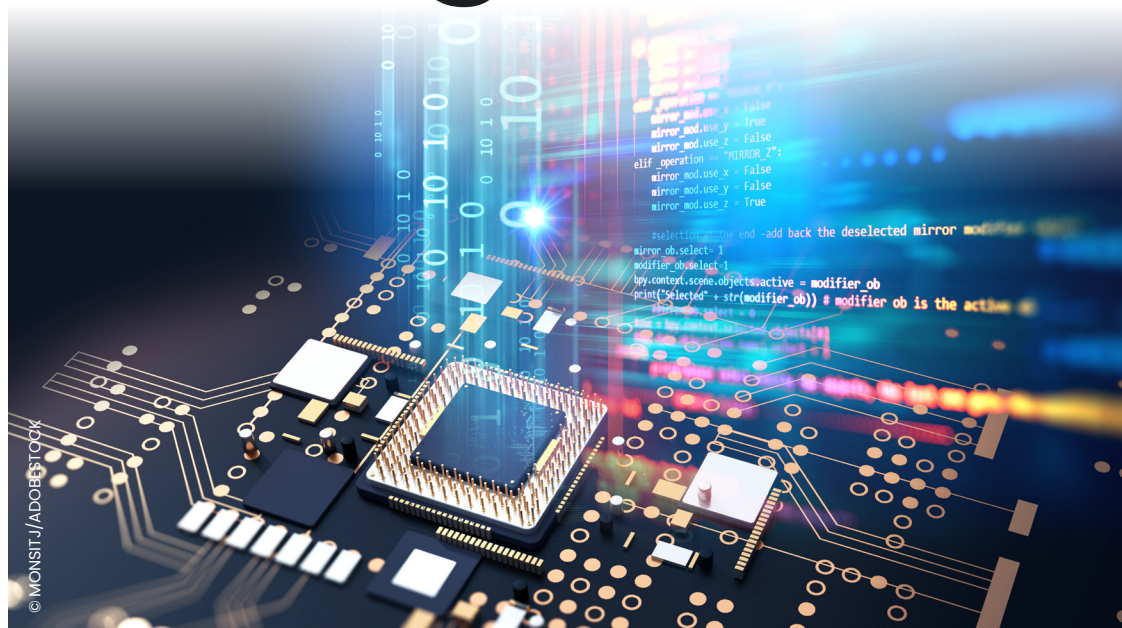# Edge Artificial Intelligence

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CEA LETI

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About edge artifical intelligence

Bringing edge artifical intelligence to life

Artificial Intelligence is no longer an abstract concept, it already fuels our everyday life with communication tools (e.g Google "Smart Compose" feature, Siri, etc). Tomorrow, AI will play a greater and perhaps a more important societal role, predicting and assessing our health risks, providing customer support, easing trafic congestion. Cars will be packed with AI features, including speech and gesture recognition, eye tracking, and so on.

Some of these applications will require unprecedent responsiveness (e.g. braking systems). In such a context, the Cloud only will not do. AI will also need to be supported locally, meaning at the Edge. Algorithms will need to be processed locally, directly on the hardware device.

With the General Data Protection Regulation in mind, European Commission for Internal Market set the challenge: 80% of data will need to be processed directly within the hardware over the next five years. Currently, only 20% are being supported locally.

CEA-Leti's experts mission will consist of combining high performance computing capacity with low energy consumption in ultra-miniaturized systems, at low cost.

Systems supporting AI at the edge will need to be able to perform thousands of billions of operations per second, consuming a single Watt or even less.

Bridging the gap: privacy and efficiency

Because connection to the Cloud or any kind of networks won't be required anymore, systems will be fully independent, able to process data and take decisions by themselves. Systems will be able to operate independently, translating into increased cybersecurity. The absence of back and forth between the object and a distance platform will help keeping citizen's data safe and private. Beyond privacy, Edge AI addresses various current technical challenges, by offering:

- **Energy sobriety:** more than 90% of data sent to the Cloud is never used again. Beyond trim waste, it has become vital to drastically reduce data transfers and cut on data storage cost.
- **Greater autonomy with fully independent systems:** In fact, complex decisions without depending on the Cloud are key for medical devices providing continuous treatment (i.e diabetics).
- **Continuous safe operation:** applications such as autonomous vehicles or production lines will require continuous safe operation.
- **Low latency:** a current data ride from a sensor to the Cloud located at 1,500+ km and back takes about 10 ms. Edge AI will help reduce latency to 1 ms or less.

