI—and explore new use cases.

3 Advanced computing and distributed systems

The edge-to-cloud computing continuum raises multiple questions around hardware and software architectures and computing models. The most pressing challenges concern how to make more frugal systems also capable of delivering very high performance for cloud infrastructure, mid-level servers, systems, and sensors at the network edge.
The pace of advances in quantum computing is also accelerating, highlighting a host of new challenges related to both programming qubits and evaluating technologies.

4 Instrumentation and the factory of the future

Innovation in industrial systems and processes depends on data capture and processing. This requires the integration of instrumentation and advanced algorithms to form unbroken digital chains from sensor to system-level control. We are addressing challenges in sensor and sensor system design, signal processing—both as close to the source as possible and at the other end of the continuum, where higher-level control takes place. And, as the factory of the future takes shape, advanced robotics will be more efficiently and seamlessly integrated into systems. Here, the challenges will revolve around controlling human-machine interactions and machine-machine cooperation. The solutions will depend on advances at the crossroads between robotics, systems engineering, digital twins, and AI.

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Systems engineering and digital twins

CEA-List's systems engineering and digital twins research program takes a holistic approach to the system lifecycle. We leverage model-driven engineering to effectively manage the complexity of new, digital-intensive systems (see sidebar on DeepLab on page 7). This approach combines engineering and modeling to simulate systems and their interactions at all levels, from components to the environment. It can be used at all scales, from very large and distributed "systems of systems" down to individual semiconductor devices.
And, for safety- and security-critical engineering use cases where there is no room for approximation, MDE can be combined with formal methods based on unimpeachable mathematical foundations. (See sidebar on TwinSec on page 5.)

In 2024, our researchers produced three outstanding results that illustrate not only the challenges that exist, but also the kinds of advances that are possible:

SIMON TOLLEC
SECURITY ENGINEER THALES DIS

MATHIEU JAN
RESEARCH DIRECTOR
AND SENIOR EXPERT

DAMIEN COUROUSSÉ
SENIOR EXPERT

Analyzing robustness of secure systems against fault injection attacks: in processor micro-architecture

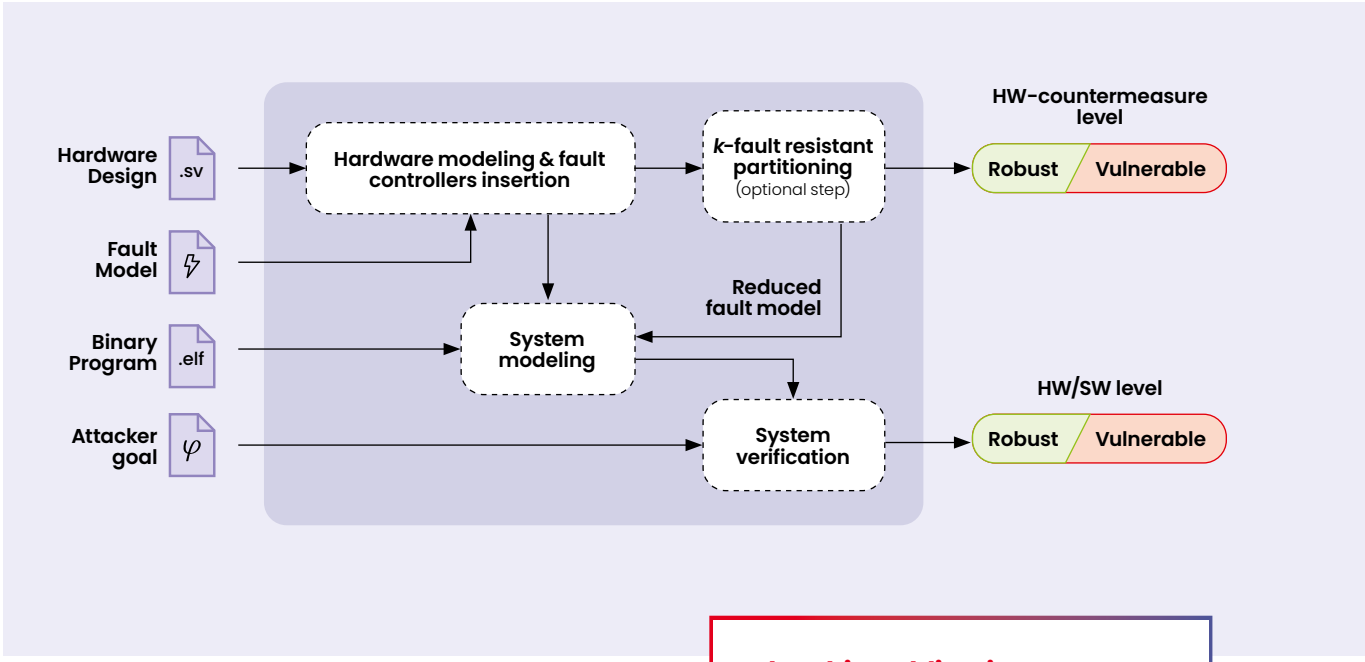
Fault injection attacks threaten the security of digital systems. CEA-List and Graz Technical University (Austria) developed a new pre-silicon analysis method that led to the world's first demonstration of the robustness of a processor and its boot code against these attacks.

Fault injection attacks exploit abnormal temperature, radiation, and other hardware parameters to disrupt systems-on-chip (SoCs), inducing errors that allow an attacker to access sensitive data or gain privileges. At the center of SoC security is the Secure Element (SE), conventionally verified through a post-silicon characterization, an approach that is not only costly, but that also produces variable results depending on the tester, tools, and other factors.
Pre-silicon analysis methods are needed to reduce security certification costs and turnaround times. The idea is to determine the extent to which the software and hardware countermeasures present can actually protect the SE. µArchiFI, developed by CEA-List, is a state-of-the-art pre-silicon analysis tool for assessing the robustness of SEs to fault injection attacks. To identify vulnerabilities or, on the contrary, formally prove that the system is robust, it uses a circuit description at Register Transfer Level (RTL), a fault model, a program, and an attack objective. Previously, µArchiFI only supported a limited fault model and around a hundred instructions—limitations that prevented the analysis of an SE's boot code under a fault injection attack.

Security analyses that were previously impossible

A method called k-Fault resistant Partitioning (k-FRP), developed in partnership with the Technical University of Graz (TU Graz), was added to our own analysis toolkit. The research led to the first-ever fault injection security analysis of OpenTitan, the first open-source SE developed by a consortium of digital systems and cybersecurity industry leaders. The addition of k-FRP (which will ultimately become an optional step in the µArchiFI workflow pictured above) made it possible to:

- Identify a previously-unknown vulnerability and formally verify that the OpenTitan design patch applied effectively corrects the vulnerability.
- Prove that the secure processor (an analyzed circuit size of 130 kilo-gate-equivalent) is robust to one fault injection.



CEA-List's pre-silicon analysis workflow for assessing robustness to fault injection attacks.

Finally, the research demonstrated that the only vulnerability identified by k-FRP was not exploitable in the 2,500 instructions of the first stage of OpenTitan's boot code. Prior to the development of this new approach, it was impossible to assess the security of this type of system, which is traditionally secured with redundant-hardware-type countermeasures.

A more realistic attacker model

Our pre-silicon analysis methodologies, integrating micro-architectural vulnerabilities, are central to the Forward project, part of the Campus Cyber tech transfer program (PTCC), and the TwinSec project, part of a special CEA program dedicated to bold, high-risk research, both of which started in late 2024. The goals are to compare such results to laboratory characterization data and to design a multi-level (physical, micro-architectural, and software) validation framework based on more realistic attacker models. Both projects address realistic multi-fault models and more complex processors.

Flagship publication

The A-ranked Workshop on Cryptographic Hardware and Embedded Systems (CHES) is one of the leading international security conferences.

Simon Tollec, Vedad Hadzic, Pascal Nasahl, Mihail Asavoae, Roderick Bloem, Damien Couroussé, Karine Heydemann, Mathieu Jan, Stefan Mangard

Fault-Resistant Partitioning of Secure CPUs for System Co-Verification against Faults. IACR Trans. Cryptogr. Hardw. Embed. Syst. 2024(4): 179-204 (2024)

The technology in use

Several manufacturers and also the French Cybersecurity Agency (ANSSI) have shown interest in our analysis methods. For example, ANSSI is evaluating the use of formal methods as part of its security architecture analyses of the OpenTitan SE.

Links to our µArchiFI and k-Fault resistant Partitioning methodologies

PATRICIA MOUY
CYBERSECURITY PROGRAM MANAGER
& LABORATORY MANAGER

Formal methods for program analysis

The ability to accurately assess software security is not only a security issue; it is a sovereignty issue, as well. CEA-List possesses a formal-methods-based toolkit that can help cybersecurity experts pinpoint vulnerabilities in software and prove that software protects data privacy and integrity—something that is required for the highest levels of software security certification.

To make systems more secure, CEA-List also develops software analysis tools using its Frama-C and BINSEC environments.

BINSEC for binary code cybersecurity

BINSEC applies symbolic execution to binary code to reveal security issues. Fixing all of the vulnerabilities in a program would be cost-prohibitive, so finding those most likely to be used by attackers is vital. The PyABD algorithm, a new feature in BINSEC, zeroes in on vulnerabilities tied to inputs that can be controlled by an attacker, as they are easier to take advantage of. Logical constraints designed to prevent vulnerabilities from being exploited are generated automatically by the BINSEC algorithm—proven correct, complete, and minimal—ensuring that each constraint generated reflects a bug's severity. The algorithm is better than existing techniques at determining bug severity, and the results are easier for evaluators to interpret. The research was presented at the Symposium on Principles of Programming Languages (POPL) 2024.
BINSEC is also being used in the SecurEval, Rev, and DefMal challenges, part of France's national cybersecurity program.


PREMIÈRE MINISTRE

Schéma français d'évaluation et de certification de la sécurité des technologies de l'information

CERTIFICAT ANSSI-CC-2023/45
Ce certificat est associé au rapport de certification ANSSI-CC-2023/45

MultiApp V5.1 Java Card Virtual Machine
Version 5.1

Développeur : THALES DIS FRANCE SAS
Commanditaire : THALES DIS FRANCE SAS
Centre d'évaluation : CEA - LETI

Critères Communs version 3.1, révision 5
EAL7

Date de validité : date de signature + 5 ans.

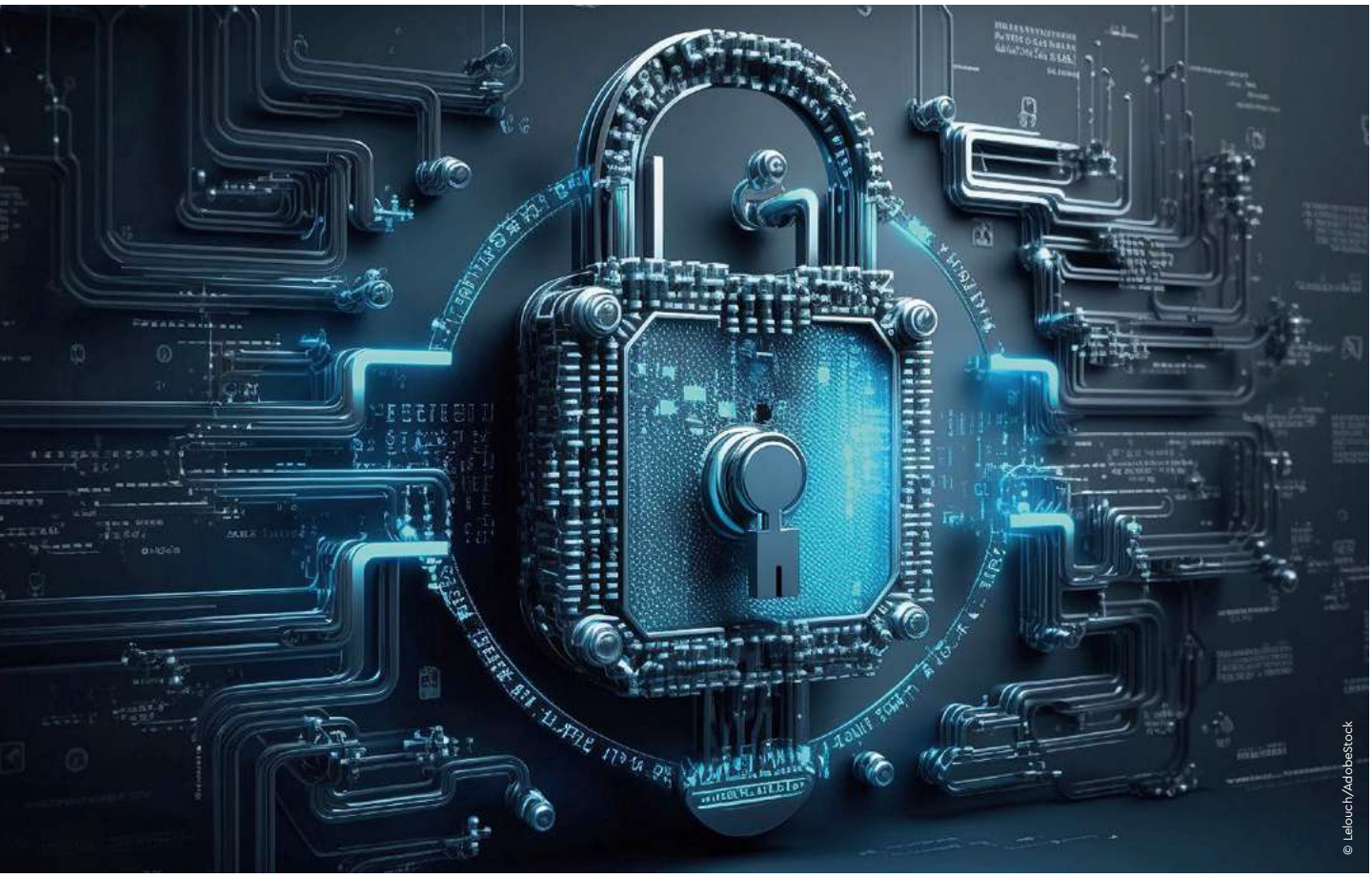
Paris, le 13 Novembre 2023

Le directeur général de l'Agence nationale de la sécurité des systèmes d'information
Vincent STRUBEL

Thales software earns ANSSI certification thanks to Frama-C.

"Whether it is to detect vulnerabilities or provide formal proof of security properties, having tools that can provide a high degree of assurance is a must in cybersecurity."

— **PATRICIA MOUY**



Formal methods for source code cybersecurity

Common Criteria, recognized internationally, is the most demanding security certification framework for information systems. The two highest levels of certification, Evaluation Assurance Levels (EAL) 6 and 7, require the formal verification of data privacy, integrity, and availability.

It was only natural for CEA-List researchers, with their broad, deep knowledge of both software security and formal methods, to tackle EAL 6 and 7. Leading digital security solutions provider IDEMIA turned to CEA-List and our experts for support with Common Criteria certification, leveraging a formal model separate from the code to obtain EAL 6 certification in the Netherlands in 2023. Thales, another leader in the security space, partnered with CEA-List on formal methods for security as early as 2015. One of the partnership's most recent innovations was to combine WP and MetACSL, two Frama-C plugins, to verify properties like data privacy and integrity. This led to ANSSI recognizing Frama-C as the third formal-methods-based tool capable of responding to the highest Common Criteria certification levels.

Using Frama-C, Thales was able to earn an EAL 6 certification for one of its products from ANSSI in 2021. EAL 7 certification was obtained in 2022. The fact that the proof is obtained directly from the product code makes the certification even more robust.

As these results show, formal proof has an important role to play in high-level security certification, and CEA-List is a key source of specialized methods and software. Frama-C is also being used in the SecurEval project, part of the national cybersecurity program. ANSSI and the French Directorate General for Armament are working with CEA-List experts on advanced software evaluation using Frama-C and BINSEC.

STÉPHANE SALMONS
RESEARCH ENGINEER PROJECT MANAGER & LABORATORY MANAGER

NACRE, a digital twin for the design of RTE's future power grid control system

CEA-List is working with RTE on the design of the power grid infrastructure operator's future power grid control system. As the proportion of intermittently-produced renewable energy on the grid rises, RTE's main challenge is to increase flexibility without compromising on safety or reliability. CEA-List used rigorous model-driven engineering to build a modeling, simulation, and analysis platform for the design of the new system.

Highly distributed renewable energy production—which cannot be managed—and the electrification of new use cases are growing. The grid must be able to adapt to an increasingly diverse and unpredictable landscape on both the supply and demand sides. CEA-List is working with RTE's R&D department to design its future power transmission control system—a major challenge in this context.

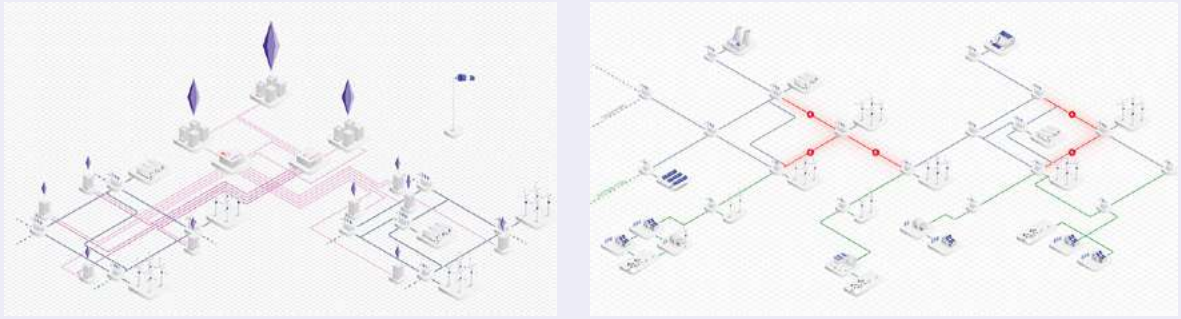
RTE's current transmission control system is made up of a local level, with line protection, and a national level, with dispatching, forecasting, and programming capabilities. To increase flexibility, RTE wanted to add a middle "area" level and make the control system more distributed and digital.

CEA-List drew on its experience modeling and simulating complex systems to arrive at the optimal functional and hardware architecture to deliver the desired flexibility, reliability, and safety performance. With expertise spanning

© Matthew Henry / Unsplash

"What made the NACRE platform a success? Our know-how in model-driven engineering, our ability to integrate a wide range of technologies, and the quality of our collaboration with RTE."

— **STÉPHANE SALMONS**



The NACRE demonstrator.
Left : power transmission control architecture modeling.
Right : power grid simulation.

model-driven engineering, system architecture, real-time simulation, formal methods for distributed systems, and smart grids, CEA-List was ideally positioned to tackle this project. The result is a modeling and simulation platform and associated analysis method for RTE's target control system.

The platform, built using CEA-List's open-source systems engineering software Papyrus, enables the rigorous modeling and simulation of various possible control system architectures. Simulations can be run to observe how an architecture will behave in different unforeseen event scenarios.

Modelling was completed in three stages:
1) Power system control architecture;
2) Computing and network architecture;
3) Unforeseen event scenarios.

The following three aspects of the situation modeled are then simulated:
1) Each control device's behavior, based on RTE's predictive control algorithms;
2) Routing of messages over the communication network, including unforeseen events;
3) The physical state of the power grid, including any electrotechnical equipment (generators and batteries) connected to the grid.

The results of the simulation are then evaluated according to safety and performance criteria like the risk of line damage or energy losses, for example.

The NACRE platform was implemented by CEA-List and RTE in 2024 to test two architectures, one centralized and one distributed, on five control areas in scenarios that included unforeseen events.

The NACRE program was extended for an additional three years at the end of 2024.

Although NACRE was designed to meet the needs of RTE, it is based on methods and tools that can be applied to a variety of use cases. With some adaptations, the same kind of platform could be developed for other energy systems. The gas distribution network, which, with the arrival of biogas, is affected by flexibility-related challenges similar to those of power grids, is one particularly relevant example.

