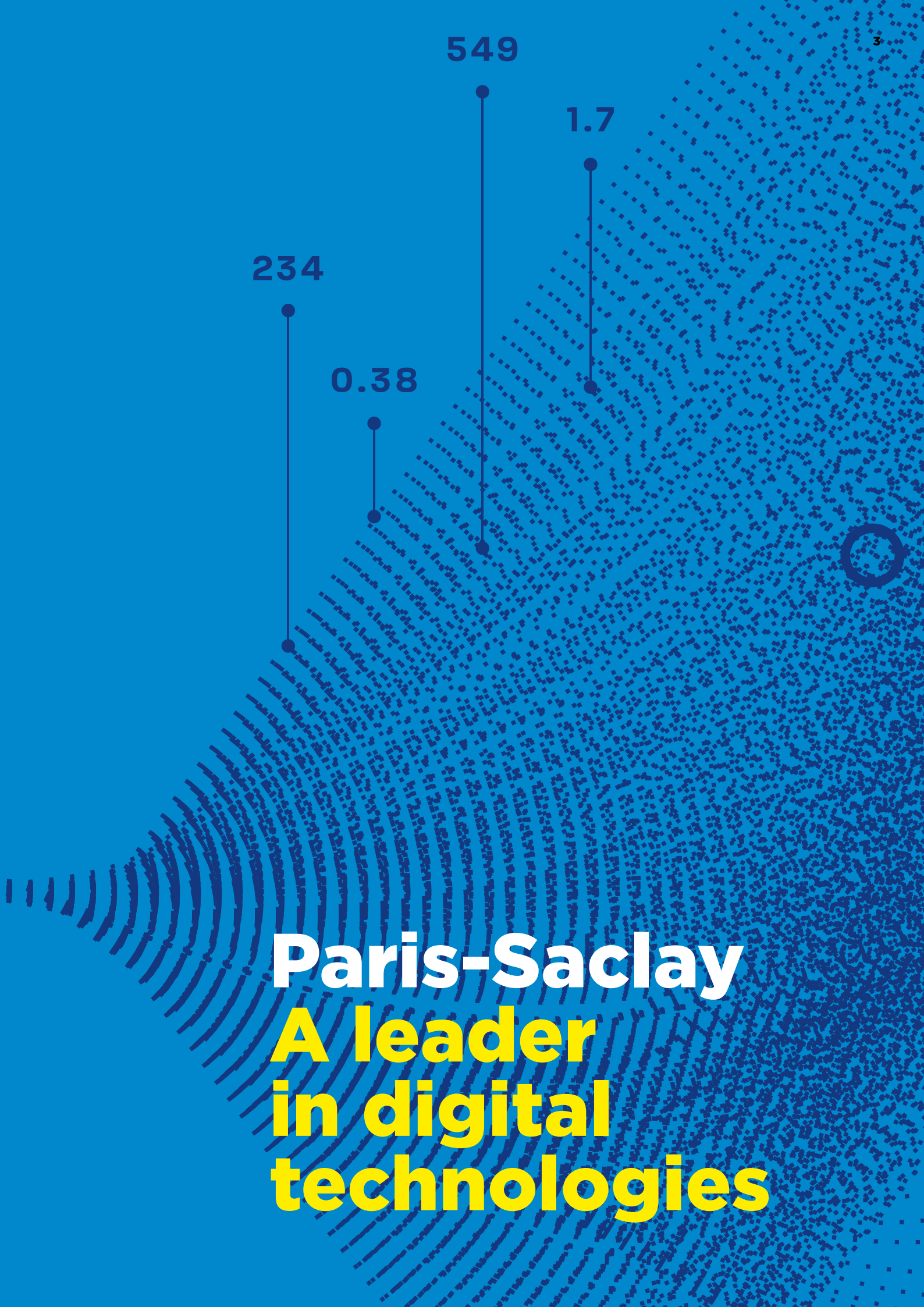


Paris-Saclay
A leader in digital technologies

Paris-Saclay, a region dedicated to innovation

With 15% of national research and 40% of public and private research jobs in the Paris Region, the Paris-Saclay science and technology cluster is one of the eight most powerful innovation clusters in the world, alongside Silicon Valley, Boston, Tech City London, Beijing, Bangalore, Skolkovo Innovation City in Russia and Israel's Silicon Wadi.

At the gateway to the French capital, this area spreads from Massy to Versailles via Saint-Quentin-en-Yvelines and is home to an exceptional concentration of higher education establishments, public research laboratories, private R&D centres and innovative companies of all sizes and reputations.

This density of resources and potential partners makes Paris-Saclay one of the most attractive innovation clusters for investors, innovators and entrepreneurs from all over the world:

- integration within the Paris Region, Europe's leading economic region*;
- excellence in education and research to the highest international standards, supported by Université Paris-Saclay and the Institut Polytechnique de Paris;
- a wealth of major scientific facilities and multidisciplinary laboratories;
- concentration, excellence and diversity of industrial players and start-ups;
- a rare quality of life in a setting that enhances the natural environment.

Created in 2010 by the Greater Paris Act, the Établissement public d'aménagement Paris-Saclay (EPA Paris-Saclay) works with local players to steer and coordinate the development of the science and technology cluster and ensure its international reputation. Its development strategy is based on three main areas: supporting innovation by leading a community of companies, start-ups and innovation centres;

One of the most attractive innovation clusters in the world.

*Source: INSEE

promoting the international appeal of the cluster and its Paris-Saclay Innovation Playground brand; and developing services to meet the needs of companies.

With this in mind, EPA Paris-Saclay is mobilising and federating industrial and academic players around strategic sectors to strengthen the links between public and private research, encourage innovation and entrepreneurship and stimulate the region's economic growth. Six areas of excellence have been identified, analysed and mapped: aerospace-defence-security, agritech-foodtech, energy-city-environment, mobility of the future, health and digital technologies. The purpose of this document is to present the digital technologies sector of excellence.

6 STRATEGIC SECTORS

Aerospace Defence Security

Airbus, Safran, Thales, Nexter, Arquus, etc.

16* start-ups
68 laboratories and platforms

#NewSpace
#Cybersecurity

AgriTech and Foodtech

Danone, Mondelez, Syngenta

77* start-ups
110 laboratories and platforms

#FoodOfTheFuture
#NutritionHealth
#SmartFarming

Energy City Environment

EDF, Bouygues, Colas

47* start-ups
123 laboratories and platforms

#EnergyStorage
#Biofuel
#SmartGrids

Mobility

Renault, PSA, Valeo, Fiat, etc.

12* start-ups
46 laboratories and platforms

#AutonomousCar
#Hydrogen
#On-BoardSystems

Health

Sanofi, LFB, IPSEN, GE Healthcare

146* start-ups
346 laboratories and platforms

#Microbiota
#GeneTherapy
#Oncology
#ConnectedHealthcare

Digital technologies

Nokia, Ericsson, HP, Dassault Systèmes, etc.

106* start-ups
252 laboratories and platforms

#AI
#Quantum
#IoT
#SmartManufacturing

*Currently listed on paris-saclay-startup.com

Digital technologies for the industry of the future

Modernising production systems to become more competitive, transforming the way companies are organised to position themselves better in the face of international competition, digitising processes and encouraging the emergence of an industry of the future – these are the key challenges facing industry in France today.

Within these challenges, new digital technologies are, as mechanical engineering, electrical energy and electronics were in their day, the foundations of a fourth industrial revolution that is currently under way.

This move towards a digital industry based on the introduction of new technologies such as artificial intelligence, the Internet of Things, robotics and big data, is strongly supported at both national and European level, as illustrated by the France 2030 investment plan, which aims to transform key sectors of the economy over the long term through innovation and industrial investment, in particular through the major leverage provided by digital technologies.

This move towards the industry of the future is also within the innovations driven by the Paris-Saclay science and technology cluster, historically a leader in digital technologies in France. With 400 major establishments, over 250 laboratories and technical platforms, a growing number of innovative start-ups and 32,000 jobs, this sector of excellence is now one of the most dynamic in the region.

To examine the main features and priority issues, the Établissement public d'aménagement Paris-Saclay, in collaboration with SATT Paris-Saclay, has launched a wide-ranging study.

400

MAJOR ESTABLISHMENTS

400 major establishments, more than 250 laboratories and technical platforms, 106 cutting-edge start-ups and around 32,000 jobs in the region.

• **Fig. 1** Interactive virtual reality simulation for learning about and working with machines and robots in complete safety - EIT Manufacturing V-Machina project - CEA-List.