Diabeloop

Diabeloop is a French independent company developing in partnership with CEA-Leti disruptive technological innovations to automate the treatment of Type one diabetes.

Its first product, the DBLG1 System, is an integrated system that allows glycemic control in an automatic and highly efficient way. The core of this innovation is an Artificial Intelligence hosted on a terminal that connects via bluetooth with a continuous glucose meter (CGM) and an insulin pump. The algorithm makes and executes the many therapeutic decisions that the patients currently have to handle by themselves. Patients are only expected to log meals and physical activities.

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Soft & hardware: the perfect match

Until recently, everything you needed to know about AI was software-related. Edge AI has slightly changed the tune, with the need for on-device algorithm processing.

As algorithms are becoming more and more complex to address most advanced AI, hardware is requiring new microelectronic solutions to meet the evolving demands of IoT packed with AI.

Transfer cloud-based software solutions within a highly miniaturized chip is no small task. Of central importance is the need to achieve unprecedented efficiency and speed in the collection and analysis of data, while also managing power consumption and form factor. In the hardware domain, this will require innovative thinking and new paradigms in sensors, processors, memory, interconnection, and packaging.

Both memory and computing capacity are key to determine the cost / performance ratio of an AI solution, including the design of algorithms. Because Software and Hardware are now going hand in hand, CEA-Leti collaborates with CEA-List to develop the best Hardware/Software solutions that will support AI locally. The program offers common laboratories to tailor, in partnership with industrials, complete solutions, from algorithms solutions to chip design.

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Spirit

CEA-Leti introduced SPIRIT, the world-first fully integrated neural network on-chip with non-volatile resistive memory. So far, memories were placed outside of chips leading to high energy consumption. With this co- integration in the same die of analog spiking neurons and resistive synapses leveraging resistive random access memory cells (RRAM), CEA-Leti enables the push for distributed computing devices to support artificial intelligence at the edge. These spiking neural networks are designed by CEA-Leti and the RRAM are fabricated in a post-processat CEA-Leti on CMOS-based wafers.

Edge AI: the fast & chip need

Because conventional chips can't keep up with the upcoming of most sophisticated AI supported within devices, a growing need for semiconductor technologies has emerged. Yesterday's Cloud-based Web giant are now heavily investing into the semiconductor industry, and actively looking for new R&D solutions to migrate most AI to the edge.

To help industry keep up the race and integrate AI into already ultra-miniaturized chips, CEA-Leti's launched a specific Edge AI program to pioneer quick and reliable semiconductor solutions, from computing, sensing to data storage.

In-memory computing

One focus is a fundamental problem of modern computing, moving data between memory and processor now costs vastly more than computation. Data transfer and memory access account for up to 90% of system energy usage. CEA-Leti is specifically developing neuro-inspired architectures to explore new programming models, and "In-Memory Computing" to bridge the gap between memory and logic units.

CEA-Leti and its partners are involved in MYCUBE an ERC-backed project to stack memories onto processors. The ERC-backed My Cube project is setting its sights on the first-ever in-memory computing technology. The goal is to be able to carry out simple computations directly in a circuit's memory. A demonstrator built on silicon nanowires—the most appropriate for the application—and non-volatile resistive memory will be completed in 2022, using 20 times less energy than a conventional circuit. CEA-Leti work on advanced 3D stacking strategies to integrate an additional memory layer on top of the logic unit.