Publications

"Modelling and simulating new power grid control architectures"
Arnaud M., Lapitre A., Lhuillier Y., Salmons S., Smaoui A., Giraud G., Guerrier A.
ISGT 2023, Grenoble

"A Domain Specific Language to Design New Control Architectures for Smart Grids"
Smaoui A., Arnaud M., Salmons S., Giraud G.
MODELSWARD 2025 (Best poster)

"Modeling and Simulating Power Grid Control Architectures: Hypotheses and First Results"
Arnaud M., Lapitre A., Lhuillier Y., Salmons S., Smaoui A., Tessier P., Giraud G., Rahmoun A.
POWERTECH 2025

Responsible artificial intelligence

CEA-List's responsible AI program—strongly rooted in our history of research on the foundations of AI—brings scientific excellence to two topics vital to our AI strategy: trust and frugality. Our research on digital trust, one of our main focus areas, grew out of the CEA's decades of experience with software safety and security. The CEA-List researchers working on responsible AI address the issue holistically. This chapter will highlight two major research topics: The first is the operating safety and verifiability of AI-based critical systems; the second is the coupling of AI with simulation models in which model imprecisions are an issue—something that is especially relevant to signal processing. Frugal AI, another challenge, is addressed from a use-case perspective. Here, natural language processing and computer vision stand out as particularly salient examples of AI use cases. Our researchers develop design methods—from data through to algorithms—capable of delivering both performance and frugality. These methods also address today's generative-AI-based approaches. The idea is to enable specialization and performance in specific operational situations by bypassing crude generalist solutions.

Over the course of the year, we reported five major advances:

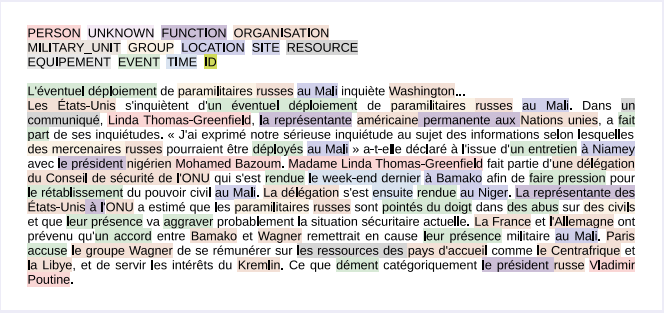
ROBIN ARMINGAUD
RESEARCH ENGINEER

ARTHUR PEUVOT
RESEARCH ENGINEER

First prize in the EvalLLM text-based information extraction challenge

The CEA won the EvalLLM 2024 challenge, organized by the French Ministerial Agency for AI and Defense *(AMIAD)* in May 2024. The challenge was to extract information from texts written in French using limited training data. Our researchers demonstrated that it is possible for encoder-type language models of limited size to significantly outperform very large generative language models.

1



The focus of the EvalLLM 2024 challenge was to evaluate neural-network-based models for named-entity recognition, a cornerstone task of information extraction. This evaluation was carried out in a few-shot setting (in French, where there is much less available annotated data than in English). In real-world information extraction, it is very rare to have enough annotated data to adapt traditional supervised learning models. For this reason, participants only had four newsletters and a blog post to work with.

The most pressing issue is whether large generative language models are better than much smaller encoder-type language models for few-shot environments of this kind. To find out, the CEA researchers used two models: GoLLIE *(Sainz et al., 2024)* and GLiNER *(Zaratiana et al., 2024)*.

GoLLIE, based on the Code-LLaMA 13B generative model, turns the named-entity recognition task into a code-generation task *via* prompts similar to Figure 2.

GLiNER, on the other hand, based on BERT-type encoder models, learns to map representations of candidate entity mentions to representations of possible entity types, which are used as prompts, as seen in Figure 3.

Both models are pre-trained on a large scale using English-language datasets unrelated to the target domain of the evaluation. For GoLLIE the training data was manually annotated; for GLiNER it was automatically generated using ChatGPT.

GLiNER clearly outperformed GoLLIE on the evaluation task, with a gain of 62% on the macro-F1 evaluation and 118.6% on the micro-F1 evaluation.

It also outperformed the—much larger—GPT-4o model used by the team that came in second in the challenge (Figure 4).

As part of EU-funded projects in progress, we are investigating how to apply the results obtained for this competition to safety data. And, as part of the French national AI initiative's Sharp project on frugal AI, we are looking for ways to improve the few-shot performance of the GLiNER model.

2

```
@dataclass
class Function(Entity):
    """Désigne les rôles, titres ou fonctions occupés par des individus, y
compris les titres professionnels,les grades militaires et les fonctions
nommées. Cette classe englobe les fonctions, les titres et les grades
militaires, ainsi que les individus désignés par leur profession."""

    span: str  # Such as: "Président de la France", "Chef Chirurgien", "PDG
de la société XYZ", "Chef Pâtissier Exécutif", "Docteur", "Ingénieurs",
"Professeur", "Général de la 2e division", "Capitaine", "Manager"
```

```
# This is the text to analyze
text = "L'ambassadeur à Séoul a pris la parole sur la situation"
```

```
# The annotation instances that take place in the text above are listed here
result = [
    Function (span="L'ambassadeur à Séoul")
]
```

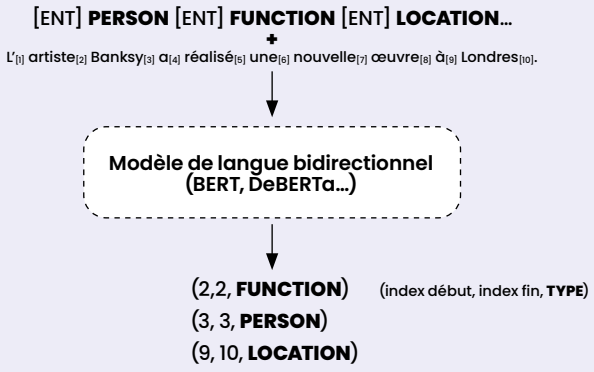
1 A sample of text, from the challenge, submitted by the French Ministerial Agency for AI and Defense
(Source https://evalllm2024.sciencesconf.org from https://cf2r.org/wpcontent/uploads/2021/10/Renseignor1203.pdf)

2 Prompt for the GoLLIE model

3 GLiNER model

4 Evaluation results (performance increases with the value of both indicators)

3



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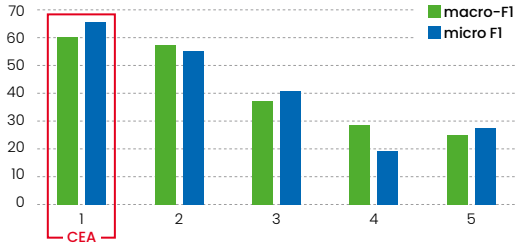

TIAM (Text-Image Alignment Metric): measuring visual generative AI performance

When it comes to AI image generation, impressive results can be achieved with text-conditional models like Stable Diffusion. However, their capacity to take into account text-based instructions is not always evaluated precisely. We developed a new metric (the Text-Image Alignment Metric, or TIAM) that is based on two key elements: the controlled generation of text-based prompts and image analysis. The goal is to determine how well a model adheres to the number of objects or color specified. We studied the six most commonly-used existing AI models to demonstrate their still-limited ability to follow a prompt that involves more than one object. This ability is even more limited when the prompt includes a color. TIAM is a useful tool for studying the influence of AI training parameters on the comprehension of and compliance with prompts. It also paves the way toward new research on noise mining—techniques to identify the "right" noises with a view to improving AI output.

Major projects

The CEA is contributing its research on few-shot named-entity recognition models to the EU VANGUARD, ARIEN, and STARLIGHT projects, which address the field of security. Ultimately, these models could be used to scan text on social media for signs of criminal activity.

Flagship publication

"CEA-List@EvalLLM2024: prompter un très grand modèle de langue ou affiner un plus petit ?"
Robin Armingaud, Arthur Peuvot, Romaric Besançon, Olivier Ferret, Sondes Souihi and Julien Tourille
EvalLLM2024 : Atelier sur l'évaluation des modèles génératifs (LLM) et challenge d'extraction d'information few-shot, Toulouse, France.

EIJI KAWASAKI
RESEARCH ENGINEER

HAN WANG
RESEARCH ENGINEER

Quantitative measurement of uncertainties in artificial-intelligence-guided simulation

CEA-List's probabilistic deep learning tools can be used to quantitatively measure prediction reliability. This advance will enable innovative solutions to the problem of predictive uncertainty—a hurdle to the implementation of AI in numerical simulation.

The ability to combine machine learning and numerical simulation in hybrid tools will facilitate major scientific advances in computational physics. Numerical simulation, for instance, is used to probe the microscopic properties of materials. However, this approach is currently limited by the complexity of calculating atomic energies and forces. To get around this computational complexity, we are using deep learning models to predict costly quantities, for faster simulation.

Although deep learning models do a good job at predicting, their inherent uncertainty introduces a bias into the calculation of physical observables from the simulation. This is because machine learning itself is based on a set of observations used to fine-tune a model with uncertain parameters. This epistemic uncertainty and the resulting bias currently constitute one of the main hurdles to the implementation of AI in numerical simulation.

Our methods for quantitatively measuring uncertainty in predictions by neural networks are intended to support innovative new simulation-bias-correction techniques. Using Bayesian statistical inference, we are able to calculate the probability that a particular neural network setting will be correct given the limited number of observations available. This probability depends on the noise that the data may contain; this second uncertainty is called aleatoric.

Calculating neural network uncertainty

The method is encapsulated in our CAUTIONER *(unCertAinty qUanTificatIOn Neural nEtwoRk)* software, which can calculate the uncertainty of a neural network by transforming it into a Bayesian neural network, which is defined by a distribution of probable weights and biases. This new model cannot be "trained" using conventional algorithms. CEA-List researchers drew on our extensive know-how in probabilistic programming to develop CAUTIONER, which is based on Markov Chain Monte Carlo (MCMC) methods—the gold standard for calculating predictions and their uncertainty. CAUTIONER is available from the CEA in the form of a Python library with all APIs, documentation, and a graphical interface to facilitate its use on GPU-based clusters.

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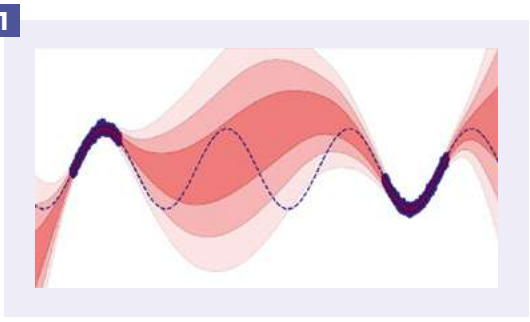

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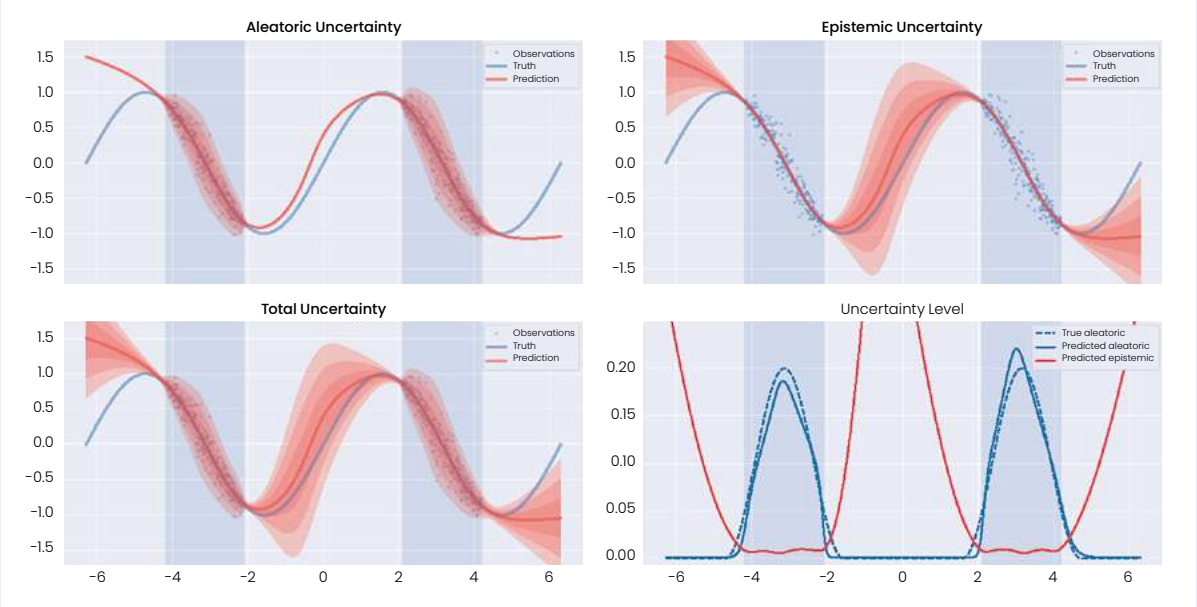
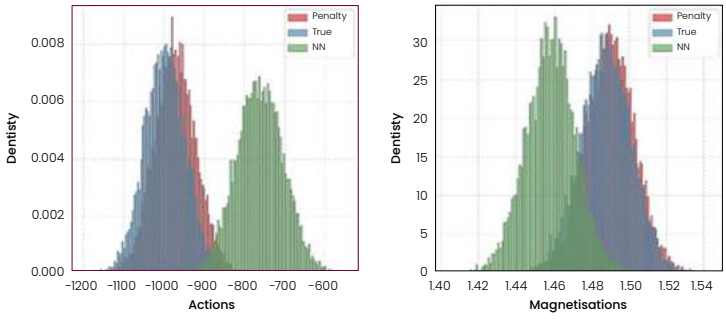


Assessing prediction uncertainty

We are also developing new probabilistic deep neural networks with a Bayesian Last Layer (BLL), a version of the classic Bayesian neural network in which only the last layer is probabilized. This offers the unique advantage of enabling the evaluation of prediction uncertainty—which can be calculated analytically—by design. This led to the development of a powerful EM (Expectation Maximization) optimization algorithm for learning neural network parameters.

With uncertainty correction tools like these, bias corrections for the numerical simulations mentioned above can be designed, opening the door to scientific advances in computational physics and materials science.

3



1 **For predictions far from the training data (blue dots), uncertainty increases (light red).**

2 **Aleatoric and epistemic prediction uncertainty of a neural network.**
Source: Figure in H. Wang *et al.* (arXiv:2405.01761)

3 **A physical property obtained by costly simulation alone (red) compared with one obtained by hybrid physical and AI simulation (green). CEA-List developed a hybrid technique combining physical and AI simulation (blue) that corrects the bias introduced by prediction uncertainties.**

AUGUSTIN LEMESLE
RESEARCH ENGINEER

JULIEN LEHMANN
RESEARCH ENGINEER

PyRAT wins formal verification competition

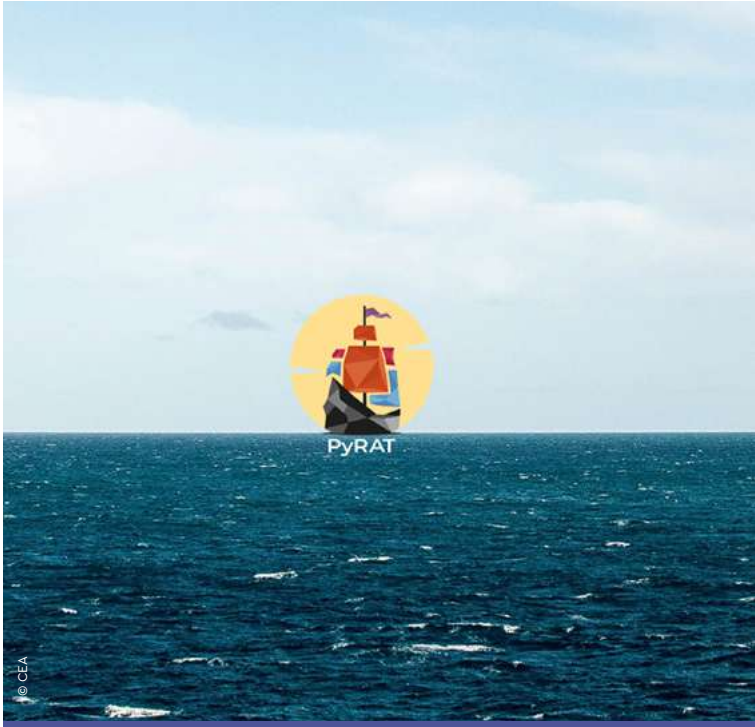
CEA-List researchers developed PyRAT, a formal verification tool for neural networks, to respond to growing demand for more reliable AI-based systems. PyRAT came in second in the VNN-Comp neural network verification competition at CAV'24, the Computer Aided Verification Conference.

AI is making increasing inroads into the systems we use every day. But AI deployment in critical systems, where there is no room for even the smallest malfunction, will be the true marker of the technology's success. With potential costs that include not only economic losses, but also irreparable harm to people and the environment, the need for software certification is pressing. Put simply, users need to know that software will behave as specified in nominal operating conditions.

CEA-List researchers are developing formal verification tools for software containing artificial intelligence. Formal verification provides robust mathematical proof of how an AI works. This assurance is vital to deploying AI in industrial and other operational environments. Our PyRAT formal neural network verification tool was created in 2019 for precisely this purpose.

PyRAT can formally verify the stability of a neural network whose inputs are exposed to minor disruptions. In automotive computer vision systems, for instance, PyRAT can verify that a neural network in charge of recognizing road signs will still work as intended in rain or low light.

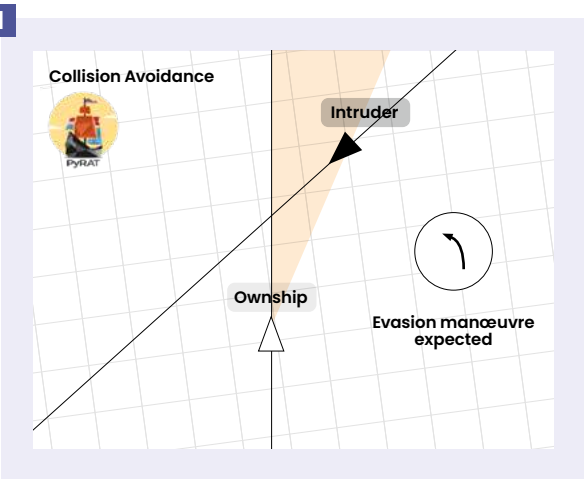
PyRAT can also verify that a neural network respects certain requirements in its specifications (as long as the requirements can be expressed using mathematical formulae).



"Our second-place win at VNN-Comp is validation that PyRAT is effective at ensuring the safety and security of AI-based systems."

— **AUGUSTIN LEMESLE**

1



Excellence in academic research

This type of verification is notoriously complex. PyRAT uses conventional abstract interpretation methods plus software optimizations (GPU parallelization, matrix operations, etc.) specific to neural networks. PyRAT also features an accurate representation of complex neural network operations. This reduces abstraction errors during analysis. And, thanks to an iterative "divide and conquer" approach and new optimization methods, PyRAT has become much faster and more accurate in just a year. PyRAT has been used in the VNN-Comp, the international neural network verification competition, for two years running, coming in third in 2023 and second in 2024.

The wins mark the research community's recognition of PyRAT as a top-tier tool—already deployed in industrial use cases—and reinforces CEA-List's position as a leader in formal verification. What is next for PyRAT? We plan to continue to improve the tool's performance and expand into new, more complex types of neural networks (recurrent, transformer, etc.). Finally, adaptations will be made to PyRAT so that it can be used for embedded (quantized) neural networks.