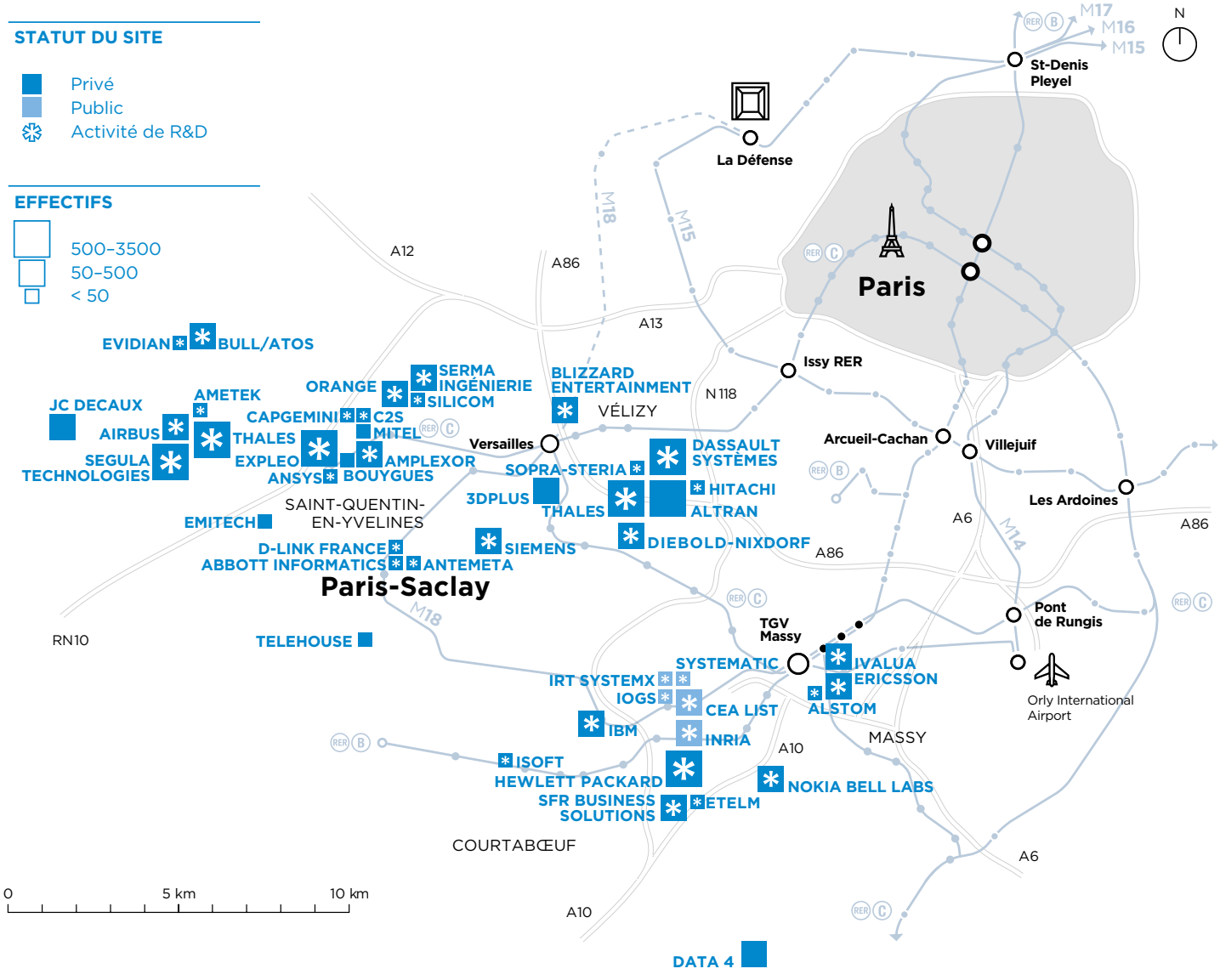
What are the key technologies deployed within the digital sector in the region? Who are the players who are bringing it to life within Paris-Saclay? How is it structured? What are its advantages? What is its capacity for innovation in the future?

The conclusions of this study, which are presented in this document, confirm Paris-Saclay's leadership in digital technologies, bringing together, along with cutting-edge higher education establishments, world-class research bodies and laboratories, international industrial groups and high-tech start-ups, the world's best in research, industry and innovation in digital technologies. Its strengths include excellent academic research at the crossroads of scientific disciplines, internationally renowned talent, equipment and technical platforms that meet the challenges faced and a particularly dynamic start-up ecosystem.

These are just some of the advantages that the leading industrial groups in the health, energy, automotive and aeronautics and space sectors, based within the Paris-Saclay science and technology cluster, are looking for in order to benefit daily from its expertise in artificial intelligence, quantum computing, cybersecurity and smart manufacturing and thus make a successful transition to the industry of the future.

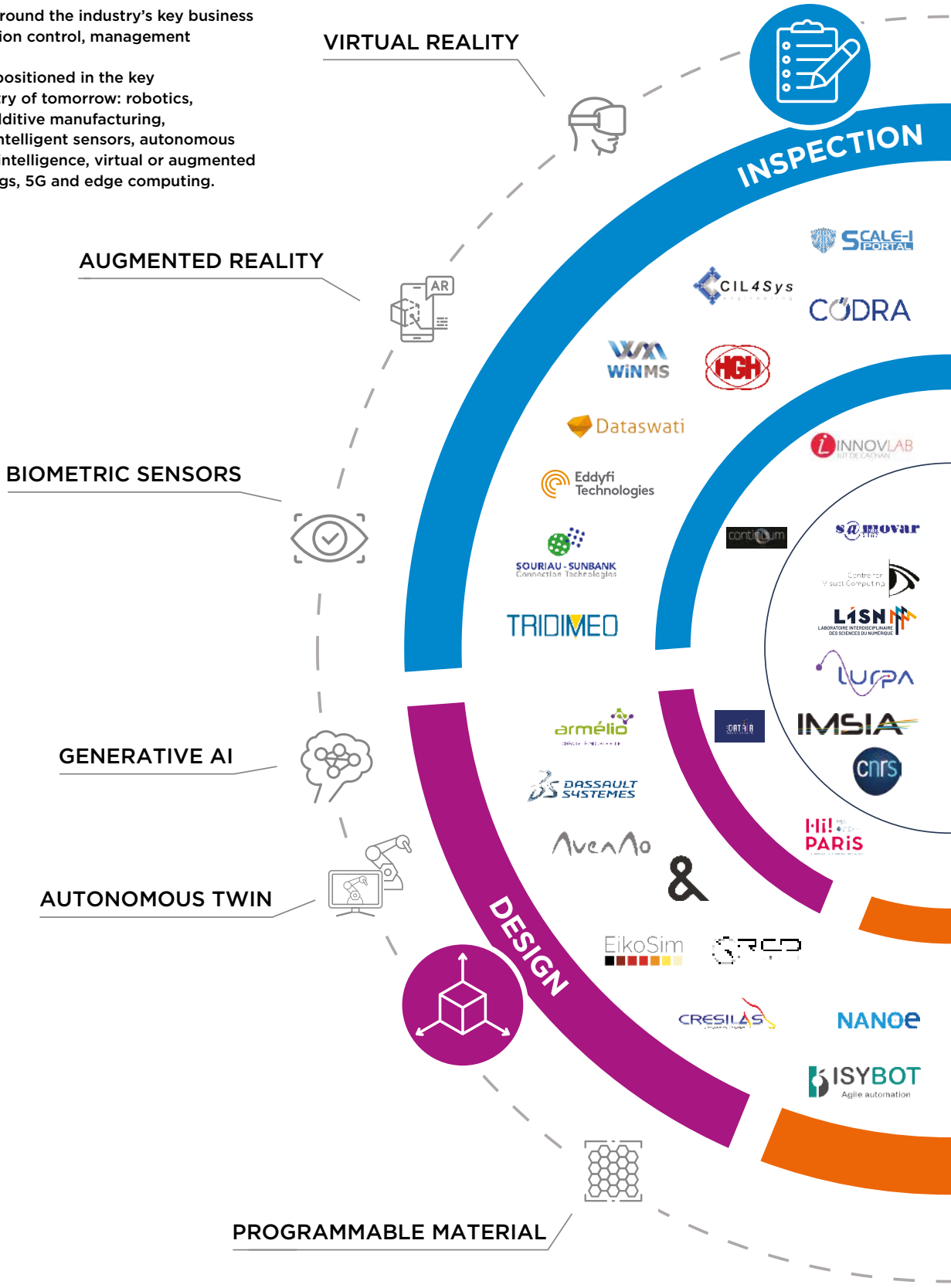
The Paris-Saclay science and technology cluster, historically a leader in digital technologies in France.