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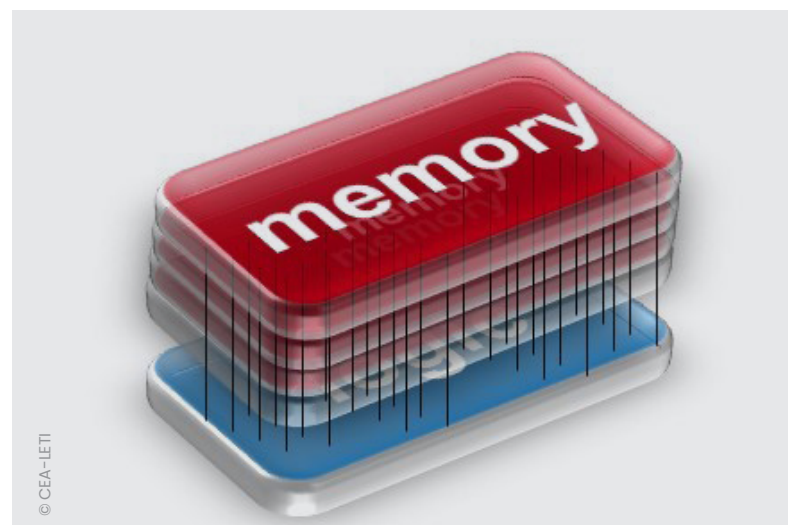
3D stacking strategies (in-memory computing)

Increasing data storage capacties

For data storage, the institute leverages its expertise in resistive non-volatile memories, including OxRAM and PCM. Resistive non-volatile memories are very power-frugal as they may quickly shift from an active saving mode to a sleeping mode. Compatible with standard CMOS processes, they are key to future edge-AI chips, for both embedded high-performance applications, like in cars or satellites, and ultra-low-power smart sensors.

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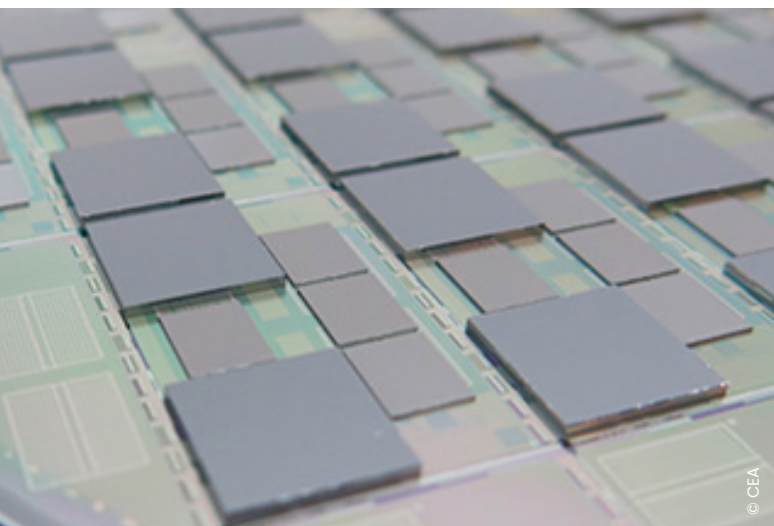
CEA-Leti and Intel partnership on 3D technologies

In October 2020, CEA-Leti and Intel have announced a new collaboration on advanced 3D and packaging technologies for processors to advance chip design. The research is focusing on assembly of smaller chiplets, optimizing interconnection technologies between the different elements of microprocessors, and on new bonding and stacking technologies for3D ICs, especially for making high performance computing (HPC) applications.

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The need for technologies

Supporting industrials

Industrial solutions for 2025

In 2019, CEA-Leti launched a program dedicated to responding to the growing and urgent need of industry for solutions to successfully migrate artificial intelligence to the edge. The program brings together some 50 multidisciplinary experts through various partnerships, possessing all the necessary skills to develop hardware and software solutions, capable of supporting Edge AI.

The goal is to tailor highly reliable and low-power solutions leveraging new approaches inspired by neural networks, combining digital and analog technologies. Consequently, the Van Neumann approach has been replaced by neuromorphic approaches and innovative hardware architectures featuring in-memory computing.

From the design phase to manufacturing, CEA-Leti experts and the program's partners' mission is to develop solutions that will be marketable by 2025.