Use cases and applications

Technip Energies
Safety assessment of an anomaly detection neural network for offshore drilling platforms

Renault
Image-based weld robustness assessment on an automotive manufacturing line

Airbus
Safety of embedded neural network for drone collision avoidance

Major projects

France 2030 - Confiance.ai
PyRAT scaleup & use cases

ANR - DeepGreen
Quantized neural network safety and robustness

Horizon Europe - TRUMPET
Neural network verification use case including the privacy of data in federated learning

Flagship publications

"Reciph: Relational coefficients for input partitioning heuristic"
WFVML 2022

"A study of an ACAS-Xu exact implementation using ED-324/ ARP6983"
ERTS 2024

Technical report

"Neural Network Verification with PyRAT", ArXiv preprint 2410.23903

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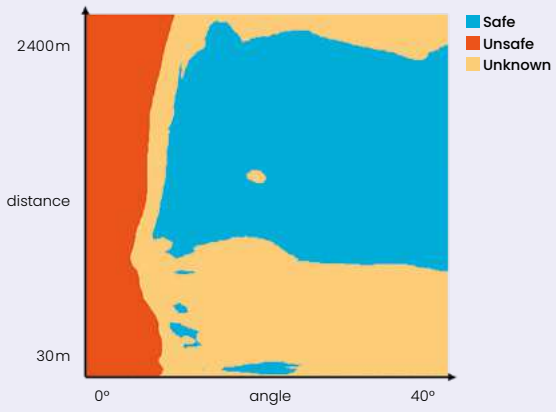


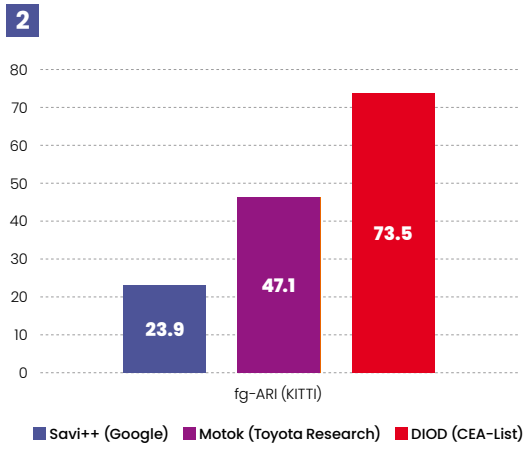
1 PyRAT analysis of a UAV avoidance AI.
© CEA

2 PyRAT effectively determines in which situations the AI behaves as expected.
© CEA

SANDRA KARA
PhD CANDIDATE

DIOD (Self-Distillation Meets Object Discovery) boosts the performance of unsupervised object discovery in videos

One of the fundamental tasks in computer vision use cases is the location of objects of interest in video footage. One of the stumbling blocks to the development of AI in this field is the need for large amounts of annotated data to train the models to perform the task sufficiently well. The principle of object discovery is the location of objects without the need for human-annotated data. And, unlike conventional object detection systems, object discovery can handle unknown object classes.



When self-distillation meets object discovery

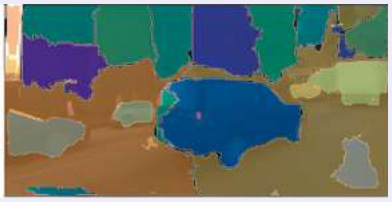
Low-level signals like motion or depth information can be used to discover objects in an image or in video—without resorting to manual annotation.

Our research focuses on motion-guided object discovery, which presents several technical challenges. First, by definition, the motion information used as a source of supervision does not target static objects. This creates difficulties generalizing to these objects. Second, camera movement generates noise that makes it hard to distinguish moving objects from parts of the background that appear to be moving.

We looked to self-distillation—a concept yet unexplored for object discovery—to address these challenges. Self-distillation depends on a teacher model used to automatically label unannotated images, and a student model, which learns to solve the main task using data annotated either manually or by the teacher model. The teacher-student setup makes it possible to learn from new unannotated data. The quality of the pseudo-labels initially generated by the teacher model gradually improves.

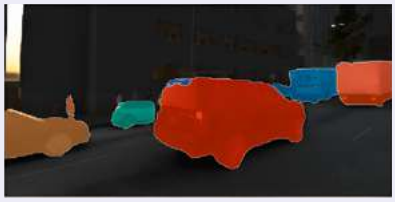
DIOD is the first method to combine self-distillation with object discovery. With the teacher-student architecture, the

Input image



Bao *et al.* (Toyota Research)

BMOD (CEA-List)



DIOD (CEA-List)

1

teacher model can be updated depending on what has been learned by the student model, which discovers objects from two sources: the teacher's attention maps, which include a confidence rating to ensure that only those objects with the highest level of confidence are kept; and the movement masks, from which noisy segments have been removed. The pseudo-labels are gradually improved, increasing overall performance during learning. This approach addresses the previously-mentioned technical challenges. The discovery of static objects (like parked cars) that the teacher has been able to generalize can be learned, and the noise generated by camera movement is reduced substantially by the filters applied.

DIOD outperforms other state-of-the-art methods by a comfortable margin (+18.8 points for fg-ARI, +43.8 points for all-ARI, +8.9 points for the F1@score on the KITTI dataset). It is more effective at discovering both moving and static objects, eliminating the noise present in the background, and distinguishing between adjacent objects of the same semantic class.

These capabilities make DIOD a high-performance object discovery method that requires no manual annotation. DIOD could be used to automate annotation, either reducing the cost of annotation or eliminating it entirely. It could also be used for 3D point clouds of LIDAR data, a potentially very useful automated driving application, and for the discovery of 2D or 3D objects using a multi-mode model to get the best of 2D RGB images and 3D LIDAR data, for example.

1 **Comparison of object discovery predictions of three state-of-the-art methods on a TRI-PD dataset image**
© CEA

2 **DIOD outperforms other state-of-the-art unsupervised object discovery methods.**
© CEA

Key features

Discover moving objects without human annotation

Smart pre-annotation of moving objects

Patent DD24102 CJ

Flagship publication

"DIOD: Self-Distillation Meets Object Discovery."

Kara, S., Ammar, H., Denize, J., Chabot, F., and Pham, Q. C. (2024).
In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (rang A*)

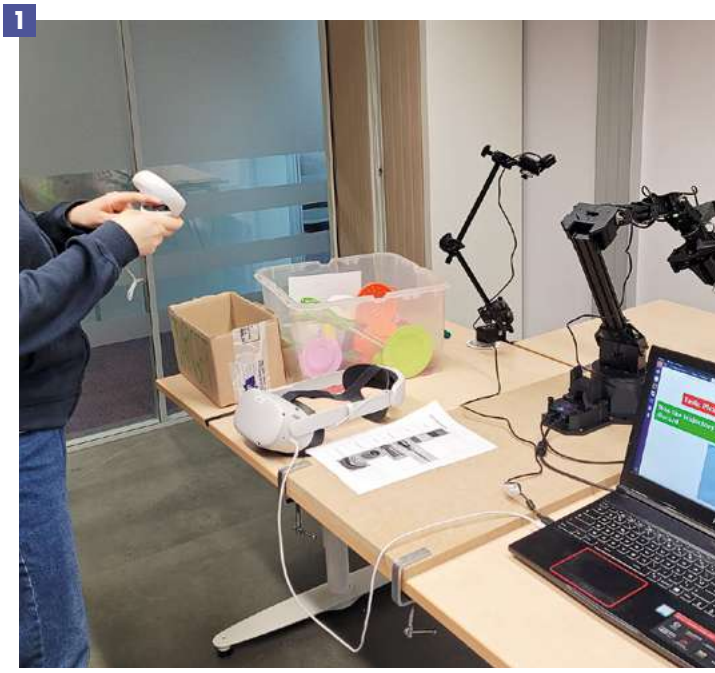
CAROLINE VIENNE
DEPUTY DEPARTMENT HEAD
© CEA

JAONARY RABARISOA
RESEARCH ENGINEER
© CEA

Generative AI successfully applied to robotic grasping

CEA-List's smart robotics demonstrator highlights generative AI's potential as an enabler of robotic tasks whose instructions are given in natural language. Our researchers designed a robotic handling agent that leverages computer vision and deep learning to accurately execute a grasping task based on a high-level natural-language instruction.

1



The purpose of the research was to design a software module that would give robots the ability to understand and execute tasks based on instructions given in natural language or provided in images. The principle is to translate intuitive interactions into specific physical actions.
We integrated a generic, or foundation, transformer AI model that had been pretrained on a large dataset of robot trajectories. We then refined the model on our own data to improve performance on the target tasks. The model we ultimately selected, Octo [1], adapts efficiently to various robotic configurations, requires relatively little data, and is reasonable in terms of computing resources. What makes Octo so flexible is a modular attention structure that allows the model to adjust to the specificities of the target tasks with ease. This in turn improves generalization to and performance on a wide range of robotic tasks.

We also developed a remote operation mode to gather data specific to the robotic grasping task at hand. The system is built on a lightweight six-axis robot remote controlled using a virtual reality joystick, enabling precise, intuitive handling—essential for quality data acquisition. To generate the actual data, volunteers performed robotic grasping tasks involving a dozen objects handled in four distinct spatial configurations. The diversity of objects and spatial configurations is important to ensure that the data is representative of real-world tasks and to give the robot an opportunity to learn on a wide variety of handling scenarios. CEA-List's PIXANO software was used to "clean" the data gathered, correcting any annotation errors. The Octo model was then fine-tuned using a cleaned training dataset containing 678 trajectories and a test dataset of 70 trajectories. Once trained, Octo was successful at identifying and

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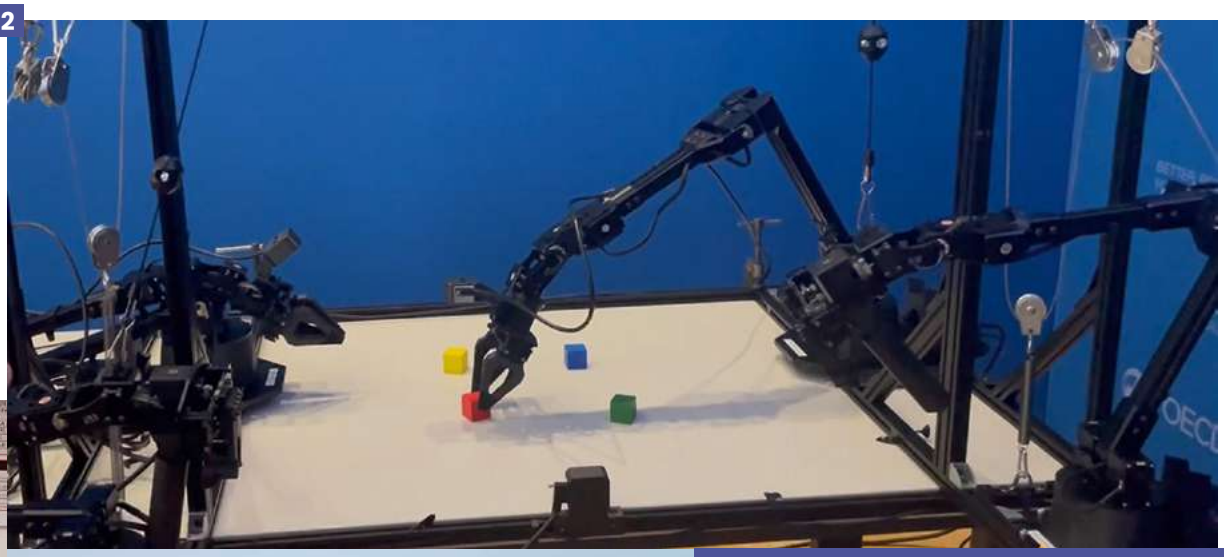


3

grasping an object from the training dataset placed either alone or with distractor objects, without a dedicated 3D perception system.
Research on more complex tasks, including bimanual object input, is underway.

[1] Octo Model Team, D. Ghos, H. R. Walke, K. Pertsch, K. Black, O. Mees, S. Dasari, J. Hejna, T. Kreiman, C. Xu, J. Luo, Y. L. Tan, P. R. Sanketi, Q. Vuong, T. Xiao, D. Sadigh, C. Finn and S. Levine, Octo: An Open-Source Generalist Robot Policy, ArXiv, 2024, https://api.semanticscholar.org/CorpusID:266379116

"These advances came out of our research on intuitive programming, the purpose of which is to help make robotics more accessible to operators without specialist knowledge or training."

— **CAROLINE VIENNE**

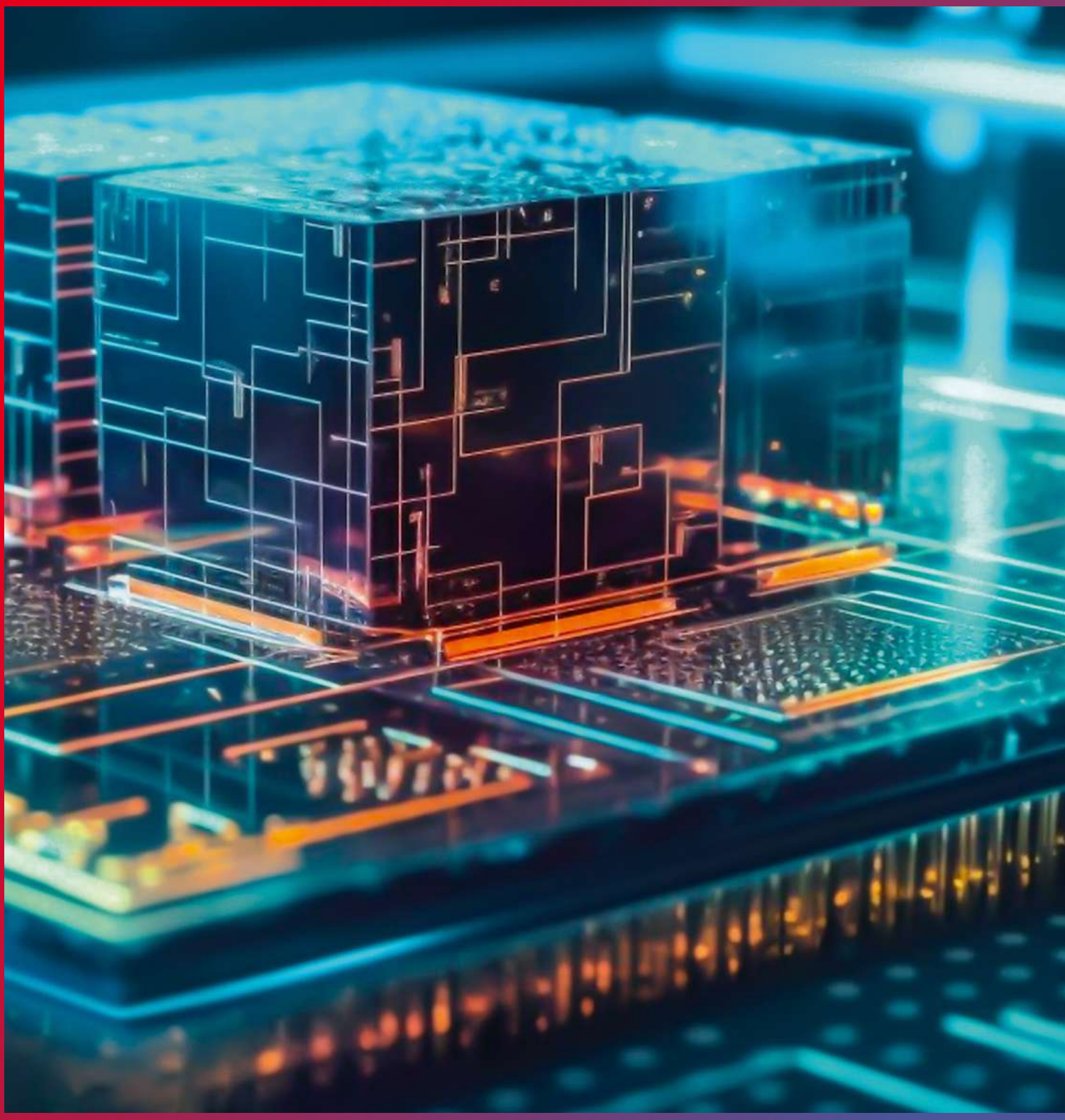
"The goal of our research is to leverage artificial intelligence to develop robotic systems that are robust, accessible, and rapidly deployable in industrial settings."

— **JAONARY RABARISOA**

1 **Data acquisition session.**
© CEA

2 **Demonstration of end-to-end robotic input at the OECD's AI Working Day.**
© Nikolas Schmidt

3 **Grasping a target object among distractor objects.**
© CEA




© AdobeStock - VicenSanh

Advanced computing and distributed systems

In today's hyper-digital world, demand for processing power and data storage is on the rise. With more and more functions being performed digitally, data processing is becoming more complex and moving closer to the source. Reducing power consumption is a must in these scenarios.
At CEA-List, we are investigating:

- Getting the full potential out of new microelectronic and nanoelectronic technologies to enable high-performance, ultra-low-power computing with the capacity to substantially reduce datacenter GHG emissions;
- Software-hardware co-design of computing architectures with the goal of integrating AI and other functions in SoCs at the network edge, close to the data source.

This research is backed by a European design platform created to speed up exploration and design of innovative computing solutions (see sidebar on DECIDE on page 7).
The edge-to-cloud continuum is another pressing need driven by massive digitalization. We are tackling this issue through research programs on data collection and transmission from edge devices to local servers, or to the cloud. This will require advances in communication layer abstraction, orchestrator implementations, and data traceability and security mechanisms. Major projects OTPaaS and Data4IndustryX, mentioned on page 6, are addressing these specific challenges.
The potential contributions of quantum-enabled approaches are raising new questions on computing, programming, compilation, and performance evaluation, as explained in the sidebar on the QLoop project on page 5.

Over the past year, we produced three major results in quantum computing, embedded computing, and cloud-based high-performance computing (HPC):

STÉPHANE LOUISE
RESEARCH DIRECTOR
AND SENIOR EXPERT
© CEA

FÉLICIEN SCHOPFER
QUANTUM PROGRAM DIRECTOR,
LNE

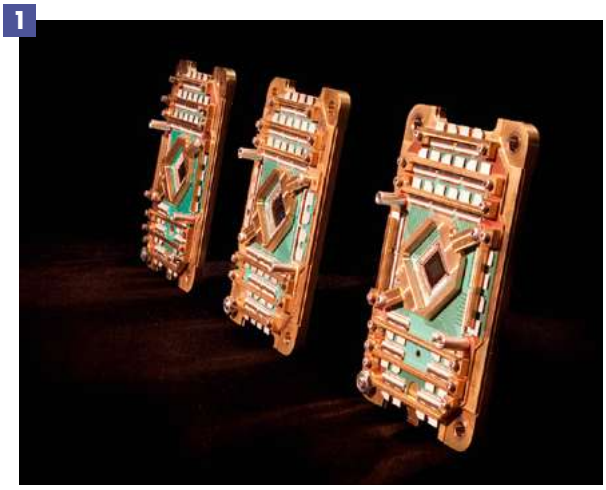
Proof-of-value: generalizing the evaluation of several quantum processors (QPUs)

Quantum computers, which promise to speed up computation exponentially for certain use cases, are now a reality. Today's quantum computers, plagued by noise, have not yet delivered on their expected capabilities, however. The most advanced quantum computers have already gone beyond the proof-of-concept stage—but that doesn't mean they are ready for practical use cases. We have entered the performance evaluation era, where the goal is to measure the gap between the current state-of-the-art and quantum utility (QU).

The entire history of classical computing has been guided by performance measurement, with evaluation tools like the SPEC® benchmark for CPUs and the BLAS benchmark, the most-cited benchmark in the Top 500 ranking of GPUs. It is still early days in the world of quantum computing, however, and a quantum-specific benchmark has yet to emerge, making performance evaluation a crucial issue for the coming years.

The MetriQs-France quantum initiative, part of the national France 2030 plan, includes a project called BACQ_, which will produce the building blocks of a future application-focused QPU evaluation method that could lead to standards at the European (CEN/CENELEC) and international (ISO/IEC) levels.

1



The tests included in the benchmark will focus on optimization problems, solving linear systems, prime number factorization, and quantum simulations of N-body problems—believed to be the four cornerstones of tomorrow's quantum computing use cases. CEA institutes List, Irig, and IphT are cooperating on these use cases.