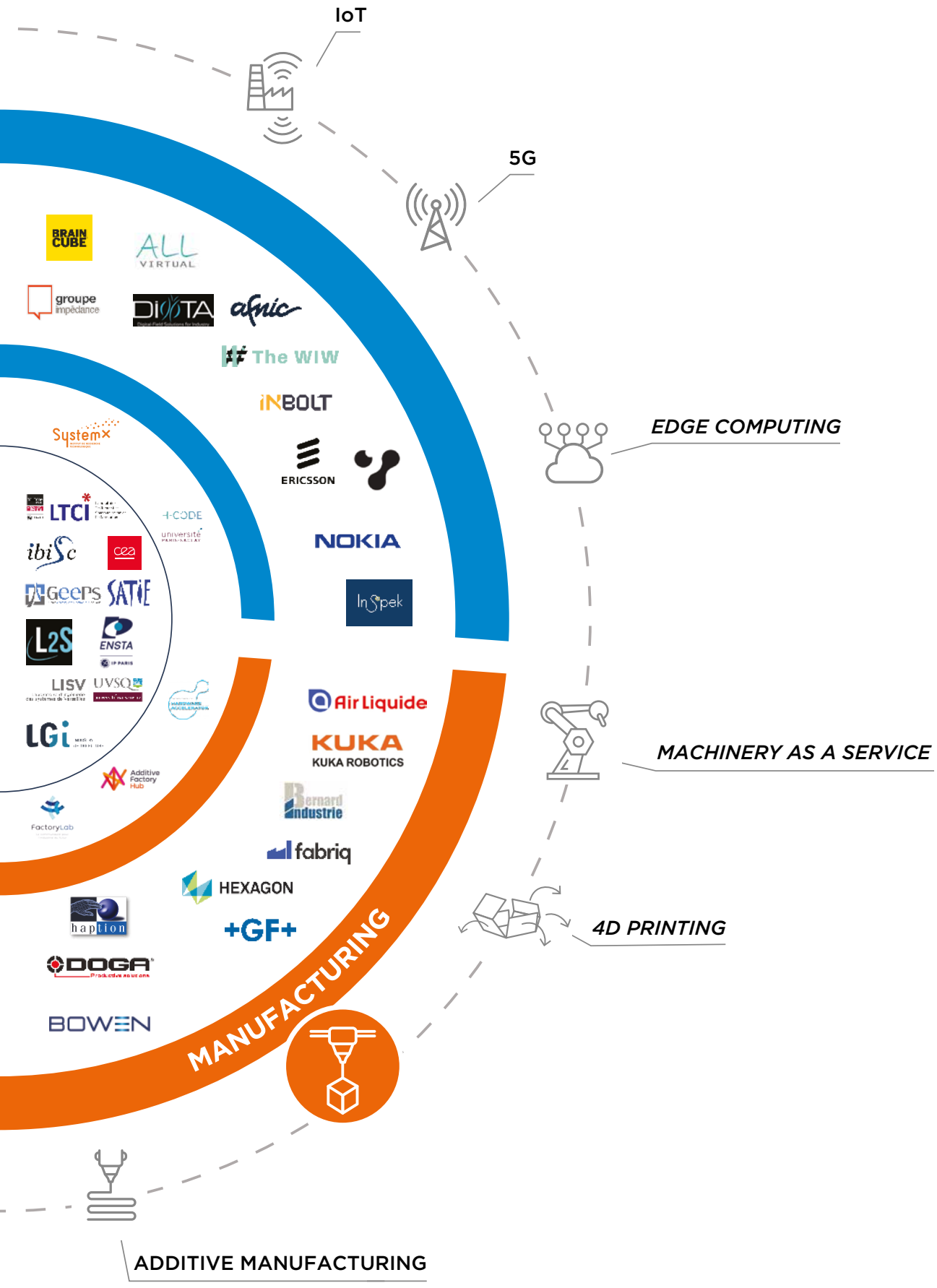
The digital technologies sector in the Paris-Saclay region



Positioned on leading solutions for the industry of the future

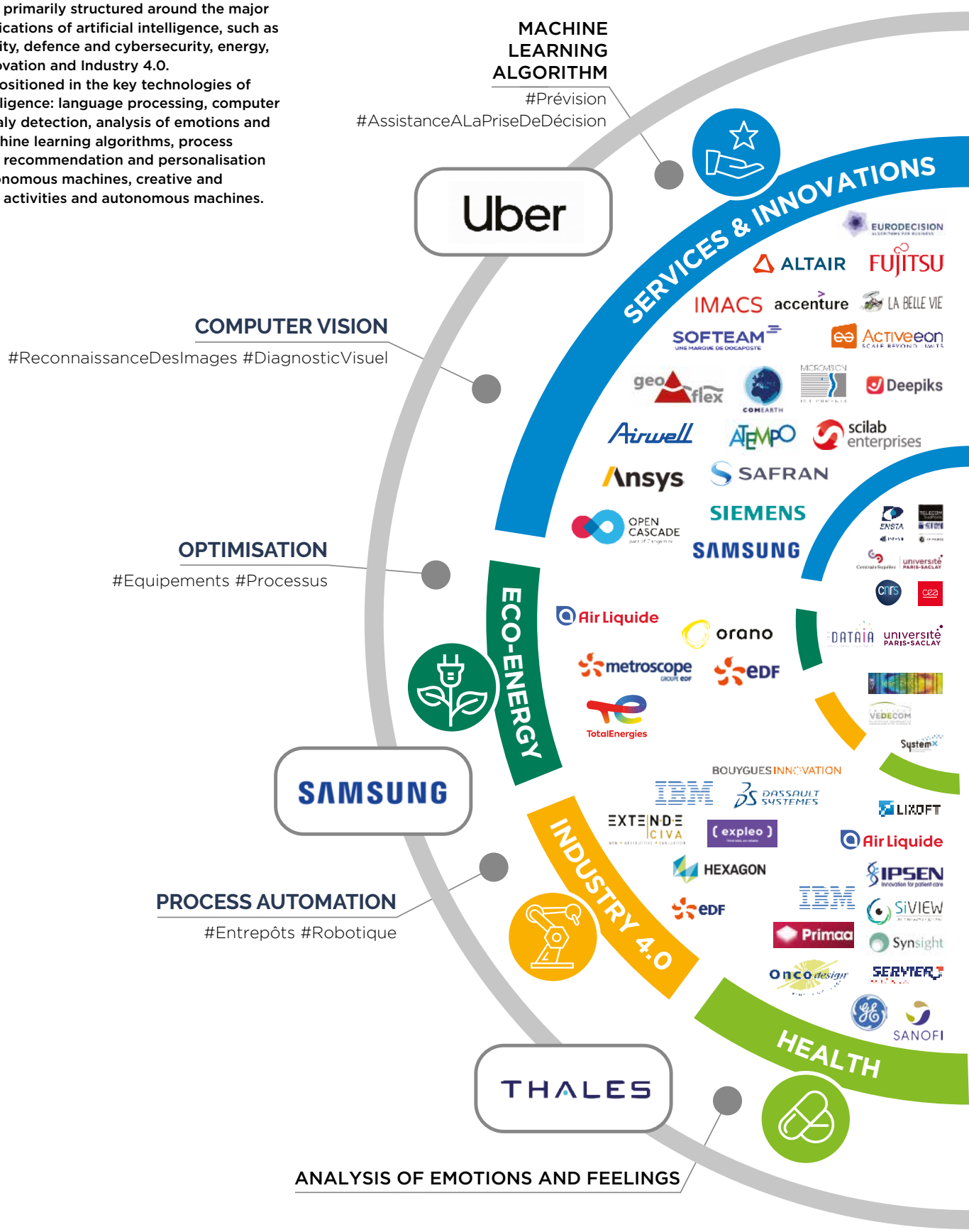
- When it comes to solutions for industry, the Paris-Saclay science and technology cluster boasts a rich ecosystem of players: world-class higher education establishments and research laboratories, interdisciplinary organisations and programmes of excellence, international industrial groups and high-tech start-ups.
- An ecosystem structured around the industry's key business segments: design, production control, management and manufacturing.
- An ecosystem that is also positioned in the key technologies for the industry of tomorrow: robotics, predictive maintenance, additive manufacturing, programmable materials, intelligent sensors, autonomous twins, generative artificial intelligence, virtual or augmented reality, the Internet of Things, 5G and edge computing.