Rethinking the architecture of electronic chips

To create hardware solutions from scratch that combine high-performance computing and energy efficiency using low-cost, integrated SoC components, the program's experts are looking into ways of designing innovative architectures, and neuromorphic architectures in particular, capable of:

- Bringing the computing units and the data storage units closer together
- Making full use of the potential of non-volatile memories capable of keeping the information even when the power supply is off
- Positioning the memories above the computing units or leveraging in-memory computing
- Combining the sensors and imagers with AI computing units, and
- Developing algorithms specific to Edge AI.

A multi-domain expertise

Software to hardware: a multidisciplinary team

The development of high-performance, low-cost and low-consumption Edge AI solutions requires a broad range of skills in the development of non-volatile memories, sensors and circuits, including the development of advanced algorithms, such as incremental machine learning.

CEA-Leti's Edge AI program relies on a multidisciplinary team, from several institutes, capable of providing competitive, made-to-measure solutions that can be industrialized quickly. The program brings together some 50 experts from various institutes, such as CEA-Leti and CEA-List.

Bio-inspired solutions

The research engineers from the Edge AI program are working with biologists and researchers in cognitive psychology to draw inspiration from working mechanisms in the living world that are both energy-efficient and possess an unbelievable capacity to adapt. They are developing neuromorphic hardware systems, equipped with artificial neurons and synapses that optimize energy-consuming interactions. Specifically, the team is exploring three paths of research:

- Impulse data coding, similar to the brain's neurons, that is both efficient and noise-resistant
- The development of dense, non-volatile memory technologies to implement the synapses, in order to bring them and the neurons as close together as possible
- The development of impulse sensors, vision sensors and micro electromechanical systems (MEMS) to take inspiration from the communications mechanisms in the natural world.

### Incremental machine learning

The recently developed, bio-inspired hardware will host the incremental machine-learning solutions that the program is also developing. Unlike current AI solutions, which require enormous learning databases, future Edge AI solutions will be able to learn gradually and economically.

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Edge Artificial Intelligence Team

Collaborative projects – success stories

The program is open to all profiles of industrial manufacturers that are looking for competitive, tailor-made solutions for incorporating artificial intelligence in their products now or in the future. The team is developing innovative and competitive technological solutions for major groups, SMEs and even start-ups. It also offers both differentiating technological building blocks and complete solutions, from software to hardware, from design to packaging, and from prototyping to small production runs.

The program demonstrators
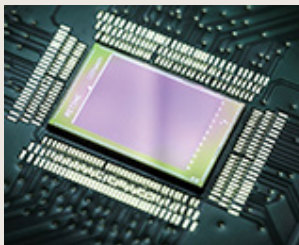
Retine

Programmable vision chip enabling high frame rate and low latency image analysis
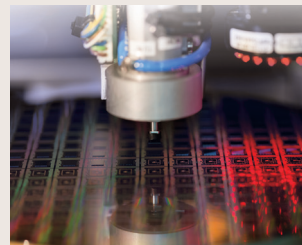
Intact

3D technologies for chiplet-based advanced system

Spirit

Spiking neural networks enabling massively parallel, low-power & low-latency computation

Sigma Fusion

Safe perception with low power sensor fusion solution based on Aurix™ second generation

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Ecosystem

Grenoble: a center of excellence

In 2019, Grenoble was cited by an international jury and the French government as one of the four French centers for artificial intelligence.

In addition to drawing from the concentration of AI expertise in the Grenoble-Alpes region, this program includes other French and international experts from the worlds of research, education and private enterprise to harness scientific excellence and build a French and European AI offer.

The regional partner companies and institutes include STMicroelectronics and Schneider, plus Inria, Grenoble-Alpes University and INP-Grenoble.

MIAI @ Grenoble-Alpes institute

CEA-Leti is a special partner of MIAI Grenoble Alpes Institute (Multidisciplinary Institute in Artificial Intelligence) located at Université Grenoble Alpes (UGA).

Though, MIAI plays a major role in:

- Artificial Intelligence (related to health, environment and energy fields
- Offering attractive courses for students and professionals of all levels
- Support innovation in large companies, SMEs and startups.