A large amount of flexibility must be allowed in how the tests are implemented. This is to make sure the advantage of a given technology for a specific use case can be assessed while still ensuring that the test is fair. The overriding objective is to leverage the full advantages of each family of QPUs. This will also require specific expertise for each architecture. The planned approach is relevant to a wide range of QPU technologies, both gate-based and analog (i.e., quantum simulators). It will also remain robust even as QPUs advance

Major projects

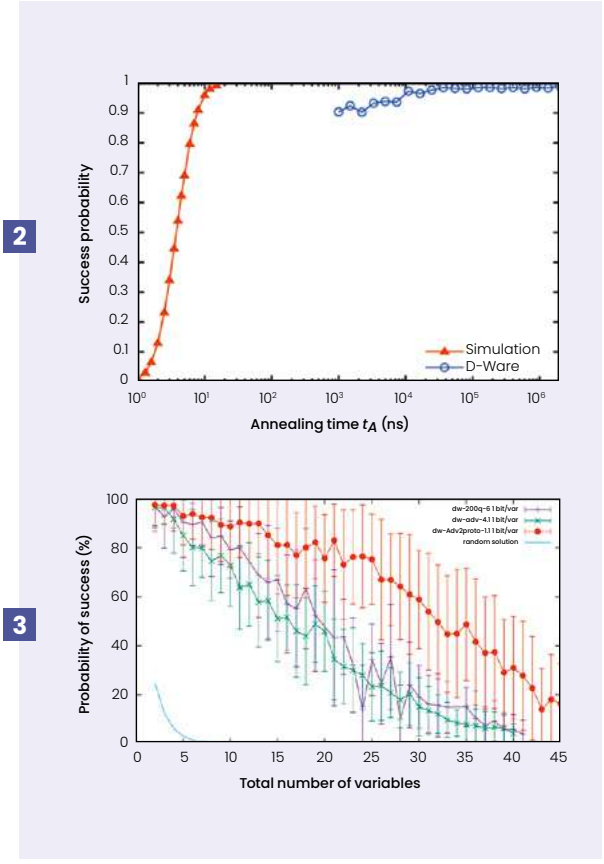
Expertise in optimization problems and solving equation systems by quantum annealing

Partnerships

Thales, Eviden, LNE, CNRS

Joint research

FZ Jülich (AIDAS project)



1 Three D-Wave 2000Q processors.
© D-Wave

2 Comparison of theoretical adiabatic and actual quantum annealing processes.
© CEA

3 Comparison of performance improvements over three generations of QPUs.
© CEA

toward fault-tolerant quantum computing (FTQC).
Recently, a hallmark optimization problem, maximum cardinality matching/Gn series [1], was studied in detail with the quantum computing team at ZF-Jülich, Germany's largest HPC center. The solving of linear systems using DWave® quantum annealing [2] was also studied.
A list of best practices for using DWave® QPUs was produced as a result of the first study, along with an overview of the QPUs' capabilities and limitations for solving the problems for which they are specifically designed. The second study revealed that, for problems that these QPUs were not initially intended to address, they ultimately bring a polynomial advantage over classical computing—under certain conditions.
These results can be considered the first building blocks of a future QPU benchmark.

[1] Daniel Vert, Madita Willsch, Berat Yenilen, Renaud Sirdey, Stéphane Louise, Kristel Michielsen: **Benchmarking quantum annealing with maximum cardinality matching problems.** Frontiers Comput. Sci. 6 (2024).
[2] Stéphane Louise: **Benchmarking Quantum Annealers with Linear System Solving**. QCE 2024: 1149–1155.

"Fault-tolerant quantum computing (FTQC) is a prerequisite to potentially exponential acceleration. However, noisy intermediate-scale quantum (NISQ) is already creating potential polynomial acceleration in certain applications, opening the door to quantum utility (QU)."

— **STÉPHANE LOUISE**

"In the minds of the general public, there are a lot of myths around quantum technologies. It is up to science and, especially, metrology, to provide the information needed for people to be able to trust quantum. This is exactly what the CEA, Eviden, Thales, and Teratec are trying to do as part of this project, which will provide a framework for evaluating the performance of QPUs for specific use cases."

— **FÉLICIEN SCHOPFER**

SÉBASTIEN THURIES
CO-DIRECTOR, IRT SMART IMAGER
@NANOELEC AND EXPERT
© CEA

BENOIT TAIN
RESEARCH ENGINEER
© CEA

J3DAI, an advanced three-layer integration architecture for a CMOS image sensor

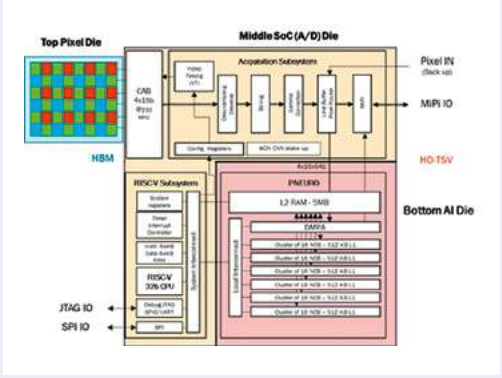
Smart imagers are revolutionizing the acquisition and analysis of visual data with real-time image capture and processing capabilities. Embedded AI, designed to run in the constrained hardware environment of a sensor, performs data processing locally, leveraging 3D integration to ensure the rapid movement of data.

3x
improvement in MAC efficiency and silicon surface area

A smart imager architecture based on a new three-layer integration was developed for the IRT Smart Imager program. The chip, called J3DAI, integrates CEA-List's PNeuro hardware accelerator, which enables inference learning by several AI networks at the imager level. The architecture developed (Figure 1) required 50 mW of power for a video stream of 30 frames per second in tests on a Mobilenet V1-type network. In addition, a performance and area comparison with Sony's AI imager published

1 patent
A smart imager for intensive real-time image analysis

1



2

	J3DAI	SONY ISSCC 2021
Techno	28 nm	22 nm
Pixel	12MPX @ 1µm pitch	12MPX @ 1.55µm pitch
MACs	768	2304
Chip size	36 mm² (4Hx3Vx3Layers)	124 mm² (7.558H*6.200V*2Layers)
CNN + Internal Memory	16 mm² (synthesis result)	31 mm² (estimated 50% bottom chip)
Internal Memories (L1+L2)	3+5 MB	1+8 MB
Latency Mobilenet v1 @262.5MHz - (8B FIQ)	3.69 ms	3.1 ms / 4.8 ms
MAC/cycle	77%	30% / 25%

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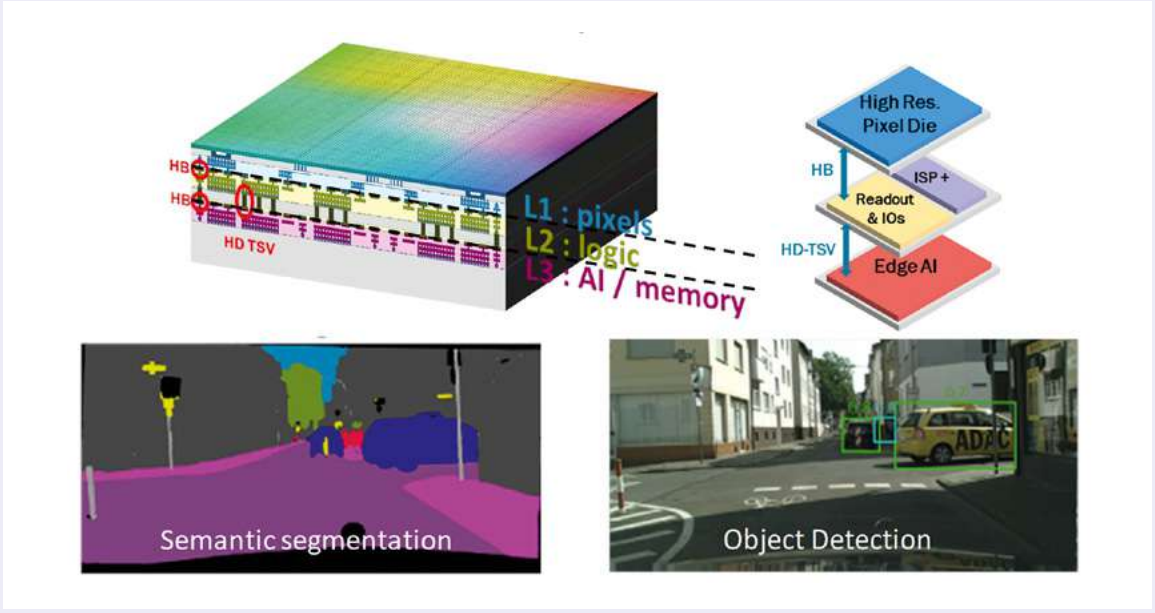
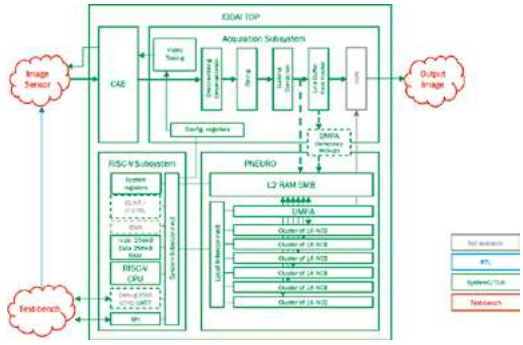


in 2021 at the ISSCC conference showed similar execution times (3.69 ms vs. 3.1 ms) but with three times fewer MACs (multiply-cumulate operations) at 768 vs. 2304, and three times less silicon area (36 mm^2 vs. 124 mm^2) as shown in the table in Figure 2.

A virtual platform (Figure 4) was also developed using Siemens CAD tools. Based on a PNeuro system and RISC-V (32-bit) processor, the platform enables significantly faster simulation (2,000 times faster at 13 seconds vs. 7h and 45 minutes) of complex tasks, with results comparable to those produced using low-level simulation.

Smartphones—once a key market for image sensors—are seeing much slower growth. Image sensors are adapting to address the automotive, industrial, and security markets, where new opportunities are being created. The multi-layer 3D integrations developed for the Smart Imager program enable embedded AI on the same chip as the sensor, responding effectively to the current and future market challenges faced by the program's partner companies.

4



1 **J3DAI architecture.**
© CEA

2 **J3DAI performance vs. SONY ISSCC 2021 (gain = 3x in MAC and surface efficiency).**
© CEA

3 **Multi-wafer 3D integration enables edge AI applications for image sensors.**
© CEA

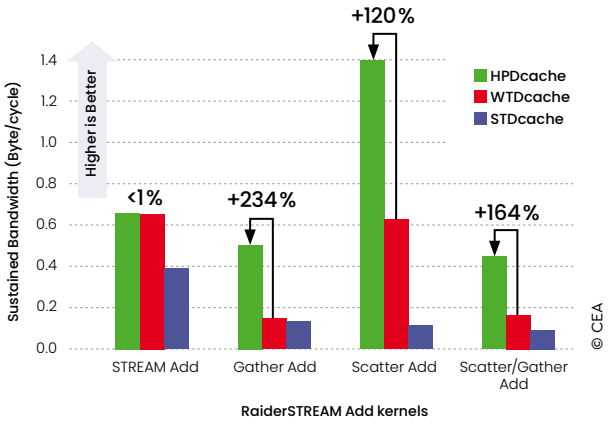
4 **J3DAI virtual platform (SysC&RTL).**
© CEA

CÉSAR FUGUET
RESEARCH FELLOW INRIA

TANUJ KHANDELWAL
RESEARCH ENGINEER

Successful open-source release of L1 data cache (HPDcache)

Latency and memory bandwidth are two of the most common factors limiting performance in high-performance computing (HPC) and artificial intelligence (AI), affecting both speed and efficiency. Improving memory systems is now vital to increasing overall performance.



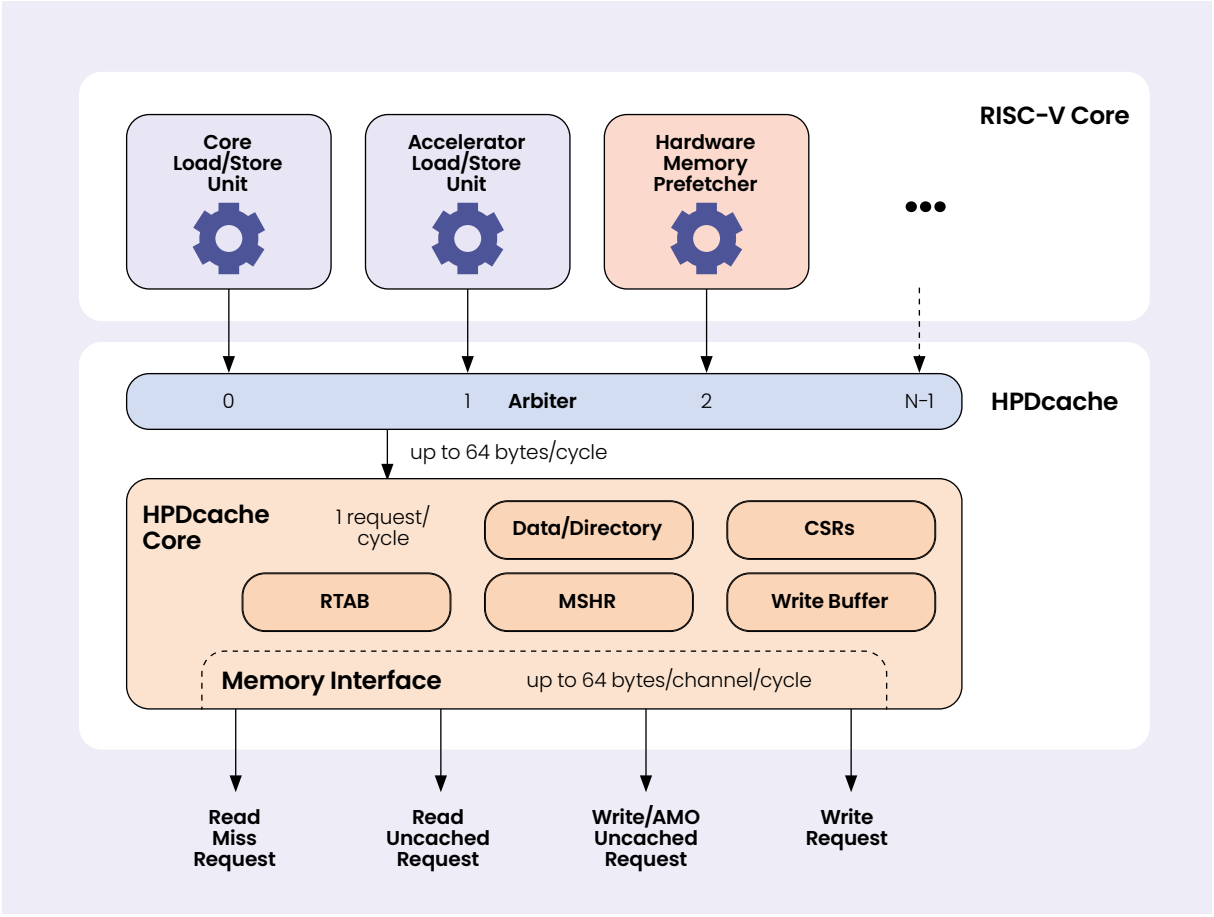
HPC and AI applications are increasingly data intensive. Plus, their memory access patterns are irregular, making the cache memory less efficient—a major barrier to improved performance. HPDcache, which allows multiple memory requests to be executed simultaneously, solves this problem, masking memory access latency and providing high bandwidth, for better overall system performance.

This advance is available through the OpenHW Group's IP catalog, where it can be accessed on an open-source basis by the broader development and engineering communities. Currently, it is used with the 64-bit RISC-V open-source CVA6 core suitable for a wide range of HPC and AI applications—widely used in Europe. In tests, the cache was up to 3.3 times faster than caches previously used with CVA6, resulting in a significant performance improvement.

HPDcache's commercial-grade quality is guaranteed by a comprehensive testing protocol and a UVM test bench. These tools can be used to test and validate cache performance and reliability for industrial use cases. Rigorous testing is crucial to ensuring that HPDcache is reliable in production environments.

As part of the European Processor Initiative (EPI), HPDcache has been integrated into EPAC and RHEA, two silicon ICs with integrated VRP/VxP accelerators, demonstrating that HPDcache is mature and ready for industrial deployment. By offering innovative solutions to latency and memory bandwidth, HPDcache represents a major breakthrough in HPC and AI.

Open-source releases of the IP and test bench have positioned the CEA to join projects like the EU TRISTAN project to make RISC-V-based solutions more readily available and has led to research partnerships through the OpenHW Group for the RISC-V CVA6 ecosystem.



The technology in use

Several European stakeholders, including Bosch and Thales, are using CVA6 with HPDcache for their automotive processors and embedded systems. In addition, HPDcache is used in the basic configuration of CVA6. The Barcelona Supercomputing Center has integrated HPDcache with high-performance RISC-V processors developed in-house. The goal is to use them in the next generation of Marenostrum supercomputers.

Flagship publication

"HPDcache: Open-Source High-Performance L1 Data Cache for RISC-V Cores"

Cesar Fuguet

(2023) 10.1145/3587135.3591413, Conférence CF-OSHW

Links to Open Hardware Group github


KUKA

© Cyrille DUPONT/CEA (Dupont Productions)

Instrumentation and the factory of the future

CEA-List's research on instrumentation and the factory of the future spans the entire value chain from sensors to decisions and actions—and the associated tools and equipment—in interaction with the real world. Automated data processing, non-destructive testing, additive manufacturing, smart robotics, sensory interfaces, and virtual and augmented reality are some of the topics we are exploring.
We develop measurement systems that leverage innovative sensors and increasingly advanced in- and near-sensor data processing and analysis. The technological advances we are working on apply to a wide range of industrial use cases, from defect detection to automated sanctioning and decision-making.
Our smart robotics and machines research focuses on modular, agile, and easy-to-program systems, and on improving robots' interaction capabilities. Specifically, we are driving progress in smart and dexterous robotic manipulation, environmental perception and decision-making, and reliable human-robot interaction.
This research is supported by dedicated laboratories and research facilities intended for our R&D partnerships with companies (see sidebar on PRISM on page 7).

We obtained four outstanding results in:

MATHIEU GROSSARD
RESEARCH DIRECTOR

CLÉMENCE DUBOIS
RESEARCH ENGINEER

Dexterous bimanual manipulation

In robotics, automating complex manual tasks involving a variety of parts in unstructured environments presents major scientific and industrial challenges. CEA-List developed a dexterous bimanual manipulation system to respond to these use cases. The system's multiple reconfigurable fingers are equipped with multi-mode perception capabilities. The system can carry out 80 different grips, using finely controlled force, and detect slippage.

CEA-List has been designing and developing control systems for dexterous robotic grippers for several years. Intended for a wide variety of industrial use cases, these systems can automate tasks that require the dexterity of both human hands. They are particularly well-suited to the challenges of unstructured environments. This research responds to pressing societal issues like improving working conditions and reducing the difficulty of physically-taxing job tasks.
In research for the European H2020 Tracebot project, the system proved to be almost as efficient as human manipulation on a bimanual manipulation task.
Each of the system's reconfigurable grippers has four fingers, each with three phalanges equipped with hybrid piezoelectric-piezoresistive touch sensors. This architecture offers eighteen degrees of freedom, fourteen of which are actuated. CEA-List provided the grippers and controller; CEA-Leti provided the sensors.

1

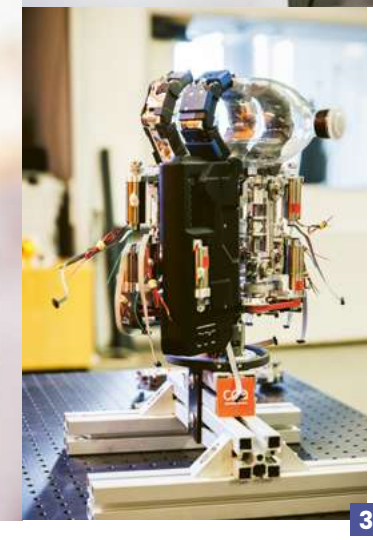
4 fingers with 3 phalanges
18 degrees of freedom, 14 actuated.