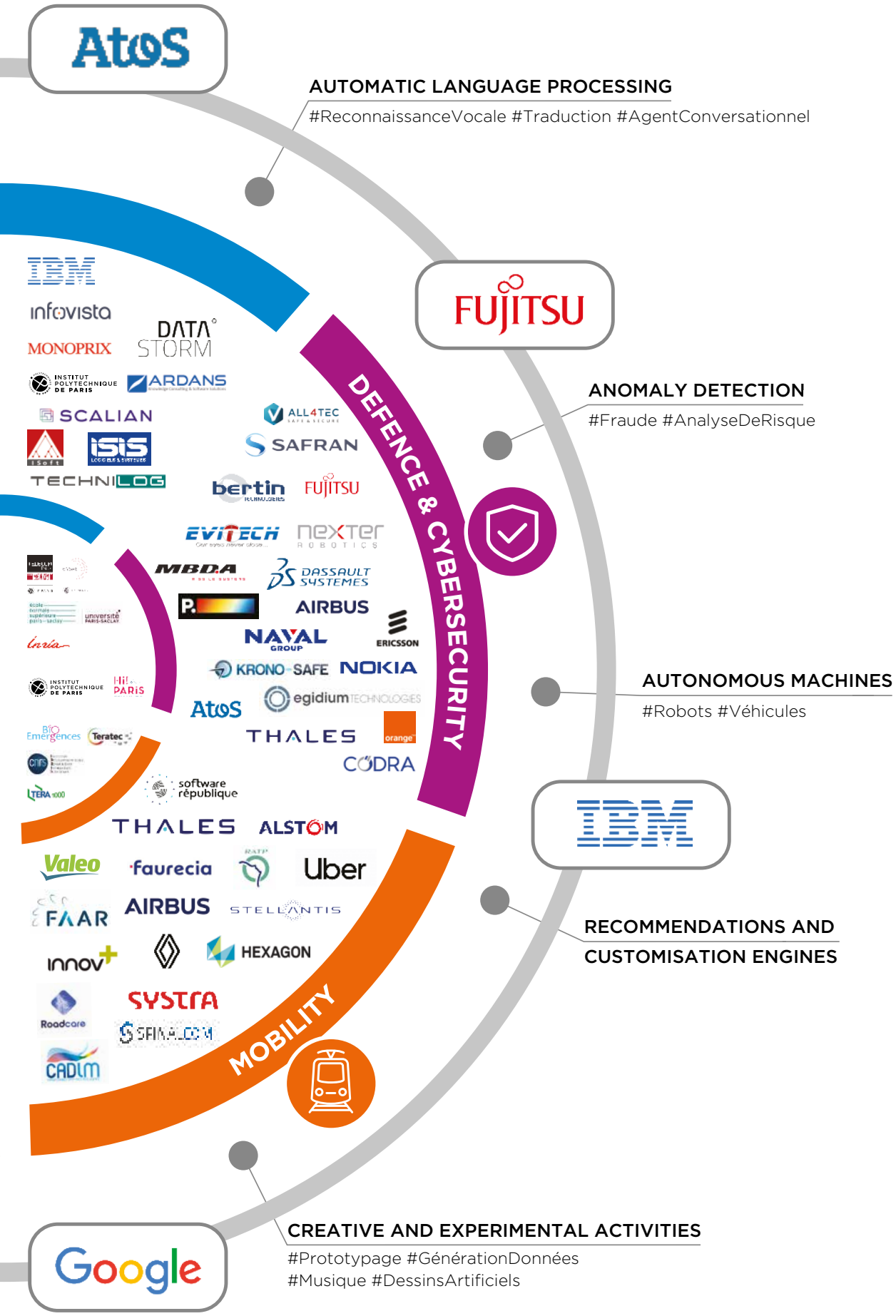



IoT
5G
EDGE COMPUTING
MACHINERY AS A SERVICE
4D PRINTING
ADDITIVE MANUFACTURING
MANUFACTURING
BRAIN CUBE
ALL VIRTUAL
groupe impédance
DIGITA
afnic
The WIW
INBOLT
Systemx
ERICSSON
LTCI
i-CODE
NOKIA
ibiSc
cea
GeePS
SATIE
InSpek
L2S
ENSTA
LISV
UVSQ
LGi
Additive Factory Hub
FactoryLab
Air Liquide
KUKA
KUKA ROBOTICS
Bernard Industrie
fabriq
HEXAGON
haption
+GF+
DOGA
BOWEN

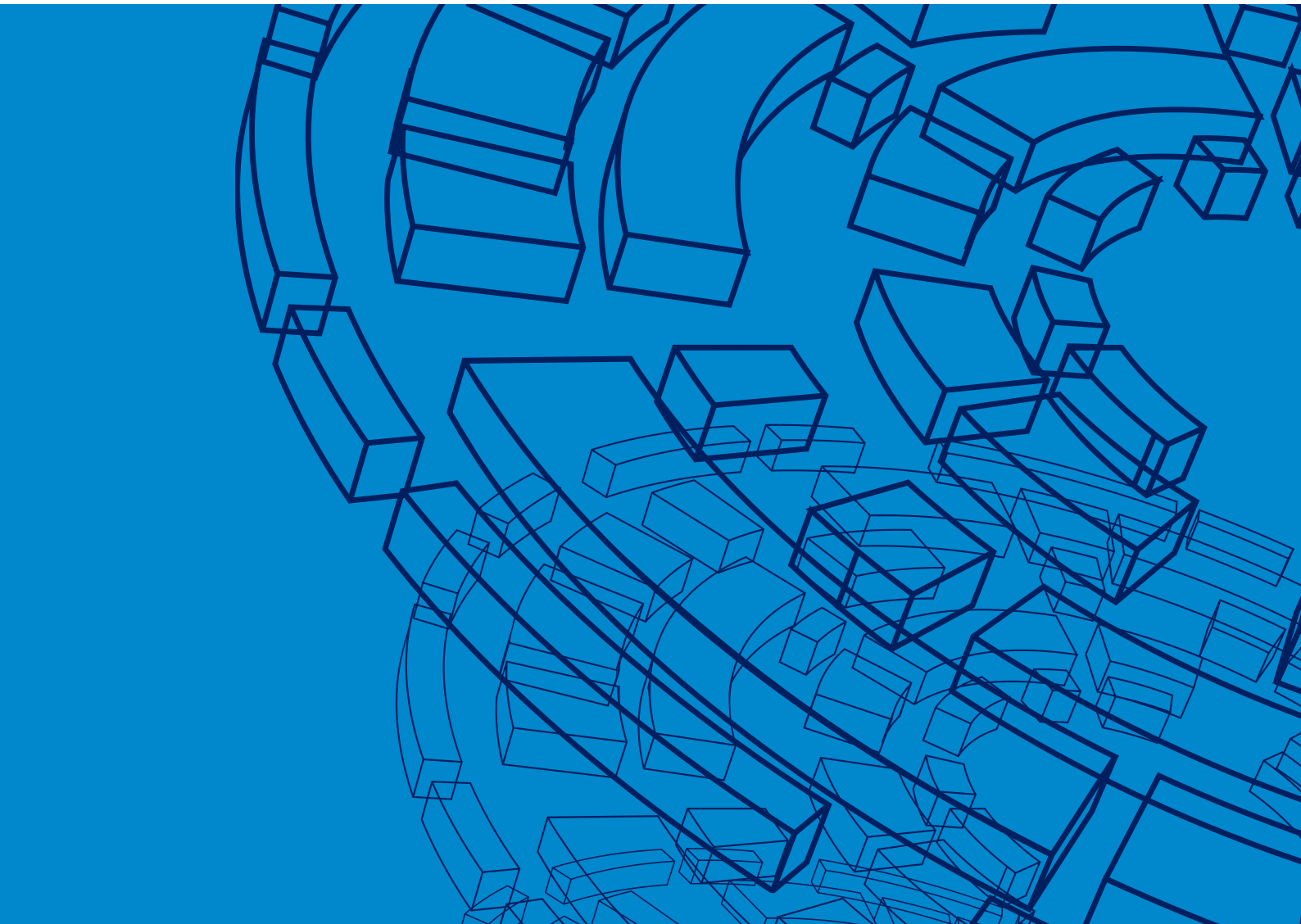
Recognised expertise in artificial intelligence

- Similarly, the artificial intelligence sector benefits from the strong presence of major players in the region, with top-quality higher education establishments and research laboratories, innovative collaborative programmes, cutting-edge start-ups and global industrial groups, including leading foreign groups such as Fujitsu, IBM, Google and Samsung.
- This sector is primarily structured around the major areas of applications of artificial intelligence, such as health, mobility, defence and cybersecurity, energy, services, innovation and Industry 4.0.
- Finally, it is positioned in the key technologies of artificial intelligence: language processing, computer vision, anomaly detection, analysis of emotions and feelings, machine learning algorithms, process optimisation, recommendation and personalisation engines, autonomous machines, creative and experimental activities and autonomous machines.




Atos
AUTOMATIC LANGUAGE PROCESSING
#ReconnaissanceVocale #Traduction #AgentConversationnel
FUJITSU
ANOMALY DETECTION
#Fraude #AnalyseDeRisque
DEFENCE & CYBERSECURITY
AUTONOMOUS MACHINES
#Robots #Véhicules
IBM
RECOMMENDATIONS AND
CUSTOMISATION ENGINES
MOBILITY
Google
CREATIVE AND EXPERIMENTAL ACTIVITIES
#Prototypage #GénérationDonnées
#Musique #DessinsArtificiels
IBM
infovista
DATA STORM
MONOPRIX
INSTITUT POLYTECHNIQUE DE PARIS
ARDANS
SCALIAN
ALL4TEC
SAFRAN
ISIS
TECHNILOG
bertin
FUJITSU
EVITECH
nexter ROBOTICS
MBDA
DASSAULT SYSTEMES
AIRBUS
NAVAL GROUP
ERICSSON
KRONO-SAFE
NOKIA
egidium TECHNOLOGIES
Atos
THALES
orange
CODRA
software république
THALES
ALSTOM
Valeo
faurecia
RATP
Uber
FAAR
AIRBUS
STELLANTIS
innov+
HEXAGON
SYSTRA
Roadcare
SAINA.COM
CADLM