In concrete terms, the program's €54 million budget enables all these multidisciplinary players to manage a number of public-private collaborative projects focusing on application-oriented subjects, and it finances 28 chairs of excellence in seven subjects, including built-in AI, health, industry 4.0, the environment and energy, and societal issues.

CEA-Leti actively contributes to these four chairs as part of the Edge AI program, in an effort to overcome the limits of neuromorphic architectures for AI, to provide better support for patients in the management of their treatment and to optimize telecommunications networks.

Edge AI in European projects

European alliances and partnership are vital to the suces of our multiple programs in which CEA-Leti is involved, as a project coordinator or as a partner.

CEA-Leti's formed an alliance with IMEC (Belgium) and Fraunhofer/FMD (Germany) to developp a pan-Euopean Technological platform to design, manufacture and test prototypes, including those using Edge AI or those which have a purpose on it.
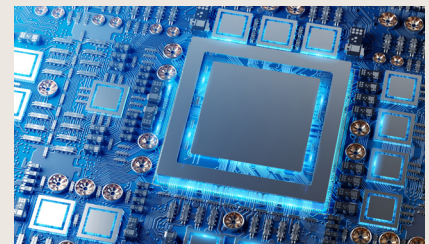
NEURAM3

Neural computing architectures in advanced monolithic 3D-VLSI nano-technologies

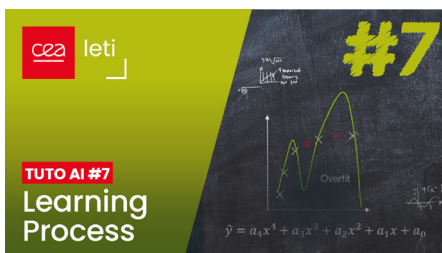### NEUROTECH

Neuromorphic Technology

TEMPO

Technology and hardware for neuromorphic computing

APPENDIX

AI tutorials

CEA-Leti host a series of tutorials to help anyone trying to understand the technologies behind artifcial intelligence.

TUTO AI #1
A brief history of Artificial Intelligence

TUTO AI #2
Machine Learning: Learning from Data

TUTO AI #3
Why dataset are so important?

TUTO AI #4
Models for Artificial Neurons

TUTO AI #5
Neuronal Networks Capacities

TUTO AI #6
Neural Network Architectures

TUTO AI #7
Learning Process

$$\hat{y} = a_4x^4 + a_3x^3 + a_2x^2 + a_1x + a_0$$

TUTO AI #8
More than just neurons: Reinforcement learning & GAN
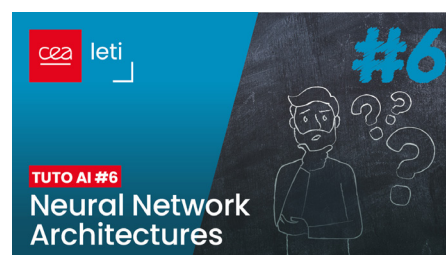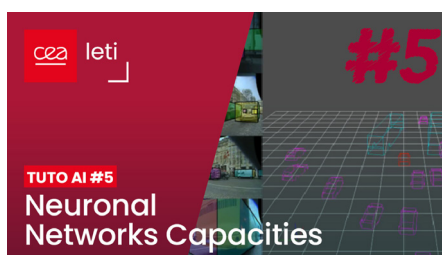
APPENDIX

Biography of Emmanuel Sabonnadiere, CEO of CEA-Leti

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Emmanuel Sabonnadière has been the Director of CEA-Leti since 2017, after occupying various strategic positions.