80 different grips

"With this new generation of multi-fingered grippers, tasks previously too complex to be automated will no longer have to be done manually."
— **MATHIEU GROSSARD**

"Multi-mode perception allows a gripper to interact dexterously with its environment."
— **CLÉMENCE DUBOIS**

2



3

1 **The fingers of the Tracebot robotic gripper.**
© R.Poulverel/CEA

2 **Exceptional tightening force: 20 N at the finger (the gripper can lift 2 kg with a single finger).**
© CEA

3 **The gripper can adapt to objects of various shapes and sizes, maintaining the same level of accuracy on small objects.**
© R.Poulverel/CEA

Kinesthetic, touch, and visual information are combined in multi-mode perception. The touch sensors detect critical events like object slippage, insertion, and assembly. Supervised learning algorithms classify these events, enabling safer and more efficient interaction with the environment. Dexterous manipulation—the ability to perform precise movements and adapt them—is the main pillar of this advance. High-performance, low-friction actuators enable 80 different grips, attesting to the system's flexibility and ability to handle a variety of objects. The controller provides a high degree of precision in both position and force, supporting smarter automation that places fewer restrictions on workers.
By reducing physical strain and improving product quality, these technologies, used in combination, could transform manufacturing, logistics, healthcare, and other industries. Use cases in other fields in which precision is crucial—medical robotics and assistance for the elderly—are also possible.

Major projects

In research for the EU H2020 Tracebot project, the CEA developed a bimanual manipulation station with two grippers fitted to collaborative robotic arms. This station was integrated into a demonstrator at project partner ASTECH. The system was tested on a real-world medical equipment handling task that addresses one of today's major challenges: automating sterile kit production.

Upcoming research will address bimanual robotic manipulation planning strategies using reinforcement learning and other methods.

The hardware and software are expected to be transferred to FINRIP as part of an R&D partnership.

Patent

Manipulation robotique et glissement, Grossard Mathieu; Aloui Saifeddine; Ayral Theo
DD24102 CJ

Flagship publications

"Comprehensive analysis of human gesture: application for the specification of dexterous robotic grippers"
2023: J. M. Escorcia, M. Grossard, F. Gosselin
ASME Journal of Mechanical Design, pages 041408, vol. 145-2023

"Spectro-temporal RNN structure for object slip detection using piezoelectric tactile sensor in robotic grasping"
2023: T. Ayral, S. Aloui, M. Grossard
IEEE/ASME AIM 2023

DR. BENOÎT SABOT
SCINTILLATION EXPERT
© CEA

CHRISTOPHE DUJARDIN
PROFESSOR, UNIVERSITÉ CLAUDE BERNARD LYON 1 (UCBL)

FRÉDÉRIC CHAPUT
PROFESSOR, ÉCOLE NORMALE SUPÉRIEUR DE LYON (ENS)

Inorganic scintillator aerogels for real-time discrimination of radioactive gas mixtures

A real-time radioactive gas measurement device that uses a scintillating aerogel was developed and tested by a multidisciplinary team of researchers from CEA, ENS Lyon, and UCBL. The innovation offers a faster, more compact alternative to current devices. It can also measure different radionuclides separately.

The nuclear industry produces radioactive gases like ^{3}H, ^{85}Kr, and ^{14}C. While these gases do not pose a major threat, their emissions are regulated and must be monitored. Accurate measurement data is vital to ensuring that nuclear facilities are functioning properly. But, because these radionuclides are pure beta emitters, special detection and measurement procedures must be used to acquire the necessary data.
Today's lab-based measurement techniques, based mainly on gas-liquid or gas-gas mixing principles, are costly, complex, slow, and waste-generating. In addition, these techniques cannot easily discriminate between pure beta emitters without resorting to cross-measurements—multiplying the number of devices or techniques that must be used.
Joint research by Institut Lumière Matière (UCBL), the Chemistry Laboratory of ENS Lyon (ENS Lyon), and Henri Becquerel National Laboratory (CEA) led to the development of an innovative real-time radioactive gas detection technology that leverages the synthesis of an inorganic scintillating aerogel. The resulting transparent composite

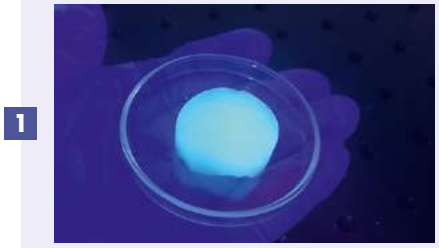
"These results, the fruit of long years spend developing new scintillation-based methods, are extremely gratifying."

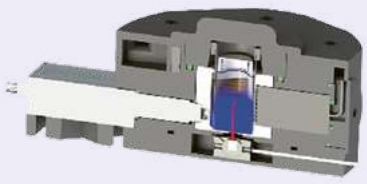
— **DR. BENOÎT SABOT**

"This dynamic, multidisciplinary partnership, which sparked many enlightening debates along the way, will create new research avenues in scintillation-based radionuclide metrology."

— **CHRISTOPHE DUJARDIN & FRÉDÉRIC CHAPUT**

is ultra-porous (pores of around 100 nm), with only 15% solid matter, a unique architecture that allows the gas to diffuse through the aerogel more easily. When a gas enters the scintillator, the beta radiation energy is converted into visible light.
The new scintillator has been integrated into various compact, highly sensitive devices that can detect the flashes of light and measure each photon almost instantaneously. The first device, intended for metrology applications, is based on a new method called Compton-TDCR. Three photomultipliers and a gamma detector combined with a single-energy beam allow the scintillation efficiency to be measured and radionuclides to be accurately counted. The second, two-photomultiplier device is a more operational prototype that must be calibrated. It can perform in-line measurements of radioactive gases. Although it is a prototype, it has been patented and can be used in the field.
This research led to new ways of analyzing pulses of light. Unlike conventional scintillation-based methods, these new devices use signal time characteristics and not just counts. The increased precision led to the development of an innovative method capable of distinguishing and measuring the pure beta emissions of different energies in-line. A mixture of ^{3}H and ^{85}Kr was measured in just 100 seconds. These advances have been validated both theoretically and experimentally.





1 **Photo of the first porous scintillator prototype under ultraviolet light.**
© ENS Lyon

2 **CAD rendering of the Compton-TDCR system with the scintillator in the center.**
© B. Sabot

Results

A standard prototype for calibration, a field measurement prototype
In-line tritium detection in 100 s on a first non-optimized prototype at 1 kBq-m^{-3}
In-line separation of pure beta mixtures with a simple 100 s measurement

Patents

Three patents have been filed: for the discrimination method, a prototype device for measuring pure beta emitters, and a device for measuring radon with thoron discrimination.

Projects

FET-OPEN SPARTE (2020-2024), EPM RadonNET (2024-2027), LNE SCINTI+ (2024- 2028).

Flagship publications

"Real-time detection and discrimination of radioactive gas mixtures using nanoporous inorganic scintillators"
Raphael Marie-Luce, Pavlo Mai, Frederic Lerouge, Yannis Cheref, Sylvie Pierre, Benoit Sabot, Frederic Chaput & Christophe Dujardin
(2024) Nature Photonics 18, 1037-1043

"Experimental facility for the production of reference atmosphere of radioactive gases (Rn, Xe, Kr, and H isotopes)"
B. Sabot, M. Rodrigues, S. Pierre
(2020) Applied Radiation and Isotopes 155,108934

"A compact detector system for simultaneous measurements of the light yield non-linearity and timing properties of scintillators"
Benoit Sabot, Chavdar Dutsov, Philippe Cassette, Krasimir Mitev, Matthieu Hamel, Guillaume H. V. Bertrand, Kheirreddine Lebbou & Christophe Dujardin
(2024) Nature Scientific reports 14, 6960

HANANE SLIMANI
PhD CANDIDATE

Innovation in machine learning for electrical cable diagnostics wins award at AUTOTESTCON

CEA-List received the Best Paper Award at IEEE AUTOTESTCON, an international automated testing event for military and aerospace decisionmakers. An innovation in accurate, low-cost electrical cable diagnostics won the award, marking a major step towards more effective and affordable preventive maintenance.

Reconstructing compressed OMTDR (Orthogonal Multi-tone Time Domain Reflectometry) data is a challenge that CEA-List is addressing through new machine-learning-based approaches that make it possible to diagnose faults from the compressed data—with no reconstruction needed.
To diagnose a fault, it must first be detected (by estimating the impedance) and then located (by estimating the position). Here, the estimations required for this two-step process are generated by the KNN (K-nearest neighbors) algorithm and a CNN (convolutional neural network).
This eliminates the need for complex, iterative reconstruction algorithms—and puts new reflectometry architectures tailored to the low-latency and real-time processing requirements of embedded systems within reach.
Both the impedance estimation and fault location results were excellent in terms of accuracy. The CNN was shown to excel at estimating impedance, while the KNN algorithm showed its strengths at fault location. The requirements of

1 Best Paper Award ceremony by Michael Seavey (Technical Program Chair) and Bob Rassa (Chair) at the IEEE AUTOTESTCON conference.
© J. Reisman/AUTOTESTCON

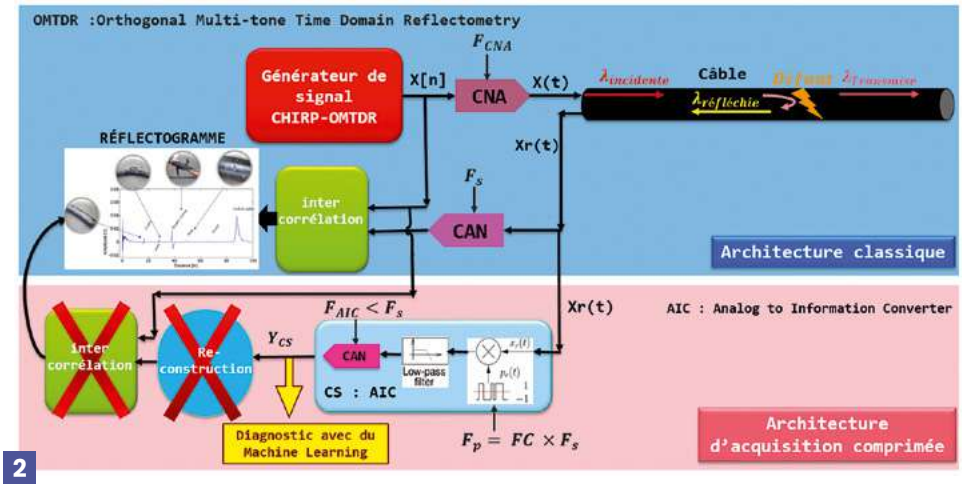
2 Classic reflectometry architecture and compressed reflectometry acquisition architecture.
© H.Slimani/CEA

3 Example of simulated measurements of compressed acquisition of OMTDR reflectometry data for different types of defects and faults.
© H.Slimani/CEA

1

"AI can take over when compressed signals get too complex, instantly revealing hidden defects and faults in electrical cables."

— **HANANE SLIMANI**



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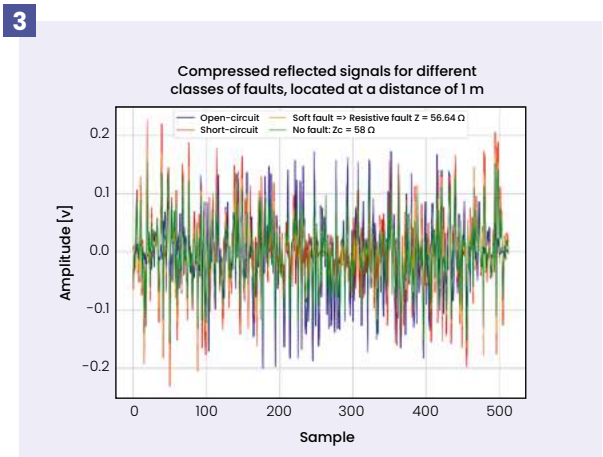
each use case—available resources, required accuracy, the amount of noise—will condition which model is best. The research also produced promising fault location results with high compression factors.
The award confirms AI's potential for processing compressed data directly in cable fault diagnosis use cases.

3



Specifications for different fault types

Type of fault	Value of impedance in Ω
Short circuit	$10^{-20} \sim 0$
Open circuit	$10^{20} \sim \infty$
Soft fault (local and resistive)	$Z_i = Z_c \pm 10\%$ $Z_i \in [52.2, 63.8]$ & $Z_i \notin [57, 59]$
No fault	$Z_c = 58.00$

Patents

One patent was filed for the diagnosis of faults in electrical cables using machine learning and reflectometry methods.

Flagship publications

"Machine Learning Approach for Classification of Faults in Cable via Compressed Sensing Time-Domain Reflectometry"
H. Slimani, Y. Gargouri, F. Ngolé and N. Ravot
979-8-3503-6058-5/24/31.00 ©2024 IEEEDO10.1109/PHM61473.2024.00061 (finalist Best Paper Award)

"Detection, Localization and Characterization of Fault in Cable via Machine Learning Approach Based on Compressed Sensing Time-Domain Reflectometry"
H. Slimani, Y. Gargouri, F. M. Ngole Mboula and N. Ravot
2024 IEEE AUTOTESTCON, National Harbor, MD, USA, 2024, pp. 1-9, doi: 10.1109/AUTOTESTCON47465.2024.10697515 (Best Paper Award)

DR. ADRIEN STOLIDI
RESEARCH ENGINEER AND EXPERT
© CEA

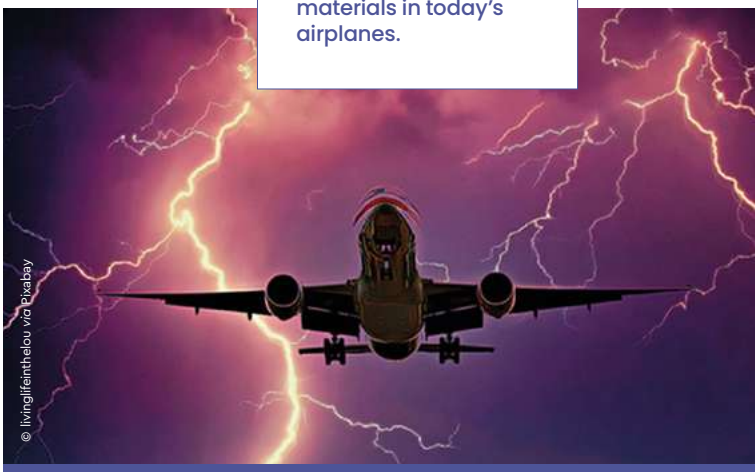
DR. AMÉLIE JARNAC
RESEARCH ENGINEER, ONERA
© Amélie Jarnac

X-ray imaging looks inside lightning damage to carbon composites

Lightweight, energy-efficient carbon composites, an aerospace-industry favorite, are prone to lightning damage. To help make aerostructures more reliable, CEA-List and ONERA are bringing innovative X-ray imaging to the modeling, analysis, and characterization of lightning damage.

Increasingly, the aerospace industry is turning to strong, lightweight carbon-fiber-reinforced polymer composites (CFRPs). These low-absorption materials, with their low thermal and electrical conductivity, can suffer delamination, fiber breakage, and other damage when struck by lightning. CEA-List is working with ONERA to develop new imaging methods to get a more complete picture of lightning damage. The partners are leveraging a technique called phase-contrast X-ray imaging, which provides additional information to round out conventional X-ray absorption and is particularly well suited to the inspection of composites. Recent research at CEA-List and ONERA, including a PhD dissertation by Laureen Guitard, resulted in a robust quantitative method for characterizing carbon fiber reinforced polymer (CFRP) materials damaged by lightning. A transient electrical discharge created by a current representative of lightning test standards was applied to a CFRP sample (Figure 1), sized in the laboratory. After impact, an image of the sample was obtained using multilateral shift

50%
The amount, by weight, of composite materials in today's airplanes.


© livinglifeinthelou via Pixabay

"CEA-List has the capacity to add significant value to phase-contrast X-ray imaging, a technique that is gaining traction, especially in medicine, but that is still little-used in NDT."

— **DR. ADRIEN STOLIDI**

"Together, CEA-List and ONERA put their expertise to work to develop cutting-edge NDT methods with multiphysics applications."

— **DR. AMÉLIE JARNAC**

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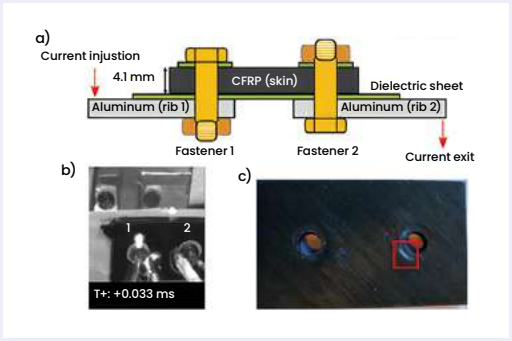

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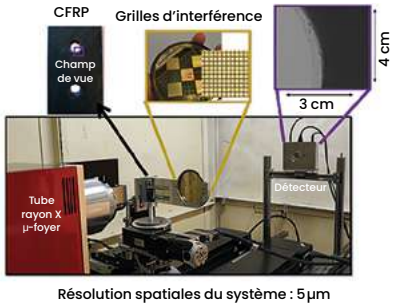
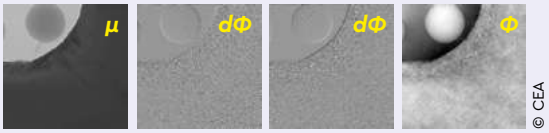


Résolution spatiales du système : 5 µm

© CEA

interferometry (Figure 2), a technique co-developed by ONERA and CEA-List on an X-ray imaging bench.
Figure 3 shows the absorption (μ), phase gradient ($d\Phi$), and phase (Φ) images of the area of the sample near the point of impact. The absorption image shows locally absorbing areas, while the phase image shows a wider, heterogeneous area (around 750 µm) around the impact point. The phase gradient images illustrate the direction of the carbon fibers (±45°). When taken together, the images are homogeneous overall, except near the impact point, where the standard deviation of the gray values doubles, indicating a disorientation of the fibers.
Then, to provide a more precise measurement of the damage, the phase values were correlated to relative density variations using a standard object. Figure 4 shows a map of density variations in percentage terms: White areas indicate unchanged density, blue areas lower density, and red areas higher density. By converting the phase data into density variations, the extent of damage can be quantified at different points in the material. At the same time, new data is produced for the numerical lightning-material interaction models developed at ONERA.
The purpose of the research was to develop an innovative non-destructive testing method for carbon composites.

3



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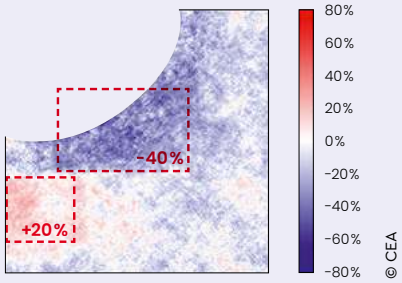

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The technology in use

Aeronautics, composites

Projects

The research is ongoing in two areas: use cases, with a parametric study of lightning strikes on carbon composites; and methodology, with a focus on
1) the transition from 2D to 3D imaging, the topic of a new ONERA/CEA-List PhD dissertation;
2) the development of a digital phase contrast imaging model (Carnot OSIRIS);
3) the design of methods for fast transient phenomena like lightning strikes (ANR DyXPLAY, PTC MOVIE).

Flagship publication

"Robust quantitative X-ray phase diagnostic for carbon composite characterisation in the context of lightning induced risk"
Laureen Guitard, Adrien Stolidi, Georges Giakoumakis, Rafael Sousa Martins, Jérôme Primot & Amelie Jarnac
Scientific reports volume 14, Article number: 21803 (2024)

Technology designed for industrial end-users

At CEA-List, our mission is to develop and transfer new technologies to industry—and speed up the digital transition of the industrial sector. Our open innovation programs and facilities are intended to encourage new forms of collaboration between partners, and across from different industries.

We believe that innovation in digital is a major source of competitive advantage, a benefit for society, and a catalyst for the environmental transition. Our mission—to speed up the digital transition of the industrial sector and of society—is rooted in these beliefs. And our world-class research engineers, deeply knowledgeable in their fields, are skilled at matching the scientific and technological advances made in their labs to the needs of our R&D partner companies, as evidenced by a recent breakthrough using TDK's spintronic memories for probabilistic AI.