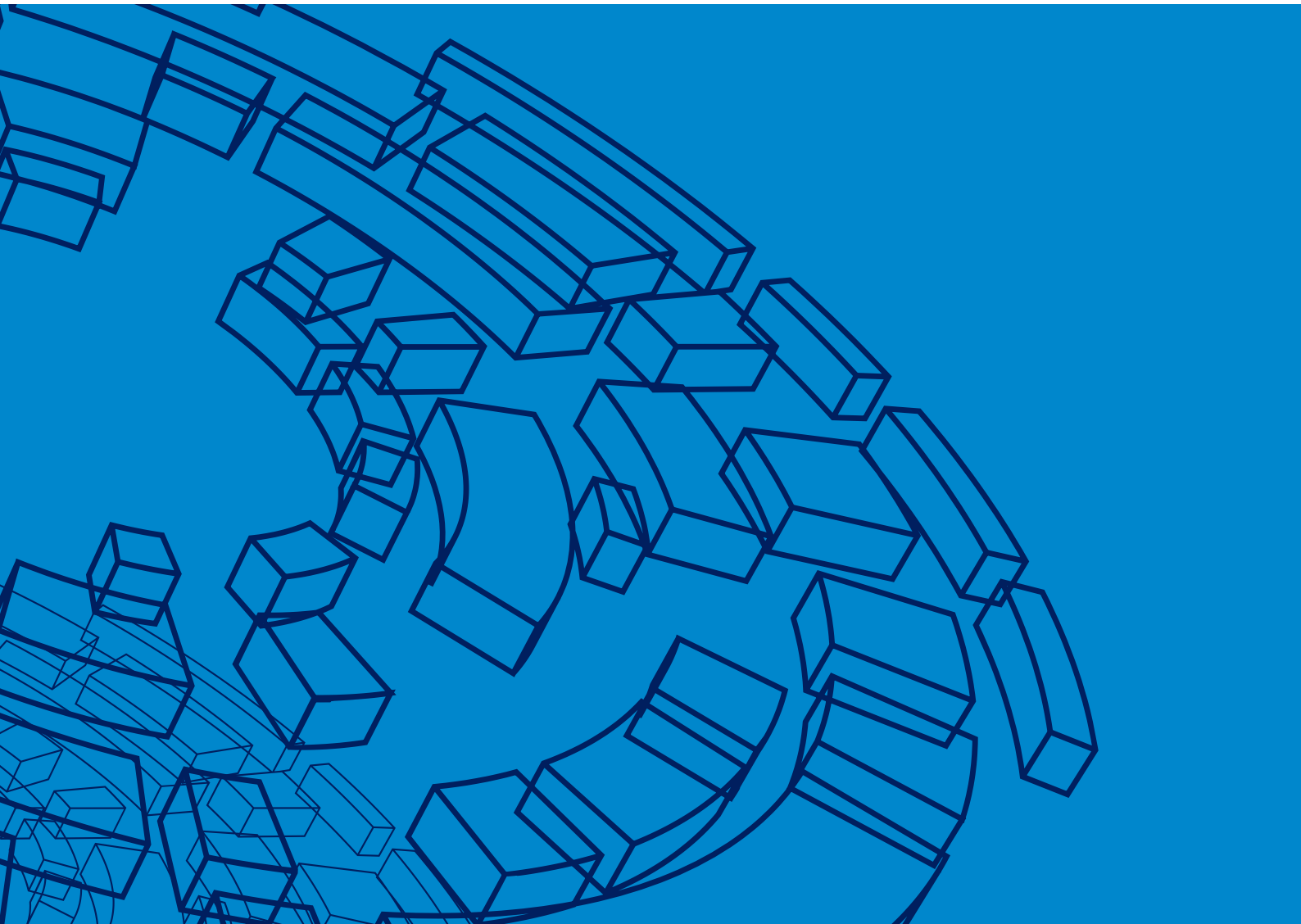
A concentration of skills in key technologies at the service of industry



By virtue of its size, the wealth and diversity of its players, the density of the skills deployed and the significant cross-fertilisation of disciplines fostering some of the most disruptive innovations, the Paris-Saclay science and technology cluster occupies today a leading position in the field of digital technologies in France.

One of the sector's key assets is its position at the forefront of innovation in key digital technologies: simulation, digital twins, machine learning algorithms, intelligent sensors, data processing and analysis, etc. Over the years, its players – researchers, scientists and engineers – have developed major skills and cutting-edge expertise that are highly sought after by the region's strategic industrial sectors in response to their challenges for the future.

Four major areas of application stand out as anchors for the industry in the region: artificial intelligence, quantum computing, cybersecurity and *smart manufacturing.*



From mathematics to Industry 4.0, a major sector for Paris-Saclay

Ranked **1st in France and Europe**, after the Anglo-Saxon universities, and **16th in the world** according to the famous Shanghai Academic Ranking of World Universities, Université Paris-Saclay is ranked **1st in the world in mathematics** and **9th in physics** among the 1,000 best universities in the world. This status of international excellence in these two major disciplines gives the Paris-Saclay science and technology cluster **cutting-edge expertise in algorithms, artificial intelligence, digital sciences and high-performance computing**, which underpins the development of a range of key digital technologies.

Paris-Saclay is particularly strong in four key application areas: artificial intelligence, quantum computing, cybersecurity and all the solutions for the industry of the future, and enjoys strong academic leadership. The Institut Polytechnique de Paris, with the **École Polytechnique** and **Télécom Paris,** ranked **2nd and 6th** respectively in the Times Higher Education **"Best Small Universities" ranking**, trains France's top engineers in artificial intelligence, the Internet of Things and quantum technologies, while the **Institut d'Optique Graduate School** at Université Paris-Saclay prepares France's leading specialists in optics and photonics. The **Quantum Institute,** set up in 2019 by Université Paris-Saclay, brings together the future elite of quantum science and technology, while the first **European School of Cybersecurity** (EECS) and the **École 2600**, newly created in the region, provide support for new experts in data, system and network security.

1ST

PLACE IN THE WORLD IN MATHEMATICS

and 9th place in physics for Université Paris-Saclay in the Shanghai Academic Ranking of World Universities.

[1] 2022 Academic Ranking of World Universities (ARWU).

Alongside these training institutes, Paris-Saclay also boasts some of the country's leading research institutes, including **CEA-List**, the **CNRS** and **Inria**, as well as no fewer than 42 research laboratories specialising in artificial intelligence, making it **France's leading artificial intelligence innovation cluster**. Paris-Saclay also offers facilities of excellence such as **Digiscope,** a network of platforms for the interactive visualisation of large quantities of data and complex calculations, and the **Jean Zay supercomputer,** the most powerful in France, with a computing capacity of almost 37 petaflops - a new record!

Thanks to these excellent academic and research skills, which have also led to the emergence of cutting-edge start-ups in the region, including European nuggets such as **Quandela** and **Pasqal,** Paris-Saclay offers companies from all industrial sectors the highest level of smart manufacturing skills. **Digital simulation, blockchain, big data, cloud computing, intelligent sensors, virtual and augmented reality, robotics or predictive maintenance... the list goes on.** These Industry 4.0 solutions are one of Paris-Saclay's great specialities.

In particular, they enable local businesses to make the transition to more flexible production systems, a more effective man-machine collaboration or the introduction of the virtual factory. The Servier group recently chose Paris-Saclay as the location for its new research institute, and the Renault group has set up Software République, an Open Innovation programme dedicated to the mobility of tomorrow, in order to benefit from the best skills in artificial intelligence and digital systems. These skills, innovations and cross-disciplinary synergies place Paris-Saclay, itself a laboratory for this digital revolution, within the challenges facing the industry of the future.

4

MAJOR AREAS OF APPLICATION

- Artificial intelligence
- Quantum computing
- Cybersecurity
- Solutions for the industry of the future

• **Fig. 2** Robotic X-ray imaging adapted to large parts – CEA-List's digital instrumentation platform at DIGITEO Labs Saclay.

Recognised expertise in artificial intelligence

If there is one field in which the Paris-Saclay science and technology cluster is currently at the forefront, it is artificial intelligence (AI). Artificial intelligence first appeared in the 1940s with the first work on artificial neural networks. Its aim is to automate one or more cognitive processes involving aspects of perception, language, reasoning or even learning, in order to provide predictions, classifications, recommendations or decisions in the context of specific objectives. The European Union's taxonomy identifies 10 key functions of artificial intelligence: **natural language processing, computer vision, anomaly detection, analysis of emotions and feelings, machine learning algorithms, process or equipment optimisation, recommendation and personalisation engines, process automation, autonomous machines and creative and experimental activities.** Medical diagnostics, voice assistants, autonomous cars, data analysis, automatic writing… thanks to neural networks and deep learning, artificial intelligence has made incredible progress in recent years.

The Paris-Saclay science and technology cluster is at the forefront of artificial intelligence.

Research is the region's main strength.

• **Fig. 3** EX-SITU team at the Inria Centre in Saclay. EX-SITU is a joint Inria, CNRS and Université Paris-Saclay team.