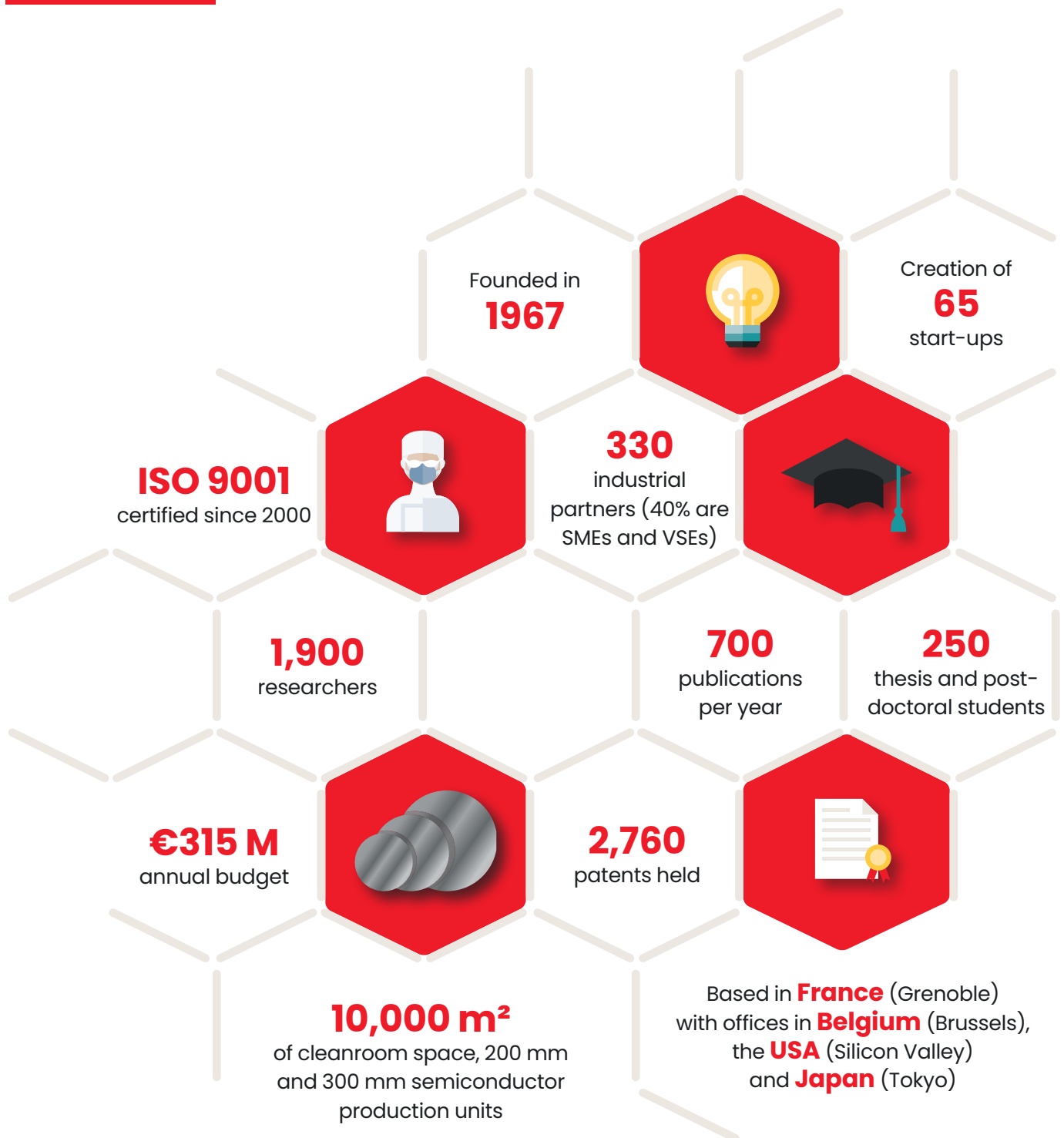From 2014 to 2017, Mr. Sabonnadière headed the "Professional" Division of Philips Lighting in Amsterdam (Netherlands), following five years at the head of Alstom T&D's Transformer Division. From 2008 to 2014, he held the position of CEO of General Cable Europe in Barcelona (Spain); and from 2005 to 2008, was CEO of NKM Noel in Würzburg (Germany). Mr. Sabonnadière started his career in 1992 with Schneider Electric, where he held several strategic positions in product development. Serving the industry for over 25 years, Mr. Sabonnadière improves operational