In a nutshell, our purpose is to leverage the results of our R&D and innovation projects in the design of innovative products and services for our partners. The Predire drone's operational deployment by SARP Veolia is one example of a CEA-List innovation in use. We are also creating new ways for companies to work with us. Designed around digital innovation and cross-industry collaboration and resource sharing, these new modalities make products and industrial processes more operationally efficient, faster.

Our world classed PRISM open innovation technology platform is one example. Partner companies can take advantage of PRISM's flexible infrastructure to develop new products and solutions that respond the industrial sector's business transformation imperatives. The

Prisma experimental cell, part of PRISM, our open-innovation platform.
© CEA

affiliate club, DEFI Lab, which uses PRISM, is a place where stakeholders from academic research and industry can come together around digital technology projects. R&D costs are reduced, because companies access shared resources to address similar problems. Access to breakthrough technologies is facilitated, allowing participating companies to innovate faster, improve the quality of their products, and optimize their industrial equipment and processes.

2024 advances

1 Innovation for industry

2 Technology transfer

ALLAN BLANCHARD
RESEARCH ENGINEER
FRAMA-C TEAM MANAGER

SÉBASTIEN BARDIN
RESEARCH ENGINEER
BINSEC TEAM MANAGER

Together, DGA and CEA-List move security code analysis forward

The procurement department of the French defense agency (DGA) relies on tools developed by CEA-List for the formal analysis of the code in the security products used by the agency and its suppliers. The software, originally developed for operating safety analysis, is being adapted to meet the agency's security requirements under a partnership signed in 2022.

CEA-List's partnership with the agency is focussed on extending the formal analysis software applications Frama-C (C source-code) and BINSEC (binary code) to new, security-specific code structures and features as needed by the agency and its suppliers.
The partnership has produced two BINSEC demonstrators:
- A tool to verify the secure deletion of confidential data (passwords, encryption keys, etc.) after a program is run;
- A binary-to-C decompiler, which checks binary code embedded in C code.

For Frama-C, the research has focused its plug-in used to verify that a program complies with its specifications. Mixed modeling of the memory has been used to analyze, in detail, low-level operations without the total analysis time being prohibitive. Two code operation models are used in the analysis: a high-level model of usual operations, and a low-level model of complex operations that act directly on the program's working memory [1].
Two feasibility studies on Frama-C confirmed that there was no leakage of confidential data or indeterminate memory access behavior.
The conclusive results led to two new projects: integration of the results into Frama-C, and a BINSEC plug-in to detect hidden channel flaws in post-quantum cryptographic primitives (i.e security algorithms protecting against attacks by a quantum computer).

"CEA-List's formal software analysis know-how is exactly what France's defense procurement agency, DGA, needs for its security code verification."

— **ALLAN BLANCHARD & SÉBASTIEN BARDIN**

[1] Jérémy Damour, Allan Blanchard, Loïc Correnson, Frédéric Loulergue. ***Formalisation d'une analyse de région pour Frama-C/WP.*** 36es Journées Francophones des Langages Applicatifs (JFLA 2025), Jan 2025 Roiffé, France. ffhal-0485948

LAURENCE BOUDET
RESEARCH ENGINEER
© CEA

SOFIANE MADANI
COFOUNDER, BIRDIA
© BPartners

ExpressIF® leverages symbolic artificial intelligence help small businesses grow

Startup BIRDIA (formely BPartners) expanded its service lineup for traditional small businesses with an analysis tool for detecting business opportunities. ExpressIF®, the CEA's symbolic AI platform, was integrated into the solution, which helps traditional small businesses sort through dozens of opportunities and target only the best-qualified prospects.

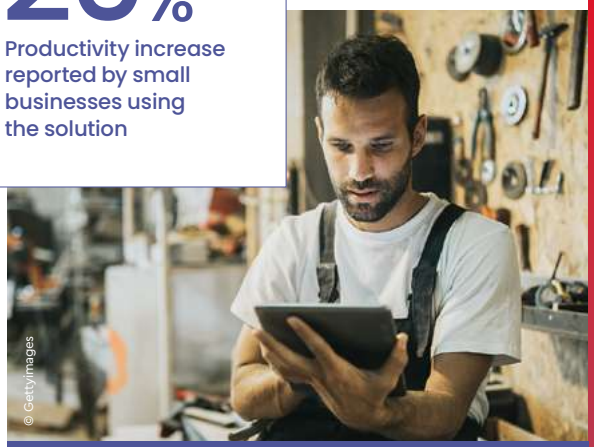
Tradespeople spend an inordinate amount of time on tasks like sales and following up with customers—time taken away from their core business. BIRDIA interviewed more than 300 small independent contractors in fields like home repair, roofing, and more to better tailor the solution to their unique needs. The company used the information gathered to gain a deep understanding of the logic unique to each kind of business, and the complex set of rules used to make decisions.

CEA-List's symbolic AI experts rapidly modeled the natural-language interviews, transformed them into rules, and integrated them into ExpressIF®. ExpressIF® simulates human reasoning, and can use heterogeneous data—especially spatio-temporal data—to arrive at explainable decisions. The partnership yielded an automated solution that replicates business-specific logic.

BIRDIA is now commercializing an end-to-end data-processing solution: information is gathered online or from databases, prospects are screened automatically using ExpressIF®, and the results are displayed *via* an intuitive, user-friendly graphical interface.

A knowledge-based approach was used to solve the problem of cold starting without any data. This advance will create a number of potential new avenues, whether it's refining the business rules with new criteria, improving them with the new data acquired, or providing the reasons for the recommendations made.

20%
Productivity increase reported by small businesses using the solution



© Gettyimages

"This partnership marks the first practical use case for our screening technology for a start-up. It demonstrates our commitment to transferring technology to economic stakeholders of all types and sizes."

— **LAURENCE BOUDET**

"ExpressIF® has allowed us to encapsulate a small business owner's reasoning in an AI. Traditional independent contractors can now delegate their customer analysis and focus on their core business."

— **SOFIANE MADANI**

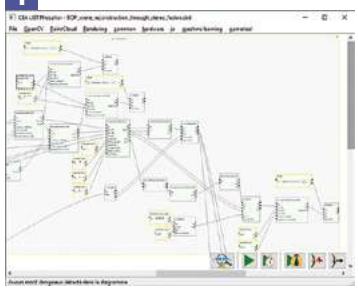
FABRICE MAYRAN DE CHAMISSO
VISION & AI RESEARCHER
© CEA

BORIS MEDEN
VISION & AI RESEARCHER
© CEA

Siemens turns to CEA-List for new vision technologies for robotics and automated control

When it comes to industrial process control, improving robotic perception is a major challenge. CEA-List and Siemens joined forces to tackle the robotic handling and visual inspection of industrial parts. Several advanced computer vision technologies were combined to perform complex inspection tasks in real time.

1



2020–2027
A trusted partnership with Siemens

5x
more data-frugal learning

The purpose of CEA-List's partnership with Siemens on computer vision for robotics was to improve robots' understanding of their environment and the resulting actions. The potential industrial use cases for the research are wide, from manufacturing and agricultural robotics to sorting waste and dismantling equipment—any job that requires adaptability, precision, and controlled cycle times. In this AI-enabled system, robotic manipulation and visual inspection of the part are combined in a way that is particularly effective for grasping the part optimally and holding it in front of a camera for a reliable visible defect inspection.

The partnership produced three new technologies:

- HC6D zero-shot object location in 3D spaces (patented);
- Calculation of dynamic object input configurations, regardless of initial position;
- One-class anomaly detection using a learning-based "normality modeling" technique to detect defects of an unknown nature. This approach is much more frugal than conventional approaches (<200 images instead of >1000+ images).

CEA-List's Phosphor software was used to integrate the technologies, which performed well in tests on several object inspection scenarios.

The focus of the partnership will now shift to applying the technologies developed to the fine manipulation of deformable objects with multi-finger grippers, and generalizing the technologies to other use cases.

1 **Phosphor software, developed by CEA-List.**
© CEA

2 **Left: One-class anomaly detection using computer vision. Missing or deformed bristles can be detected on a toothbrush.**
Right: The robot's task is to grasp the previously-located toothbrushes, hold them in front of a camera for inspection, and sort them into two bins (OK, and not OK).
© CEA

2

"When you design smart robotic systems, it forces you to come up with new perception technologies."

— **FABRICE MAYRAN DE CHAMISSO & BORIS MEDEN**

ADRIEN GIRARD
RESEARCH ENGINEER
© CEA

VINCENT GOUDIER
INSPECTION DIGITALIZATION COORDINATOR
SAFRAN AIRCRAFT ENGINE
© CEA

CEA-List and Safran team up on digital twin for robotic inspection

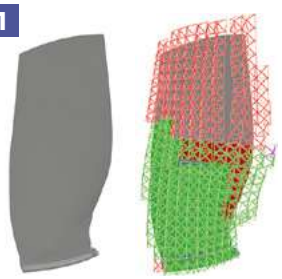
The SPRING cell at CEA-List was designed specifically for robotic non-destructive testing (NDT) using infrared thermography.

To meet Safran's optimization needs, we created a digital twin of SPRING that leverages a patented algorithm that automatically calculates all control "poses" and robot trajectories from CAD (computer-aided design) data for the part to be controlled.
An alternative to chemical-based testing methods (like penetrant and magnetic particle testing), active infrared thermography is a non-destructive digital method for inspecting surfaces that can be performed 100% robotically—another advantage.
Safran currently programs its robotic inspection cells manually. All robot control "poses" are programmed by a roboticist on the actual equipment. Given the complexity of the parts inspected (skewed surfaces, etc.), programming is a long and tedious process. Plus, the slightest programming error can significantly impact the process, and even cause physical damage to the part being inspected.
For Safran, the challenge was to use a functional, physics-based digital twin to eliminate manual programming and make programming the inspection sequence faster and more reliable.
The digital twin, named ADRA, offers a 3D representation of the cell, CEA-List's real-time physics engine XDE Physics, a functional model incorporating robot controller emulators from ABB, a Siemens PLC emulator, and a Mastermind supervisor, a standard communication protocol developed by Safran.
ADRA significantly reduces robot programming time, limits the actual robotic inspection cell's downtime, and lowers the risk of damage to the part and camera.

1 joint CEA-Safran patent
resulting from this project: Automation of robot programming tasks

Learn more about XDE Physics

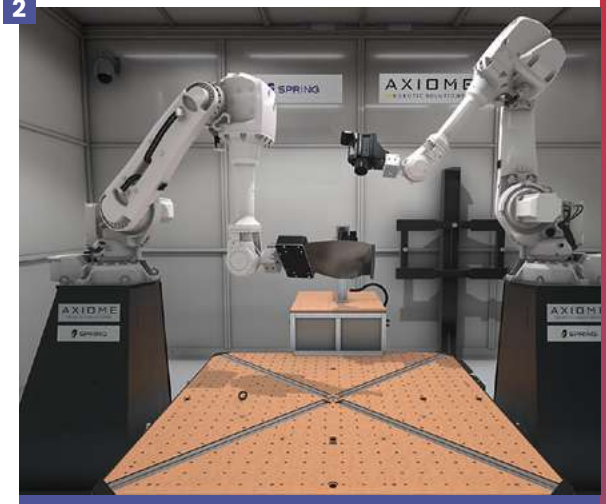
1



1 Left: Rendering of engine blade before inspection. Right: Rendering of engine blade after inspection with ADRA.
© Axione, Safran and the CEA

2 Digital twin of SPRING cell during simulation of robot trajectories
© Axione, Safran et CEA

2



"The developments made for ADRA will provide crucial support to Safran Aircraft Engines' inspection digitalization and automation rollout."

— **VINCENT GOUDIER**

THOMAS DALGATY
EXPERT
© CEA

A major milestone on the path to using TDK's spintronic memories for probabilistic AI

CEA-List is working with TDK to investigate new hardware-based probabilistic computing paradigms that leverage the intrinsic stochastic physics of TDK's spin memristors. This key memory technology could enable tomorrow's AIs to learn and adapt more efficiently, at just a hundredth of the power consumption of previous-generation components.

TDK turned to the CEA-List to help expand into AI and, in particular, edge learning, with its magnetic spin memristor technology. The challenge is memristors' intrinsic noise, which makes them difficult to program accurately. Even with costly variability reduction strategies, standard machine learning techniques produce sub-optimal results.
Instead of trying to eliminate noise, the CEA-List's research engineers took a different approach: They decided to use the noise inherent to memristors to their advantage. Since 2020, the CEA-List has been pioneering Bayesian in-memory computing, an approach that uses memristors' randomness to implement efficient probabilistic algorithms. We developed a programming strategy that leverages an advanced probabilistic method and the physics of TDK's memory devices, achieving power and latency improvements of two to three orders of magnitude over today's digital hardware. Model sizes could be increased fivefold with exceptionally low power consumption on this new type of hardware.
This disruptive approach turned a limitation into a powerful strength, revolutionizing how we think about computing for the AI of the future. The partnership between the CEA and TDK has earned international recognition in the form of a best paper award at the NeurIPS conference. Two patents have also been filed.

A disruptive approach to AI computation models

1,000x
power efficiency gains


© CEA

"Bayesian in-memory computing is an emerging field. This research will create new avenues to more sustainable, reliable, and efficient solutions to meet the growing demands of modern artificial intelligence applications."

— **THOMAS DALGATY**

"This new development by the CEA opens up new applications for the spin memristor, and represents an advance toward future ultra-low-power AI chips—a goal shared by both organizations."

— **THE TDK CORPORATION**

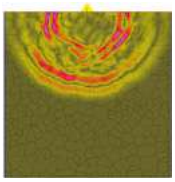
VINCENT DORVAL
RESEARCH ENGINEER AND EXPERT
© CEA

GUILLAUME COUSIN & PHILIP MEILLAND
RESEARCH ENGINEERS, ARCELORMITTAL

High-performance ultrasonic simulation for optimized steel manufacturing processes

An understanding of the behavior of ultrasonic waves in metal microstructures can be useful in many industrial applications. One aspect that has remained elusive to researchers is the influence of the complex internal structure of certain metals.

CEA-List developed Microstruct, a simulation and analysis tool, for precisely this purpose. ArcelorMittal is using it to fine-tune process control methods in its steel mills.
Microstruct combines microstructure descriptions, finite element calculations, and automated ultrasonic field analysis in a single interface in the CIVA software environment. Users can access methods developed for elastodynamics research and apply them directly to their specific use cases.



Microstruct simulation of the ultrasonic field emitted by a laser in a steel sample
© CEA

ArcelorMittal is using laser ultrasound measurements to monitor changes in the properties of high-performance steels during manufacturing. The ability to control these processes with a greater degree of precision brings financial and environmental benefits, reducing energy consumption and optimizing the percentage of recyclable raw materials used.
ArcelorMittal was one of the first companies to adopt Microstruct, and is still contributing to ongoing software development as part of the European ANNEAL-LUS project. Combined with CIVA's existing modules, Microstruct also enables multi-scale simulations that can be applied to the ultrasonic testing of a range of heterogeneous materials. CEA-List is currently working with other partners on weld inspection, inspection of parts made by additive manufacturing, and concrete.

"The simulation tool will create new possibilities for early-stage modeling research and for application to actual materials problems in real-world industrial use cases."

— **VINCENT DORVAL**

"The key link in the modeling chain, Microstruct interprets ultrasonic wave propagation in steel to better understand the material's microstructures."

— **GUILLAUME COUSIN & PHILIP MEILLAND**

Strip-mill reheating furnaces in Ghent, Belgium.
© ArcelorMittal

GWENOLÉ CORRE
RESEARCH ENGINEER

Faster detection of radioactive materials at border crossings

European customs officials are facing two major challenges around inspecting vehicles for radioactive materials at border crossings: higher vehicle traffic and false alarms. CEA-List developed new, faster approaches to vehicle inspection and integrated them into Bertin Technologies' gantry-type detectors.

Customs officials must be prepared to handle more than just "traditional" threats like drug and arms trafficking, cigarette smuggling, and fraud. New risks like counterfeit goods, psychoactive substances, dual-use technologies, and nuclear and radioactive materials have also emerged. CEA-List's nuclear instrumentation experts teamed up with Bertin Technologies, a major European defense and security company, to improve the detection of radioactive materials (gamma radiation) and reduce false alarms. The European ENTRANCE project offered ideal testing conditions—similar to actual border controls, especially those conducted in ports.

3-fold increase in the number of trucks inspected

False alarm rate reduced to less than 1 per 10,000

CEA-List's technologies enabled a three-fold increase in the number of trucks inspected. Ionizing radiation detection quality was good, and the number of false alarms was less than 1 in 10,000. New algorithms that correlate information from several detectors and better separate natural and industrial isotopes led to the excellent results. Customs officials confirmed the benefits of the technologies developed for inspecting vehicles without disrupting activity at the border. The solutions will be integrated into a new generation of gantry-type detectors for the control of all vehicles in transit. Highway tool booths will also be equipped with the technology.

"This is an effective nuclear and radioactive risk inspection method that is well suited for use in border control scenarios, where it doesn't disrupt operations."

— **GWENOLÉ CORRE**

© CEA/ Entrance

GUILLAUME LAPOUGE
RESEARCH ENGINEER
© CEA

BERTRAND LUVISON
RESEARCH ENGINEER
© CEA

QUENTIN GARNIER
CEO OF AIHERD

AIHerd uses CEA-List AI technologies to analyze cattle behavior

Correct heat detection rate
80%

The solution is in use on **more than 20 farms**

AIHerd commercializes a powerful AI-enabled herd monitoring solution for cattle farmers. The technology, developed by CEA-List, provides a precise analysis of herd health. It can track and re-identify each animal in real time and analyze individual animal behavior.

AIHerd's solution is designed to help farmers understand the reasons for their animals' behavior, quickly alerting them to unusual behavior (e.g. heat or disease) in an animal. An individual behavior "signature"—robust over long periods of time—is calculated using CEA-List's AI and vision algorithms.
Machine learning without human annotation is one of the major innovations to result from this project, and it is what made it possible to very quickly get actionable information out of the huge amounts of data acquired by AIHerd [1]. This AI model delivers 80% accuracy detecting animals in heat, a success rate far superior to competing wearable technologies.

1

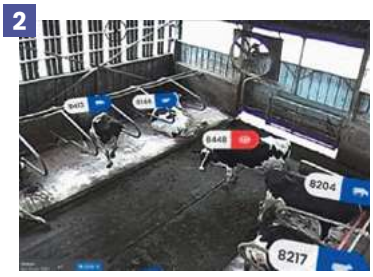
"This project is the perfect illustration of the CEA's capacity to transform research results into technologies that can respond to the most demanding use cases."

— **GUILLAUME LAPOUGE & BERTRAND LUVISON**

"Our motto is to bring improved wellness to livestock and financial benefits to farmers."

— **QUENTIN GARNIER**

2



1 **A network of cameras in an indoor environment for 24-7 monitoring of cattle.**
© CEA

2 **Example of AIHerd interface.**
source : www.aiherd.io ©AIHERD

[1] **Cumulative unsupervised multi-domain adaptation for Holstein cattle re-identification.** Fabian Dubourvieux, Guillaume Lapouge, Angélique Loesch, Bertrand Luvison, Romaric Audigier. Artificial intelligence in Agriculture, December 1st, 2023.

XAVIER ZEITOUN
RESEARCH ENGINEER

Framatome integrates new optimization tool into its design chain to improve EPR control system performance

Framatome offers an analog backup control solution for its EPR nuclear power plants. The allocation of software control functions to hardware is complex, however.

CEA-List developed the HAllo analog I&C allocator to assist engineers with this task. HAllo, which draws on CEA-List know-how in both modeling and operational research, uses a description of functions and electronic circuits to calculate the allocation of circuit components to boards. The solution was validated and transferred to Framatome, where it was integrated into the ERP engineering chain. Framatome worked with its engineering teams to determine user protocols for the tools and initiate a change management process. The company now has a versatile solution for optimizing its security systems.