At Paris-Saclay, **France's leading centre of academic excellence in artificial intelligence,** research is the region's main strength. No fewer than **42 research laboratories** are located on the Saclay plateau, representing 17% of French public laboratories dedicated to AI, including **Inria** (National Institute for Research in Digital Science and Technology), the **Centre Borelli, CEA-List**, dedicated to intelligent digital systems, **LISN** (Interdisciplinary Laboratory of Digital Sciences), the **CVN** (Digital Vision Centre) and **IDRIS** (the Institute for Development and Resources in Intensive Scientific Computing). They work in particular on machine learning, modelling and monitoring, optimisation, representation and knowledge data processing. **41% of France's 200 leading talents in the field are linked to Paris-Saclay**, including **Luc Julia,** currently Scientific Director for the Renault group and best known for creating Apple's Siri voice assistant, **Jérôme Pesenti**, Vice-President of artificial intelligence at Facebook and former head of IBM's Watson programme, and Laurence Devillers, a researcher in artificial intelligence at LISN (Interdisciplinary Laboratory of Digital Sciences).

In particular, Paris-Saclay is well integrated into the national artificial intelligence research programme, as one of its flagship institutions, DATAIA, is a founding member of Prairie, one of the four Interdisciplinary Institutes for Artificial Intelligence (3IA) created in 2018 following the Villani report. **32 Inria project teams are also based within the region**, and **40% of the winning projects in the call for projects for "Research and Teaching Chairs in Artificial Intelligence"** launched by the French National Research Agency (ANR) are led by researchers from Paris-Saclay.

1ST

CENTRE OF ACADEMIC EXCELLENCE IN ARTIFICIAL INTELLIGENCE IN FRANCE

with 42 public research laboratories and 41% of the 200 French talents associated with Paris-Saclay.

• **Fig. 4** Frédéric Chazal, Director of the DATAIA Institute, at the Institute's second biennial conference, organised to mark its four years of existence, held on 7 April 2022.

The DATAIA Paris-Saclay Institute The quintessence of AI research

The DATAIA Paris-Saclay Institute is the artificial intelligence institute of Université Paris-Saclay. It is within France's leading artificial intelligence and data science ecosystem. It federates and structures multidisciplinary expertise. The Institute brings together a community of more than 1,200 teacher-researchers, 42 laboratories (Inria, CNRS, INRAE, CEA), faculties (Université d'Évry and Université de Versailles Saint-Quentin-en-Yvelines) and top-ranking higher education establishments, all located in the region, including AgroParisTech, CentraleSupelec, the École Polytechnique and its affiliated schools, ENS Paris-Saclay, HEC and Institut Mines-Télécom. Created in 2017 following the call for "Convergence Institutes" projects published by the French National Research Agency, since January 2021 the Institute has refocused its activities on the University of Paris-Saclay's centre of excellence by becoming the bearer of its strategy in the fields of AI, for both research and training. It now extends the concept of cutting-edge research and interdisciplinarity to a wider range of fields, such as the humanities and social sciences. DATAIA supports research in data science through calls for proposals launched at the beginning of each year. The Institute also offers more long-term support, including funding for PhD students working in collaboration with partner laboratories, and funding for Data Challenges.

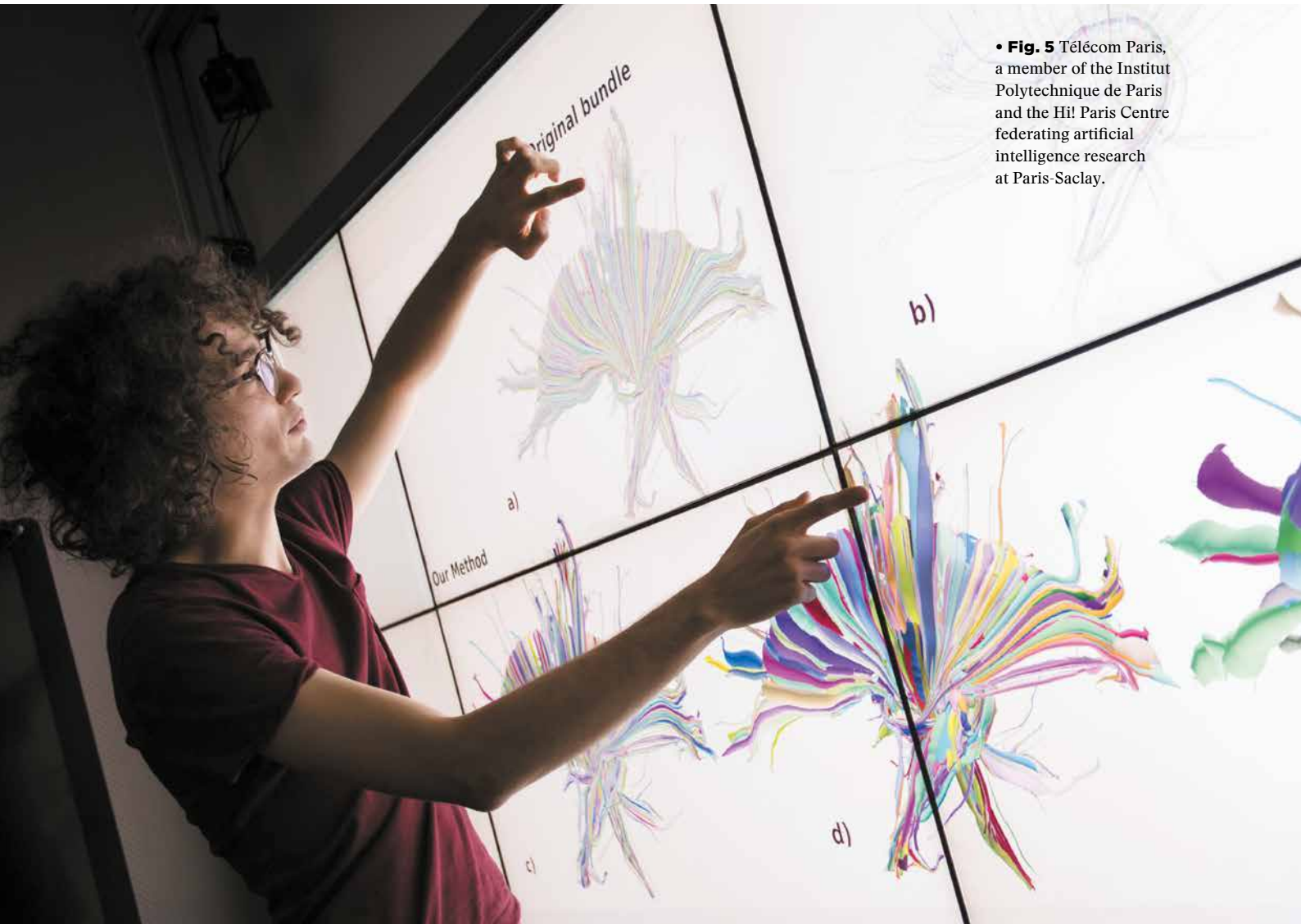
On a local level, these national institutions are complemented by two particularly remarkable interdisciplinary initiatives: the **DATAIA Institute**, created in 2018 by Université Paris-Saclay, which aims to develop research in data science, train engineers and researchers of excellence and boost relations between the academic and industrial worlds, and the **Hi! Paris** Institute, created in 2020 by the Institut Polytechnique de Paris with the ambition of creating a unique framework for research, education and innovation based on the intersection of fundamental sciences, technology, management and social sciences. These major institutes now federate artificial intelligence research in Paris-Saclay.
And let us not forget, on the training front, the **Mathematics, Vision and Learning (MVA) Master's Degree at ENS Paris-Saclay** , which is training the world's elite in artificial intelligence.

Paris-Saclay also benefits from a strong industrial fabric specialising in artificial intelligence or collaborating with local research in these areas. **70 companies – micro-enterprises, SMEs, ISEs and large groups** – have been identified in the region. These include international digital leaders based in the heart of Paris-Saclay, such as **IBM**, which announced that it would set up its artificial intelligence innovation centre in Paris-Saclay in 2021; **Atos**, which also opened a new global R&D laboratory in 2021, bringing together 350 engineers in quantum computing, cybersecurity and artificial intelligence in Clayes-sous-Bois (Yvelines), **Fujitsu**, whose centre of excellence in artificial intelligence is based on the École Polytechnique campus, and **Thales**, which is working on the

70

COMPANIES

70 companies - micro-enterprises, SMEs, ISEs and major groups - and 110 start-ups are working on artificial intelligence in Paris-Saclay.



• **Fig. 5** Télécom Paris, a member of the Institut Polytechnique de Paris and the Hi! Paris Centre federating artificial intelligence research at Paris-Saclay.

subject as part of the Software République programme. Alongside these industrial leaders, Paris-Saclay is proving to be a particularly dynamic breeding ground for start-ups. **110 start-ups from Paris-Saclay working closely with artificial intelligence** have been counted in the region. These include **Alkalee, Roadcare, Labcoor, PrOph3cy, AiiNTENSE** and **SpacesenseAI**. Today, these start-ups employ 2,500 people and operate in a wide range of sectors, including space, medicine, insurance and security, with equally diverse areas of expertise, such as data science, language processing, computer vision and modelling.