performance by building motivated teams. He has acquired solid experience in multicultural management, developing new markets both in Europe and globally. Innovation is key to all his actions.
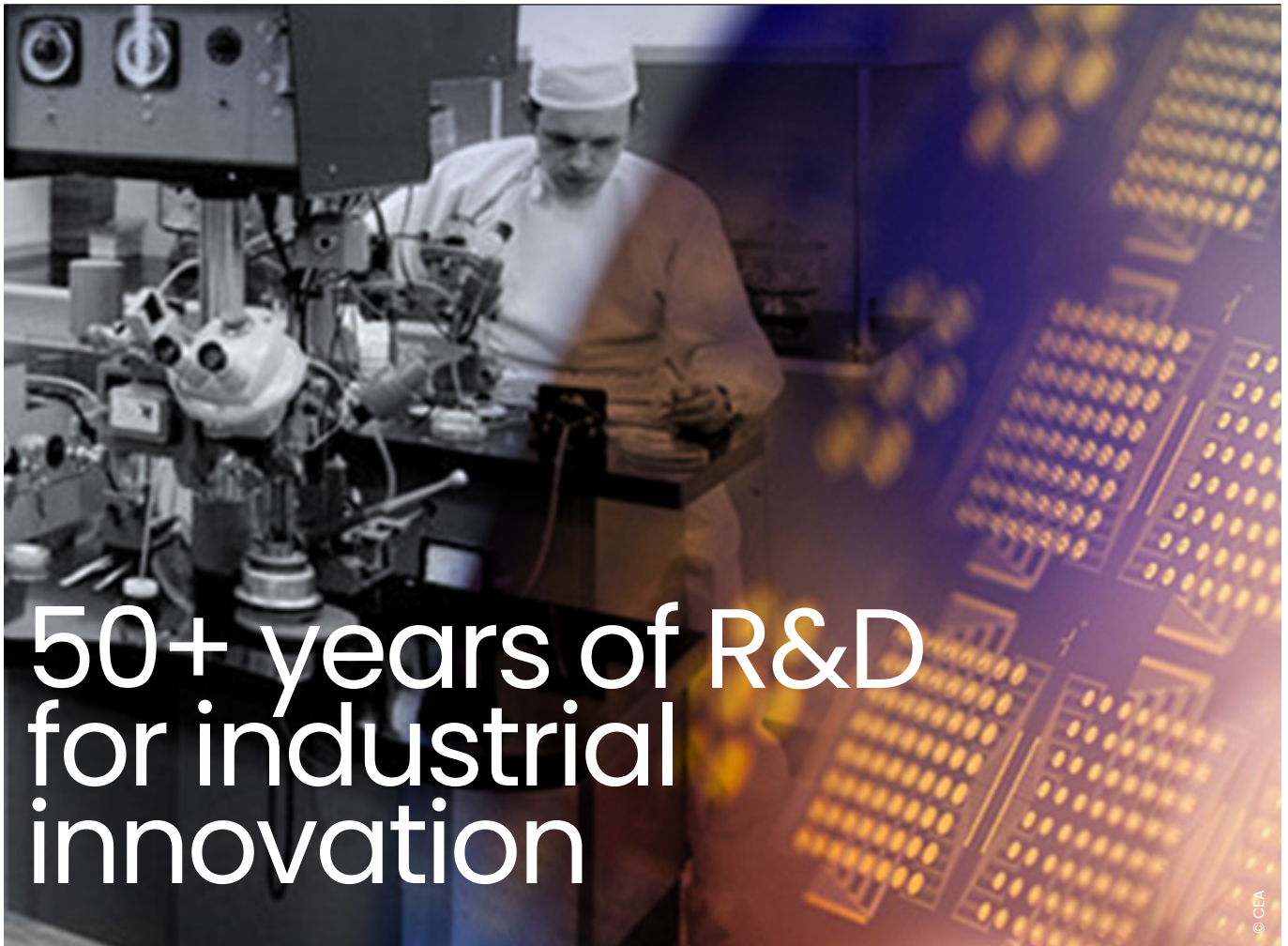
Emmanuel Sabonnadière's outlook is shaped by operational excellence, technological innovation, talent management, and enthusiastic team building. Emmanuel holds a Ph.D. degree in physics from the Ecole Centrale de Lyon, a master's degree in electrical engineering from the Université Technologie Compiègne and an MBA degree from the Ecole Supérieure des Affaires de Grenoble.