"The HAllo project gave us an opportunity to use our expertise in complex systems modeling and in operational research to respond to a real-world use case in the nuclear industry."

— **XAVIER ZEITOUN**

MEHDI BOUKALLEL
RESEARCH ENGINEER
© CEA

JÉRÔME TAUFOUR
OPERATIONS DIGITIZATION AND TECHNICAL DIRECTOR AT SARP, A VEOLIA COMPANY

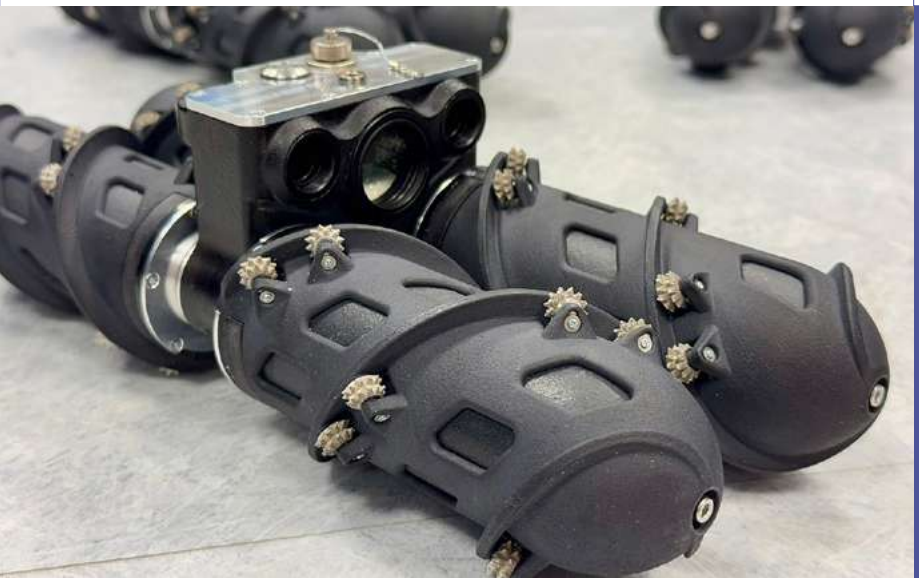
An autonomous robot to inspect SARP's pipework

Veolia company SARP and CEA-List worked together for a decade to produce a breakthrough operations technology, PREDIRE. This stand-alone wastewater pipework inspection system enables rapid, reliable preliminary evaluations, for better targeted and more efficient maintenance interventions.

PREDIRE, which takes maintenance from curative to predictive, is a low-cost solution for frequent inspections. There are five units in operation with Veolia in France, with additional rollouts in progress in Japan and Australia. Cleaning-related GHG emissions and water consumption have been cut by half.
PREDIRE distills the best in technology to respond to challenges around operational performance and environmental responsibility. With its four motorized screws, high-definition imaging, automated acquisition, and embedded sensors, PREDIRE is designed to be efficient in complex environments.

3
patents filed

2,700 km
inspected



PREDIRE D150 autonomous robot.
© G. CHANGEON/CEA-List

"PREDIRE analyzes the condition of infrastructures in detail, so that optimized cleaning programs based on objective data can be implemented more easily."

— **MEHDI BOUKALLEL**

Supporting societal transitions

Our research addresses pressing economic and societal challenges, providing answers to three major transitions of our century—digital, climate, and demographic. People are at the center of our research, and our societal and environmental values are our guide.

Solutions for an aging population, health, climate, the environment, energy, and digital

Through scientific discovery and technology development, CEA-List contributes to economic performance. It also actively engages with major societal challenges such as health, combating disinformation, eco-responsibility, and nuclear energy—all of which are addressed by CEA-List innovations.

In health, our researchers harness digital technologies to address critical needs: improving prevention and early diagnosis, supporting individuals with disabilities, and optimizing the organization of healthcare facilities.

Countering disinformation and manipulation is another priority for our researchers, who are grappling with the challenges posed by generative artificial intelligence—a technology that is currently upending traditional models of producing and disseminating information.

Eco-innovation is also a strategic pillar of our research. We not only develop solutions; we also establish robust methodological frameworks to optimize resource use, reduce the environmental footprint of production, and ensure product traceability through digital passports.

Finally, digital innovation plays a key role in nuclear energy. CEA-List delivers systems engineering solutions to enhance the operational performance and safety of future nuclear power plants and pioneers technologies for decommissioning facilities and managing waste.

These examples illustrate how technological research extends far beyond addressing corporate operational needs, maintaining a direct connection to society—from innovation to economic impact.

2024 advances

1 Health

2 Toward more respectful AI

3 Eco-responsibility

4 Technological challenges in the nuclear industry

FLORIAN NOYRIT
RESEARCH ENGINEER

VICTOR LAVAIRYE
PhD CANDIDATE

Keeping human factors at the center of functional digital twins for hospitals

Functional digital twins (FDTs) help optimize organization within complex systems. For digital models to be relevant in healthcare settings, they must account for the rich intricacies of human behavior. This is crucial to ensuring the quality of the analyses and predictions generated.

Notoriously complex hospital systems present a prime use case for FDTs. In collaboration with Foch Hospital in Suresnes, CEA-List developed its first process-centric FDT. This twin integrates all associated administrative and regulatory steps, aiming to evaluate how a project manager's decisions can impact quality indicators for clinical studies. To ensure the FDT was representative, process models were enhanced with stochastic data on task durations and event probabilities, alongside annotations specifying human agents' objectives. CEA-List's model-driven system engineering platform, Papyrus, was tailored to simulate human-driven scheduling guided by goal achievement, leveraging a Monte Carlo Tree Search heuristic. Additionally, fuzzy logic was incorporated into decision-making processes, particularly for task scheduling, using the institute's symbolic AI technology, ExpressIF®.

We developed two knowledge extraction modules to maximize FDT accessibility. The first module extracts relevant information from regulatory texts using CEA-List's multilingual linguistic analyzer, LIMA, and enables exploration of legal databases such as Légifrance and EurLex. The second module extracts insights from process data to generate execution logs and a set of constraints based on Allen interval logic.

This approach is applicable to any sector where establishing a functional perspective is critical, and where humans are central to system operation.

© Image générée par IA

"Human decisions must not be forgotten in systems modeling and simulation."

— **FLORIAN NOYRIT**

JEAN-MARC BORDY
DIRECTOR OF RESEARCH
© CEA

ISABELLE FITTON & CLAIRE VAN NGOC TY
MEDICAL PHYSICISTS GEORGES POMPIDOU EUROPEAN HOSPITAL, APHP

Optimizing doses and screening accuracy in breast tomosynthesis

Breast tomosynthesis, a novel 3D-imaging method, represents the latest technological leap in mammography for breast cancer screening. The use of new X-ray radiation qualities demands it demands new dosimetric benchmarks and equipment quality control protocols to precisely quantify and optimize delivered radiation doses.

In 2022, there were
2.3
million women diagnosed with breast cancer and
670,000
deaths globally.
Source: WHO website

Metrological evaluation of these advanced mammography systems requires rigorous characterization of the clinical X-ray beams used. To achieve this, our Henri Becquerel National Laboratory (LNHB-MD) replicated the beam configurations used at the Georges Pompidou European Hospital (HEGP).
Through sophisticated analysis and correction procedures that address escape effects caused by fluorescence and pile-up effects caused by high counting rates, the team reproduced clinical spectra with exceptional precision. These beams now enable the LNHB-MD to calibrate clinical radiameters, ensuring accurate monitoring of patient exposure levels during diagnostic exams.

This makes it possible to balance diagnostic image quality with the varying radiation dose requirements of individual breast anatomy.
This research is part of the national metrology program, a collaboration with HEGP and a doctoral thesis aimed at automating the measurement of mean glandular dose, the indicator for optimizing patient exposure. This tool will enhance dose traceability during mammograms and improve the safety of tomosynthesis in breast cancer screening.

Mammograph at the Georges Pompidou European Hospital.
© CEA

"Tomography invites us to rethink the metrological traceability chain, from defining the dosimetric quantity to the measurement methods."

— **JEAN-MARC BORDY**

"By improving our knowledge of the doses delivered to patients, this collaboration helps make using breast tomosynthesis for breast cancer screening safer."

— **ISABELLE FITTON & CLAIRE VAN NGOC TY**

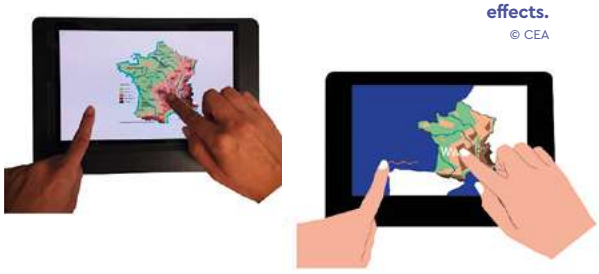
SABRINA PANËELS
RESEARCH ENGINEER
COORDINATOR OF
THE ABILITY PROJECT

CHARLES HUDIN
RESEARCH ENGINEER

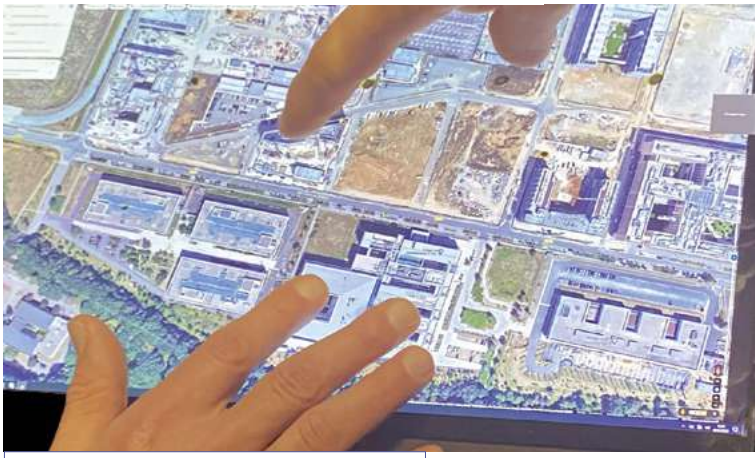
ABILITY, a digital accessibility revolution for the visually impaired

In a digital world dominated by sight and sound, visual disabilities pose accessibility challenges, especially for graphical content. To make digital content accessible, we've developed the world's first multisensory tablet as part of the European ABILITY project, leveraging CEA-List's innovative haptic technologies.

We took a conventional tablet and integrated localized, multi-point, vibrotactile feedback capability as well as AI algorithms for image analysis/simplification, text extraction, and predictive input.
This vibrotactile feedback is output by a matrix of piezoelectric actuators in the form of a patch, glued directly under the screen using cleanroom-compatible processes developed by CEA-Leti. The first 10.5-inch OLED tablet prototype is now ready for testing by target users.
The localized, multi-point tactile feedback, made possible by CEA-List efforts, has a wide range of practical use cases—from already-common confirmation vibrations, to button feedback that matches input force, to even more complex and rich experiences, such as textures.
For example, a visually impaired person who wants to familiarize themselves with a travel route can pull up a map on their tablet and explore it with both hands (in particular to use a second finger as a reference point). They can feel the different elements of the map—the road, buildings, open spaces, etc.—thanks to different textures assigned to each one and triggered on contact, with an added effect of attraction toward the destination. This multisensory tablet aims to use other visual and auditory feedback to adapt to users' varying needs and forms of visual impairment.



Left: Prototype 10.5-inch screen. Right: Illustration of colored zones and their associated haptic effects.
© CEA



The user explores a map with their fingers to find points of interest.
© CEA

1 patent
3 publications

+ 1 patent and 2 publications before the project

Ongoing collaboration on related topics: *Continental Automotive Technologies (A touchscreen tablet for the cabin of a car)*

SYLVAIN CHATILLON
RESEARCH ENGINEER
© CEA

JEAN-LUC GENNISSON
BIOMAPS RESEARCH DIRECTOR
© Jean-Luc Gennisson

Wearable ultrasonic sensors for health monitoring

Smart watches are surging in popularity by enabling users to monitor their fitness and cardiovascular health daily. Yet their reliability and robustness for blood pressure measurement remain insufficient. To address this gap, CEA-List, in collaboration with CEA-Leti and BioMaps, has developed an ultrasound-based technology designed to improve confidence in these wearable devices.

Accurate, continuous blood pressure monitoring requires detecting changes in the volume of arterial blood pumped by the heart. To tackle this challenge, we developed an ultrasound method for tracking variations in arterial diameter. Pairing this with optical measurements of pulse wave velocity allows us to determine blood pressure using a wearable system developed by CEA-Leti.
To meet the performance demands of a device worn on the wrist, the ultrasound probe's design was optimized using simulation tools in our CIVA Healthcare software platform. We also engineered algorithms to reconstruct arterial images, fine-tuned for precise, dynamic detection of peaks in the echo pattern from the proximal and distal walls of the artery in the arm. By analyzing the delays between these peaks, we were able to track the arterial diameter and its fluctuations continuously. Initial validation was conducted by the Paris-Saclay multimodal biomedical imaging laboratory (BioMaps) using medical ultrasound systems and probes. Tests began *in vitro* with silicone artery models of varying diameters, followed by human trials. These early *in vivo* assessments confirmed the system's ability to perform dynamic arterial measurements with the reliability and robustness required by a wearable medical-grade blood pressure monitor.

4 patents
have been filed relating to this ultrasonic technology


© drobotdean sur Freepik

"The excellent results we obtained are highly promising, and this synergy has highlighted how different CEA teams' skills complement each other."

— **SYLVAIN CHATILLON**

"This research opens the door to the development of embedded ultrasonic sensors for health and wellness monitoring."

— **JEAN-LUC GENNISSON**

HEALTH

EVAN DUFRAISSE
RESEARCH ENGINEER

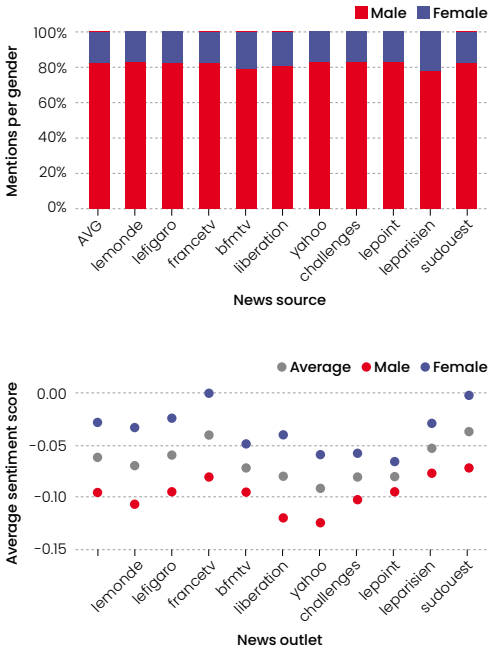
In-depth analysis of political news

News items published widely on social media are known to play a pivotal role in shaping political opinions. And yet, the algorithms driving these platforms often amplify content polarization. To enhance content diversity and foster a deeper understanding of the issues, CEA-List created an algorithm that enables automated news content analysis.

Developed as part of the BOOM (ANR) and AI4Media *(Horizon 2020)* projects, this innovative tool merges advanced language processing—including entity detection, theme analysis, and politician-centered sentiment classification—with political knowledge databases. It offers granular insights into media coverage, both traditional and social, including editorial biases, thematic framing, the evolving portrayal of public figures, and demographic biases.
When applied to French and Flemish (Belgium) media ecosystems, a pattern emerged: a persistent gender imbalance in political news, with women significantly underrepresented. Still, the average sentiment associated with female politicians was more positive than that of their male counterparts.
Current research priorities now focus on four fronts: (1) quantifying selection bias to spotlight underrepresented perspectives on specific topics or events; (2) broadening sentiment analysis to include entities beyond politicians; (3) extending the framework to socially impactful areas; and (4) embedding the methodology into recommendation algorithms to diversify political news feeds—a critical step toward mitigating algorithmic polarization.

62%
of French people get their news via social media
(Guénaëlle Gault, David Medioni, Survey *"Les Français et la fatigue informationnelle"*, L'ObSoCo, Fondation Jean-Jaurès, ARTE, June 2022)

CEA-List analysis tool results: distribution of mentions and sentiment by gender in the most popular French media online.
© CEA



"Automated news characterization is a useful tool for navigating the complexity of opinions expressed in the press."

— **EVAN DUFRAISSE**

"The tool provides journalists with an analysis that combines objective and subjective perspectives in news articles."

— **VRT (AI4MEDIA PROJECT PARTNER)**

SONDES SOUIHI
RESEARCH ENGINEER
© CEA

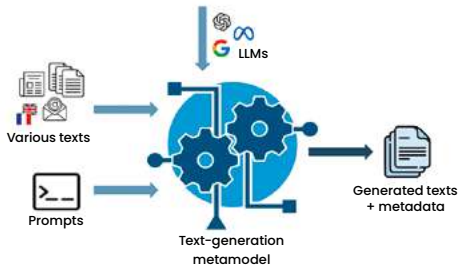
ROMARIC BESANÇON
RESEARCH ENGINEER
© CEA

Detecting texts generated by artificial intelligence

Today, large language models (LLMs) can produce customized texts similar to those written by humans, creating new cyberattack vectors. At the request of cybersecurity firm Vade, CEA-List engineered a first line of defense: AI-generated text detection. The solution pairs a system for generating text from target data with an AI-generated text detector.

The text generation system (Figure 1) integrates a generation meta-model compatible with state-of-the-art LLMs. It ingests source texts in French or English and produces similar outputs (models used: Llama2 7B Chat, Flan-T5 XXL, Bloomz 7B1 Mt, Falcon-7B Instruct, GPT4All 13B Snoozy, and OpenAI GPT-3.5).
The detection system (Figure 2) identifies AI-generated text using a "black-box" approach applicable to both open-source and proprietary models. Built around a fine-tuned multilingual model, it classifies input text and assigns a confidence score. Bidirectional transformer models proved more effective for this task than autoregressive models. In F1-score performance, mDeBERTa V3 almost always outperformed mBERT and XLM-RoBERTa.
To generalize the system across diverse datasets, experiments focused on mDeBERTa V3, with F1 scores detailed in Figure 3.
These results validate the black-box approach's effectiveness and highlight the critical role of diversified training data in enhancing detection robustness.

1



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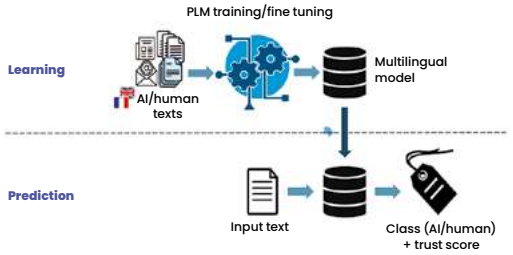

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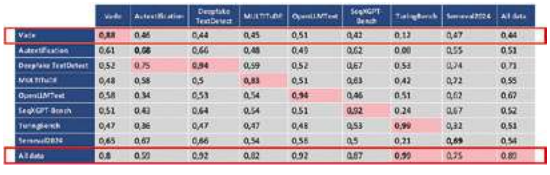

1 Text generation process.
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2 AI-generated text detection process.
© CEA

3 Experiments with crossing datasets: evaluating the generalizability of the mDeBERTa V3 model.
© CEA

CHIARA SANDIONIGI
RESEARCH ENGINEER
AND EXPERT
© CEA

BÉNÉDICTE ROBIN
ECO-INNOVATION
PROGRAM MANAGER
© CEA

EECONE: A major European project on the sustainable development of electronics

Electrical and electronic waste is one of the fastest-growing waste categories in the EU, with only 40% currently recycled. As part of the European project EECONE, the CEA is exploring strategies to effectively reduce electronic waste, minimizing environmental impacts while improving reliability, repairability, refurbishment, reuse, and recyclability.