Artificial intelligence has the potential to increase the annual economic growth rate by an average of 1.7% between now and 2035, with sectors such as manufacturing, agriculture and commerce being the first to benefit. However, its future will require scientific research to address the fundamental issues of responsibility and ethics, flexibility and energy efficiency.

The Hi! Paris Centre Thinking differently about the impact of AI

Launched in 2020, the Hi! Paris Centre is, along with the DATAIA Institute, one of the two major structures federating artificial intelligence research at Paris-Saclay. The result of a partnership between the Institut Polytechnique de Paris and HEC Paris, and joined in 2021 by the Inria Saclay centre, Hi! Paris is an interdisciplinary centre for research, innovation and technology transfer in data science and artificial intelligence, developing initiatives for industry. Hi! Paris therefore represents a major tool for the transition to Industry 4.0. All this while encouraging research and educational innovation by combining their areas of expertise: fundamental science and research for economic value. In order to provide a comprehensive overview of the growing role of AI in our society, the Centre also includes more societal aspects such as data confidentiality, the legal framework, the impact of artificial intelligence on financial markets, etc. Hi! Paris brings together researchers from a variety of backgrounds, including the social sciences, to take two approaches to artificial intelligence: one focusing on AI, data and business (Industry 4.0, industrial automation, finance, a “consumer” approach to the web), the other focusing on AI, data and society in the broadest sense (health, energy, intergenerational interactions, smart cities). In addition to its interdisciplinary nature, the Centre has another distinctive feature: its exemplary partnerships with local companies such as Rexel, Capgemini, Kering, L’Oréal, TotalEnergies, Vinci and Schneider Electric.

Future skills in quantum computing

Another area of excellence in the Paris-Saclay science and technology cluster is quantum computing. A fast-growing technology capable of outperforming current supercomputers for certain types of calculation, quantum computing exploits the laws of quantum mechanics to solve problems that are too complex for conventional computers and supercomputers at incredibly high speed.

In this race for quantum performance, which promises to revolutionise computing and computer technology, the Paris-Saclay science and technology cluster occupies a prime position. Firstly, because Paris-Saclay is home to some of the world's leading groups in this field: **IBM, Atos** and **Thales** for the design of quantum technologies; **EDF, TotalEnergies** and **Orano** for their use.
As a recognised leader in quantum computing, Atos opened its brand-new global research and development laboratory in Les Clayes-sous-Bois in 2021. The purpose of the laboratory is to house the work carried out as part of its quantum computing research programme, Atos Quantum, the first major industrial quantum computing programme in Europe.

In the race for quantum performance, the Paris-Saclay science and technology cluster occupies a prime position.

• **Fig. 6** Quandela develops quantum computers based on photonic qubits. Particular attention is paid to the design of its computers.

Quandela: the company taming photonic qubits

Created from research carried out within the CNRS, Quandela was founded in 2017. Based in Palaiseau, Massy and Munich, the French start-up is developing quantum computers based on photonic qubits, called MosaiQ. In March 2023, it sold its first quantum computer to OVHCloud, the European leader in storage, guaranteeing independence from GAFAM in terms of access to data and calculations. In 2022, Quandela also opened up online access to Ascella, its first 6-qubit quantum computer, to as many people as possible. Quandela's quantum computers have been designed to be rapidly reconfigured, reaching 12 qubits by the end of 2023.
At the end of 2022, the start-up organised the LOQCathon (Linear Optical Quantum Computation), a quantum hackathon. An opportunity to discover linear optical quantum computing, which is still little known in student circles. Its founders have strong links with the Paris-Saclay region. The first two, Niccolo Somaschi and Valérian Giesz, met while working in the team of the third co-creator, Pascale Senellart, at C2N (CNRS). Valérian Giesz, who trained at the Institut d'Optique Graduate School, is a member of the Board of French Tech Paris-Saclay. As for Pascale Senellart, she is still Director of Research at the CNRS and teaches at the Institut Polytechnique de Paris. She has also worked for the President of Université Paris-Saclay, within the Quantum Institute.
The decision to locate the company in Palaiseau was therefore an obvious one for these three key players in the region's scientific and economic community.

12 QBITS: THE POWER LEVEL THAT SHOULD BE REACHED BY THE END OF 2023

The ecosystem of start-ups working in the field of quantum computing is also particularly strong in the region, with **Kets Quantum Security, Multiverse Computing, Alice & Bob**, and above all two European nuggets in the sector: **Pasqal**, which specialises in quantum computing based on neutral atoms, was co-founded by **Alain Aspect**, Emeritus Research Director at the CNRS and winner of the Nobel Prize in Physics in 2022. **Quandela**, which develops quantum computers based on photonic qubits, was co-founded by **Pascale Senellart,** another leading figure in quantum computing.

On the academic front, Paris-Saclay boasts renowned researchers in the field of quantum physics, as well as cutting-edge organisations such as the **CEA**, with its **Très Grand Centre de Calcul** (TGCC), dedicated to intensive computing and high-performance simulation located at Bruyères-le-Châtel (Essonne), and the **Quantum Institute**, recently opened by Université Paris-Saclay. This interdisciplinary centre for quantum science and technology brings together all the region's laboratories, representing more than 80 research teams contributing to advances in quantum technology. In particular, it has developed research partnerships with major industrial groups in the region such as Thales, EDF, Air Liquide, TotalEnergies and IBM, and provides training in quantum science and technology through master's, engineering and doctoral degrees.

80

RESEARCH TEAMS AT THE QUANTUM INSTITUTE

These companies and institutions are working together on major quantum development initiatives, particularly in the Paris Region. As part of its **Quantum Pack,** since 2020 the Paris Region has been funding three initiatives involving major industry players (Airbus, MBDA and the Naval Group), leading academic players (ONERA and Inria) and innovative local start-ups (Pasqal, Quandela and Alice & Bob) as part of a support programme for the sector that is unique in Europe. As for Thales, Pasqal, the Paris Region and GENCI (Grand Equipement National de Calcul Intensif), at the end of 2021 they launched a new partnership aimed at optimising critical infrastructures (logistics, air transport, industry, space) using Pasqal's quantum technology. These partnerships and collaborations confirm the key role played by Paris-Saclay players in the development of this technology of the future.

Pasqal: will our next unicorn be quantum?

The start-up Pasqal, which specialises in quantum computing based on neutral atoms, was founded in 2019 by Georges-Olivier Reymond and Christophe Jurczak, as well as by Antoine Browaeys and Thierry Lahaye, both from the Institut d'Optique Graduate School, and Alain Aspect from the CNRS, who has since become the 2022 Nobel Prize winner in Physics. After an initial round of financing of €25m in 2021, the start-up raised the largest amount for a European start-up in January 2023: €100m.

Seeking to develop a quantum system with 1,000 qubits, Pasqal merged with Dutch company Qu&Co in 2022. This Tech nugget, based in Massy and now employing around a hundred people, has already produced a Qubit Pasqal calculation system, and others are in the pipeline. It also gave everyone online access, in 2022, to their own quantum processor for a "live" test. Major groups such as EDF, Crédit Agricole, BASF, BMW, Siemens, Airbus and Thales are beginning to use these tools for cutting-edge calculations. Ultimately, the company wants to offer its computing power via the cloud, in the form of "computing on demand". With its recent fundraising, Pasqal aims to double its workforce and give itself the means to be more present on the European market, while setting out to conquer the United States and Asia. This future unicorn is already producing 100-qubit emulators and expects to quickly reach 200 qubits.

INTERVIEW WITH VALÉRIAN GIESZ, CO-FOUNDER OF QUANDELA**.**

The future of quantum computing at the heart of Paris-Saclay

Optimising flows and traffic with energy savings at its core is one of the promises of quantum computers, which are on the way to becoming a reality. Valérian Giesz, co-founder of Quandela, a Paris-Saclay spin-off that has developed a photon-based solution inspired by the work of 2022 Nobel Prize winner Alain Aspect, who has been with the project from the outset, explains.

If you had to start by pitching Quandela?

VG Founded in 2017 by Nicolo Somaschi, Pascale Senellart and myself, Quandela is a spin-off from the Centre de nanosciences et de nanotechnologies (C2N) - a joint CNRS/Université Paris-Saclay unit. It relies on the principles of quantum mechanics to provide industry with new generations of calculations that are more powerful, more efficient and consume less energy. Compared with other players in the quantum computing sector, our approach is unrivalled, since it consists of using light flows to carry out calculations, on the scale of a single particle of light, i.e. a single photon. In itself, the idea of making calculations using beams of light is nothing new. But we kept coming up against the difficulty of generating photons. This is precisely the technological barrier that we've managed to overcome, with the help of C2N, by using semi-conductors, a totally new solution. And it's in Paris-Saclay that it saw the light of day! Today, we're able to manipulate photons one by one, to include quantum information by taking advantage of the fact that a single photon can be in several states simultaneously – it can be "entangled" with other photons, which therefore share common properties.