Emmanuel Sabonnadière also chairs the Nanoelec IRT (Technological Research Institute) and is the president of CEA-Leti Carnot Institute. He is president of France's industry strategic committee (CSF) for bioproduction and a member of the CSF for "electronics industry." Finally, Mr. Sabonnadière is a member of SEMI's European Council and has been assuming chairmanship for the JESSICA France Association since January 9, 2020 (CAP'TRONIC program).

APPENDIX

CEA-Leti in brief

Founded in **1967**

Creation of **65** start-ups

ISO 9001 certified since 2000

330 industrial partners (40% are SMEs and VSEs)

1,900 researchers

700 publications per year

250 thesis and post-doctoral students

€315 M annual budget

2,760 patents held

10,000 m² of cleanroom space, 200 mm and 300 mm semiconductor production units

Based in **France** (Grenoble) with offices in **Belgium** (Brussels), the **USA** (Silicon Valley) and **Japan** (Tokyo)

© CEA

50+ years of R&D for industrial innovation

I n 1957, an "integrated electronics" research group was formed at the CEA in Grenoble. It was tasked with the design and maintenance of nuclear reactor electronic systems and to a range of civil and military nuclear engineering needs. At that time, many integrated circuits were produced in American factories and this motivated Leti's integrated electronics group to develop its own transistor technology. In 1963, the Institute produced its first integrated circuit and, in 1966, it announced production of the first MOS transistor.

The CEA integrated electronics group became the "Laboratoire d'électronique et de technologie de l'information" (Leti) on October 10th, 1967. Very quickly, Leti was organized to work and set up partnerships with industry. The *Étude et fabrication de circuits intégrés spéciaux* [design and production of special integrated circuits] subsidiary, known as Efcis, was founded in 1972. In 1982, it was integrated into Thomson Semiconducteurs, a company that merged with Italian SGS to form STMicroelectronics.

In 1976, CEA-Leti produced and installed the first French scanner at Grenoble's General Hospital.

Six years later, in 1982, the Institute completed construction of 6,000 m² of buildings, including 2,000 m² of cleanrooms, in response to development needs in microelectronics, infrared technologies and magnetometry. Initial developments in micro-electro-mechanical systems (MEMS), especially accelerometers, were achieved at this time. CEA-Leti lodged a first generic patent for silicon-based comb capacitive lateral micro-accelerometers.

Minatec was founded in 2006 around Leti's activity, the aim being to bring together academic research, R&D laboratories and industry. Minatec focuses on micro- and nanotechnologies, and constitutes a new model for the research-education-innovation "knowledge triangle". Today, this model structures the formation of major French university campuses like Paris-Saclay and Giant (Grenoble).

San Francisco

Brussels

CEA-Leti
Head Office

Tokyo

About CEA-Leti (France)

CEA-Leti, a technology research institute at CEA, is a global leader in miniaturization technologies enabling smart, energy-efficient and secure solutions for industry.
Founded in 1967, CEA-Leti pioneers micro-& nanotechnologies, tailoring differentiating applicative solutions for global companies, SMEs and startups. CEA-Leti tackles critical challenges in healthcare, energy and digital migration. From sensors to data processing and computing solutions, CEA-Leti's multidisciplinary teams deliver solid expertise, leveraging world-class pre-industrialization facilities. With a staff of more than 1,900, a portfolio of 3,100 patents, 11,000 sq. meters of cleanroom space and a clear IP policy, the institute is based in Grenoble, France, and has offices in Silicon Valley and Tokyo. CEA-Leti has launched 70 startups and is a member of the Carnot Institutes network. Follow us on cea-leti.com and @CEA_Leti.

Technological expertise

CEA has a key role in transferring scientific knowledge and innovation from research to industry. This high-level technological research is carried out in particular in electronic and integrated systems, from microscale to nanoscale. It has a wide range of industrial applications in the fields of transport, health, safety and telecommunications, contributing to the creation of high-quality and competitive products.

For more information: cea.fr/english

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