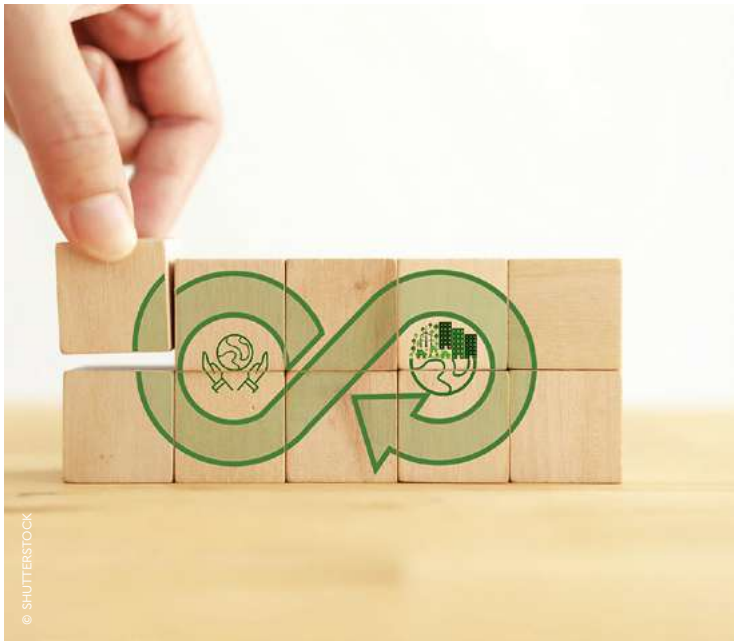
EECONE aims to create a European ecosystem for developing electronic systems and components with low environmental impacts, integrating a reduction of the electronic waste. Three CEA institutes—CEA-List, CEA-Leti, and CEA-Liten—are contributing, with a particular focus on design-assistance metrics.

Central to the initiative are two complementary strategies to address electronic waste that must be evaluated together: improving the environmental performance of electronic components and systems and ensuring their operational reliability over time.

To measure progress, the CEA has introduced two novel metrics. Eco-reliability is defined as the ratio between a system's operational lifespan and a second metric, the System Earth-equivalent Time (SET). The SET represents the time required to regenerate or recover the resources consumed during the production and use of an electronic component or system.

The primary goal of the eco-reliability metric is to enable rapid comparison of different designs for the same electronic component or system. It can also be used to quickly compare the sustainability of various electronic products. [1]

[1] https://www.europarl.europa.eu/topics/fr/article/20201208STO93325/dechets-electroniques-dans-l-union-europeenne-faits-et-chiffres-infographie



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Publication

"Eco-reliability: A new metric for the eco-design of electronic systems"
C. Sandionigi
IEEE SusTech 2024

Video introduction to the EECONE Project

CHIARA SANDIONIGI
RESEARCH ENGINEER
AND EXPERT
© CEA

BÉNÉDICTE ROBIN
ECO-INNOVATION
PROGRAM MANAGER
© CEA

Characterizing eco-innovation in a technological research project

As awareness of planetary boundaries and the desire for more sustainable solutions grow, industrial and academic stakeholders are setting their sights on eco-innovation. However, when applied to technology, the concept is hindered by inconsistent terminology and varying definitions. To address this challenge, CEA-List conducted a study to clarify associated terms and definitions and produce a methodological framework.

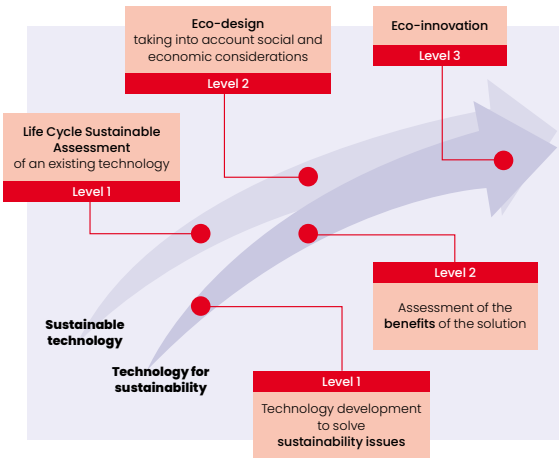
Despite increasing societal interest in eco-innovation, its practical application has been stunted by inconsistent concepts and definitions. CEA-List researchers analyzed existing literature and standards to establish clarity in eco-innovation terminology. The goals of this work were threefold: to define a framework for positioning sustainable development research activities; to provide guidelines for achieving eco-innovation ambitions; and to ensure consistency across related concepts.

The primary outcome of the study was the creation of a methodological framework designed to characterize and align research projects and technological developments toward sustainable innovation.

The framework organizes research and development activities along two axes and three levels. The first axis, Sustainable Technology, focuses on sustainable development driven by technology, emphasizing the reduction of its direct environmental impacts. The second axis, Technology for Sustainability, prioritizes the application and use cases of technology, ensuring it serves sustainability objectives. The three levels are grounded in international standards, in particular ISO 14040 and ITU-T L.1480.

This shared vision, adopted internally at CEA-List, has also gained external recognition. A paper detailing the framework was accepted at the Electronics Goes Green conference (Berlin, June 2024), a premier gathering of leading stakeholders in sustainable development of electronics.

Description of identified research and technology development activities on the path to eco-innovation.
© CEA



Publication

"Sustainable technology and Technology for sustainability: The paths towards Eco-innovation"

C. Sandionigi, J.-F. Berrée, M. Péralta, A. Piel, B. Robin
Electronics Goes Green 2024

CAROLYNN BERNIER
EXPERT AND
RESEARCH ENGINEER
© CEA

ILIAS IAKOVIDIS
DG CONNECT
EUROPEAN COMMISSION

The Digital Product Passport is becoming a reality in Europe

To improve repair and recycling and reduce the environmental impacts of goods, Europe has officially adopted the Digital Product Passport. This initiative will streamline access to information on the full lifecycles of products on the European market. The European project CIRPASS, coordinated by CEA-List, proposed a blueprint for the connected information system that will support the circular economy.

The project focused primarily on batteries, electronics, and textiles—industries with high recycling potential and significant environmental footprints. The proposed information system consists of a globally distributed database, though its large-scale deployment faces technical challenges, particularly in industries with limited digital maturity:

- Developing interoperable data-sharing systems;
- Implementing distributed approaches for identity management and data access permissions;
- Creating tools to support dual-purpose objectives (both regulatory and non-regulatory).

A technical specification for the system was developed in collaboration with the European Commission's inter-directorate committee (GROW, CONNECT, ENV, DIGIT).

As a critical piece of digital infrastructure for European industry, the passport unlocks new opportunities in data management and modeling, interoperability across data spaces, industrial digital twins, environmental impact assessment for products and services, and trusted distributed systems.

To support passport deployment across four targeted sectors, CEA-List is now leading the CIRPASS-2 project (2024–2027), which includes a comprehensive evaluation of the system's environmental impact at every stage.

© Getty Images

"CIRPASS and CIRPASS-2 are at the crossroads of technological innovation and environmental considerations."

— **CAROLYNN BERNIER**

"CIRPASS is one of the most important projects for meeting EU objectives around product sustainability, the circular economy, supply chain traceability, and the domestic market."

— **ILIAS IAKOVIDIS**

The adoption of the Digital Product Passport will lead to significant gains in high-purity recycled materials:

from 6% to 78%	from 13% to 84%	from 24% to 81%
for plastics	for aluminum	for steel

Source: https://eur-lex.europa.eu/resource.html?uri=cellar:ccd71fda-b1b5-11ec-9d96-01aa75ed71a1.0001.02/DOC_1&format=PDF

JEAN-PIERRE GALLOIS
RESEARCH ENGINEER

NICOLAS RAPIN
RESEARCH ENGINEER

System engineering for future nuclear power plant operation

The tightening of operating regulations by nuclear safety authorities post-Fukushima has led to increased workloads for plant operators. To boost automation in the operation of its future nuclear power plants, EDF has partnered with CEA-List. The collaboration aims to create a systems engineering environment for designing new operational control systems.

Conducted at the CEA-EDF-Framatome research institute (I3P), this project seeks to deliver an integrated environment for multidisciplinary engineering teams (operations, ergonomics, etc.) and plant operators. It will enable prototyping and evaluation of I&C architectures with diverse requirements, including functional and safety criteria. The environment will also incorporate tools for real-time operational requirements monitoring and operator training.
The project has four components:

1. Automation of operational requirement monitoring using the ARTiMon tool to prevent undesirable or suboptimal operational practices;
2. Topological transformation of mechanical schematics for control-specific applications, with the central data model defined in our Papyrus tool;
3. A formalization language (combining process algebra and fuzzy logic) to convert operational procedures—currently represented as flowcharts or in natural language—into virtual operators for validation;
4. An I&C function tool to assign system roles.

The environment will link multiple modeling levels, allowing engineers to measure how design changes impact interconnected systems. Integration with existing nuclear engineering tools is also being explored.
ARTiMon is currently being brought to market at EDF's request. Meanwhile, the I&C function allocation tool is undergoing internal deployment within EDF.

"CEA-List contributed innovative technologies through a digital lab designed for our people in charge of developing tomorrow's nuclear I&C systems."

— **LAURENCE PICCI, RESEARCH ENGINEER, EDF R&T**

© FRhodes/CEA

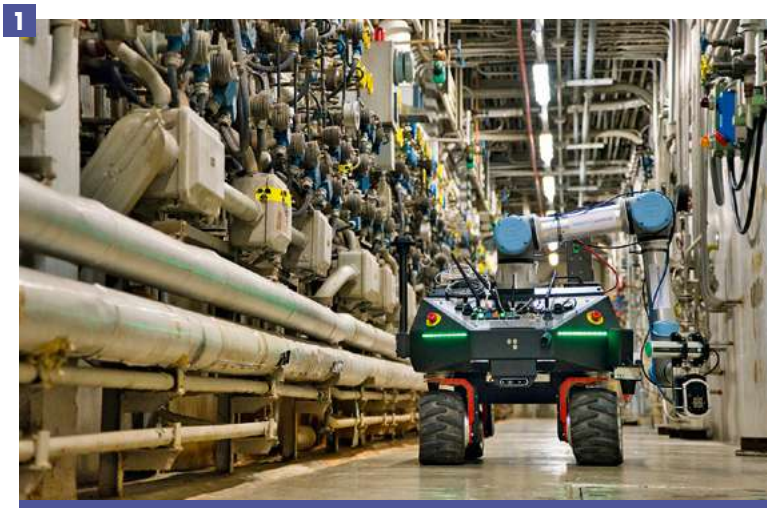
MAUGAN MICHEL
EXPERT

Technological innovations for nuclear decommissioning

CEA-List is driving progress in digital instrumentation for nuclear dismantling and decommissioning (D&D), critical for the safety and public acceptance of nuclear power. We are contributing through three PhD contracts funded under the FOCUSDEM program and *in situ* demonstrations of radiological measurement technologies as part of the European CLEANDEM project.

The results of the FOCUSDEM program and CLEANDEM project mark a pivotal shift in optimizing the D&D operations essential to the life cycles of nuclear facilities, whether aging or newly planned.
The FOCUSDEM-funded PhD theses, supported by CEA-List, addressed three major challenges in the radiological characterization of decommissioning sites—a cornerstone of operational safety. Andréa Macario Barros' research focused on a modular system for radiological mapping. This system automates sensor localization with SLAM (simultaneous localization and mapping) technology, enabling more precise data acquisition and significantly reducing human error. This breakthrough is vital for reliably mapping contaminated areas, a key priority for field operators.
Dilan Tüzün's research, building on pioneering work by the LNHB *(Laboratoire National Henri Becquerel)*, developed moldable or deformable radioactive sources tailored to the diverse surfaces and materials encountered in the field, improving instrument calibration accuracy.
Aya Kanj's research advanced a portable neutron spectro-imager designed to identify neutron radiation sources. This system complements gamma imagers and proves particularly valuable in environments with shielding that blocks gamma detection.
In parallel, the European CLEANDEM project—dedicated to robotic measurement technologies for D&D—concluded with real-world demonstrations of three CEA-List innovations deployed on an autonomous robot:

1

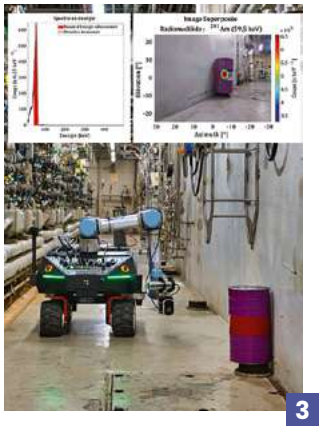


"These breakthrough innovations will improve detection, mapping, and identification of radioactive sources in D&D operations."

— **MAUGAN MICHEL**

- Nanopix3, a gamma spectro-imager, was successfully tested at SOGIN's Eurex site in Saluggia, Italy, where it located a ^{241}Am radioactive source in under 10 seconds at a 2-meter distance (dose rate at the camera: ~0.2 µSv/h), proving its effectiveness at rapid hotspot detection.
- The pixelated contamination monitor, designed to measure surface contamination on complex shapes, adapts to the irregular geometries of decommissioned structures for faster and more precise contamination assessments.

2



3

1 **3** The CLEANDEM robot at the Saluggia Eurex plant with Nanopix3 during the *in situ* measurement of a ^{241}Am radioactive source contained in a metal drum, with spectro-imaging reconstruction.
© CEA

2 Modular mapping system mounted on NuCoMo-100.
© CEA

- Finally, the integration of shape sensing and OSL/FO technologies combines optically stimulated luminescence in optical fibers with 3D fiber shape reconstruction to deliver accurate dose measurements, even in hard-to-reach locations.

These advances underscore CEA-List's commitment to addressing nuclear decommissioning challenges—a field where safety, precision, and technological innovation are more crucial than ever. They reduce worker exposure, enhance measurement accuracy, and streamline site management. They also enable greater automation, making processes more efficient and less hazardous for personnel.

"The system is also able to provide a digital model of the studied area, enriched with the radiological information provided by the sensors, allowing creation of a digital twin."

— **SOGIN**

Publications

Dissertation by Andréa Macario Barros, available on Thèses en ligne

Dissertation by Dilan Tüzün, available on Thèses en ligne

Dissertation by Aya Kanj, available on Thèses en ligne

Open access to CLEANDEM publications and data

Also read in the journal Robotics:
A Comprehensive Survey of Visual SLAM Algorithms
A. Macario Barros, M. Michel, Y. Moline, G. Corre, and F. Carrel

The technology in use

By delivering reliable radiological data, these technologies also pave the way for crisis management, accelerating information gathering. In the case of autonomous drones and robots, they can free first responders to focus on their primary tasks while an autonomous fleet collects data to avoid exposing them to radiological hazards.

Projects and partnerships

This work is part of ongoing R&D efforts, including CEA's participation in the European project XS-ABILITY, which aims to enhance and miniaturize Nanopix3 and a neutron/gamma measurement system for improved characterization of nuclear decommissioning sites—particularly by deploying them on drones and autonomous robots.

PAULINE DEVILLE
RESEARCH ENGINEER

Model-driven engineering for nuclear fusion reactor maintenance

Experimental nuclear fusion facilities involve many complex systems. The CEA's IRFM institute is already working on the maintenance requirements for the ITER installation. IRFM called on CEA-List's expertise in model-driven engineering to model maintenance processes in this complex environment.

The vast amount of engineering data generated by replacing experimental devices and managing ITER's multiple system configurations demands a more efficient approach than traditional documentation-based methods. CEA-List's open-source Papyrus platform, combining power and versatility, is ideally suited for detailed modeling of complex systems. Our researchers developed a new domain-specific language tailored to nuclear fusion system maintenance, enabling IRFM to model the assembly and disassembly phases of experimental systems. The platform demonstrated its ability to segment and visualize large datasets at two distinct scales:

- Tables for an overview (e.g. full replacement sequences);
- Diagrams for granular detail (e.g. partial sequence actions).

Once modeled, functional simulations of assembly/disassembly sequences can be run using Papyrus' Moka tool to validate model coherence and generate simulation traces. Future developments will integrate risk analysis *via* CEA-List's Sophia software, alongside requirements modeling and traceability. Additionally, coupling the Papyrus model with the virtual reality representation of the system in its environment will create digital continuity between the two, enhancing scenario analysis accuracy and relevance.

"Model-driven engineering is critical to the development of fusion reactors, especially when international cooperation is part of the mix."

— **JEAN-PIERRE FRICONNEAU, IRFM**

BAPTISTE TRUFFET
RESEARCH ENGINEER AND EXPERT

Monocrystalline diamond: a detector for nuclear fuel recycling

France has made increasing the nuclear fuel recycling rate a strategic priority. As of now, 96% of fuel is recycled after four years of use. To enhance alpha radioactivity measurement—critical for separating reusable materials from waste—CEA-List has developed a monocrystalline diamond detector resistant to extreme operating conditions.

The nuclear fuel recycling process involves multiple stages, from dissolving the used material in concentrated nitric acid to separating its constituent elements. Since these elements exhibit characteristic alpha radioactivity levels, precise measurement is essential for effective separation. The final phase relies on *in situ* alpha radioactivity measurement *via* a diamond sensor designed to withstand high pressure, temperature, and acidity.

Alpha particle detection is achieved through an active diamond layer that converts energy into electrical signals. The sensor's performance depends directly on the diamond's purity, homogeneity, and defect-free structure. An optimal sensor combines detection efficiency, signal stability, minimal current leakage, and operation at up to 80°C without performance loss. Additionally, the sensor's sealing mechanism ensures the system's overall leak-tightness. To refine the industrial separation process, our teams optimized both the sensor (by developing four diamond variants) and its mounting methods (four techniques using gaskets, resins, and brazing).

Our monocrystalline diamond detectors demonstrate

x9

greater charge collection efficiency compared to previous detectors.

"For nuclear fuel recycling, a monocrystalline diamond alpha radioactivity sensor offers remarkable efficiency and durability."

— **BAPTISTE TRUFFET**

MP-CVD reactor for diamond growth.
© CEA

This research yielded a new protocol for growing monocrystalline diamonds that balances performance, simplicity, speed, and cost. A novel sensor design—featuring a durable, supply-chain-resilient polymer gasket—was selected. The project is now turning its focus to manufacturing and characterizing a full prototype for real-world testing.

Making CEA-List a great place to work

Over the past few years, we've launched several initiatives to provide our employees with an attractive, welcoming work environment that fosters the emergence of new ideas. Whether it is creating spaces where all employees can gather, displaying art inside—and on—our walls, or strengthening our employer brand, we are making CEA-List a place people feel good about coming to every day.

Espace campus, a relaxed gathering place at Nano-INNOV

For the past two years, Nano-INNOV research engineers have been gathering in the new *Espace campus*. By encouraging informal conversations, the space helps make our workplace more conducive to creativity—and more relaxed. Located at Nano-INNOV, *Espace campus* is where our employees, academic and industrial partners, and visitors come together. *Espace campus* is also an alternative to the inter-company cafeteria, with quick food options selected to meet our employees' needs, tables where food brought in from outside can be enjoyed, plus cubicles and lounge areas where people can unplug, play board games, and organize a range of activities.
Espace campus has become a can't-miss for all Nano-INNOV staff and visitors looking for the perfect place to take a relaxing break during the workday.

***Espace campus* at Nano-INNOV.**
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Opening of the exhibition of Claude Mercier's works at Nano-INNOV.
© Philippe Ribeyrolles

Exceptional gift of sixteen works by artist Claude Mercier

CEA-List, as a member of Paris-Saclay University, received a donation of sixteen works by the French sculptor and painter Claude Mercier (1924–2019). The works are exhibited at Nano-INNOV and Digiteo.
This gift from the artist's widow, Mrs. Colette Mercier, was given as part of Paris-Saclay University's long-standing art acquisition policy. Over the years, this policy has allowed many University-affiliated institutes and research organizations, including the CEA, to receive donations. In addition to CEA-List, several University institutions, such as Neurospin and Cachan IUT, will enjoy Mercier's sizeable collection.
Claude Mercier is internationally recognized for his innovative exploration of shapes and materials—particularly metals—that left the artist's unique mark on the contemporary art world. His works, which combine sculpture and painting, are now bringing a new artistic dimension to our workspaces. This donation is the first step in cultivating a growing collection through further donations.

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