What about the quantum computer? Is this the next step that will enable you to enter an industrial phase?

VG Without waiting for this type of computer to be developed, we're already marketing equipment – photon emitters for research laboratories – which we've exported to Australia and Italy. In parallel with this commercial activity, we've pursued intense R&D activity to develop a first-generation quantum computer. A demonstrator exists, which we've made available via our Quandela cloud. We already have a number of users around the world – in the United States, Singapore and Italy, for example.
All they have to do is log on to the internet to perform their calculations, which are carried out here at our Massy facility, part of the Paris-Saclay ecosystem. Already, industrial companies have told us that they're convinced by their tests and have ordered computers from us. Now we have to manufacture, test and deliver them. We're currently in the process of setting up this industrial activity.

Where do you plan to do this?

VG In Massy, a stone's throw from our offices, in the building at the end of the street. The components, manufactured in a clean room in Palaiseau, will be assembled there with the lasers and other optical elements. The finished product will then be delivered to our customers – industrial companies or GENCI [the organisation responsible, at national and European level, for promoting the use of intensive computing associated with artificial intelligence for the benefit of academic and industrial research communities]. Quandela will therefore be one of the first players in the European quantum industry to be able to deliver quantum computers. Naturally, this requires investment. That was the challenge of the €15 million fundraising we completed in November 2021.

Does this mean that the seemingly mythical quantum computer is about to become a reality?

VG Yes, the quantum computer has indeed emerged from the imaginations of researchers and engineers to become a reality! For the time being, our platform is itself accessible to all those who are curious, both industrial companies and researchers. Anyone can sign up to try out quantum computing and check out its advantages, provided they're familiar with the specifics of the programming language – it's more sophisticated than the programming language used in conventional computing. We're also working with a number of manufacturers, including MBDA and Thales, as well as banks (BNP Paribas and Crédit Agricole) to see how they can program their own computing techniques to adapt them to our quantum computers.

Beyond the uses for industry and business, what benefits can be expected for ordinary people, even if they are not the direct users of a quantum computer?

VG We can expect quantum computing to have a major impact on our lives, as it will make it possible to optimise all kinds of flows and traffic in a wide range of fields, starting with banking, logistics and transport – rail, air and sea. It will also speed up the design of new pharmaceutical molecules – even today, it takes several years of R&D before new ones are brought to market. Quantum computing will also mean greater efficiency in predictive maintenance. It is estimated that the added value generated each year by the introduction of quantum computers will be in the region of 500 billion dollars, not counting the energy savings achieved by optimising flows and traffic.

Quandela will be one of the first European players to be able to deliver quantum computers.

When you created Quandela, did you expect it to have so many applications and so much impact? Has your vision of quantum computing evolved since the creation of your spin-off?

VG If someone had told me in 2017 that 5 years later we would have such powerful computing capabilities in the cloud, I wouldn't have believed them. Today, we're on the verge of launching the production of quantum computers. I can't imagine where we'll be in another 5 years. Of course, we try to predict it. But, as with the weather, there are always errors of judgement! One thing is certain: things are moving faster than expected, and this is largely thanks to the fact that we can count on brilliant minds with very good ideas to implement new techniques, both in algorithms and in the manufacture of new components. In short, we're undoubtedly on the cusp of even more promising innovations.

If you had to describe a quantum computer?

VG It has nothing to do with the laptop we use every day. It takes the form of cabinets like those found in a data centre, inside which, instead of electronic components, there are photonic components connected by numerous wires, lasers and mirrors. The advantage of our approach lies in its compactness and modularity, in a fibre optic connection, which is a guarantee of stability.

Have you given any thought to the design of this computer?

VG Naturally, we're keen to give our products a visual identity. The choice of design and the colour blue underline the robust yet mysterious nature of quantum photonics. We worked on a structured façade to create an undulating effect.

Where do you stand in terms of staff numbers? What skills and expertise are you mobilising?

VG We currently employ around 70 people. The profiles are varied: experts in semiconductors, optics, IT, mathematics and algorithms, as well as administrative staff and sales engineers – in short, all the skills needed to run a commercial business.

One more word on the factory project. Does it reflect a desire to participate in the country's industrialisation drive?

VG The drive to industrialise and regain our digital sovereignty. It's an issue that's so close to my heart that I agreed to co-lead one of the working groups on digital trust, headed by Michel Paulin, CEO of OVHcloud. This effort involves preserving our sovereignty over data storage infrastructures, software and hardware technologies. It's important not to be dependent on a single country for our supplies. As far as quantum computing is concerned, I believe that France has a card to play: this is a brand-new cutting-edge industry in which we have all the assets and skills. Let's make the most of it.

Alain Aspect, winner of the Nobel Prize in Physics in 2022 [shared with the American John F. Clauser and the Austrian Anton Zeilinger] has been a member of your Scientific *Board* since its creation…

VG Alain Aspect has always been very committed. He takes part in our scientific meetings with the other members. We are all the more indebted to him in that we are reproducing on nano-chips the results of his first experiments, carried out in the 1980s, which consisted of interweaving photons. We are now able to do this on a smaller, almost industrial scale. In addition to Quandela, he plays a major role in promoting quantum technologies, both in France and in Europe. The community of researchers and entrepreneurs in computer science and quantum physics owes him a debt of gratitude.

Interview by Sylvain Allemand

At the heart of cybersecurity issues

Since the digital revolution, which transformed the way information is produced, distributed and consumed, information management has become one of the priority security issues, not only for States, in terms of their defence and sovereignty, but also for the economic and industrial activities of our companies. The increase in cyberattacks on public authorities and businesses in recent years has thus demonstrated the extent to which security issues are now, above all, cybersecurity issues.

Within these challenges, the Paris-Saclay cluster of scientific and technological excellence, and more specifically the Saint-Quentin-en-Yvelines Conurbation Community, has developed specific expertise, notably with the presence of leading companies that are heavily involved in the field of cybersecurity, such as **Airbus Defense and Space, Airbus CyberSecurity, Thales, Renault, Atos, C2S Bouygues, Orange Cyberdefense** and **RTE,** the public electricity transmission system operator , which opened in 2021 a national operational centre in Montigny-le-Bretonneux to monitor all of the company's IT, telecoms and cybersecurity infrastructures.

The sector also boasts an ever-growing number of start-ups within the ecosystem. Some specialise in vulnerability detection and risk and threat assessment, such as **Ozon, United Biometrics, Cryptosense** and **Citalid,** a start-up founded by CentraleSupélec, which has developed a particularly innovative technology for cyber risk management, and in 2018 won two innovation awards at the Assises de la Sécurité, among the most prestigious in France in this field. Others in turn focus more specifically on secure cloud solutions or the transformation of information systems and infrastructures.

1ST

FRENCH ACADEMIC STRIKE FORCE IN CYBER-SECURITY

• **Fig. 7** CyberNDT, a solution developed by CEA-List to ensure the reliability, traceability and compliance of manual non-destructive testing (NDT).

CEA-List
Expanding the scope for digital innovation

The List – one of the CEA's three research institutes – specialises in the design, analysis and security of intelligent digital systems. Its mission is to ensure the competitiveness of businesses by transferring technology and innovation to the industry. The List has developed several technology platforms in the fields of health, robotics and artificial intelligence, including one dedicated to cybersecurity. With more than 70 experts, this platform is unique in Europe. The breadth of its work has enabled it to collaborate with some 30 major industrial players, including EDF, Thales and Systerel, which develop data security software, and Trialog, a leader in complex systems management solutions. Furthermore, since its inception, 50% of its partners have been SMEs and start-ups, enabling high-quality exchanges. The experts at the cybersecurity platform, in constant liaison with the region's academic institutions, are also involved in major French projects in the field, such as the Grand Défi Automatisation de la cybersécurité and Campus Cyber projects, and European projects such as Sparta. More broadly, the solutions created within the List are likely to affect all sectors thanks to work linked to geolocation, robotic gripping, compliance monitoring or 3D reconstruction. With more than 1,000 researchers and technicians and numerous partnerships, the List files numerous patents and creates start-ups every year. Since 2009, four of them have been launched: Arcure (3D vision and on-board AI for industry), Diota (digital solutions for Industry 4.0), Tridimeo (3D solutions for robotic guidance) and AIHerd (herd monitoring in livestock farming).

These include **Massa Labs** and **Uniris**, which are active in blockchain technologies, **Snowpack** , which has developed an innovative data anonymisation solution, and **Kleverware, Storit** and **Alkalee**.

But it is once again in the academic field, and even more so in training, that Paris-Saclay occupies a leading position. To this end, the Saint-Quentin-en-Yvelines Conurbation Community is gradually building a genuine centre of academic excellence in cybersecurity. The region's leading higher education establishments offer dedicated training courses. Specific schools have also been created, such as the first **European School of Cybersecurity** (EECS), the **École 2600** and the latest **IPSSI campus** dedicated to IT and cybersecurity. These courses are designed to meet the growing skills needs of companies in the sector. Between 2017 and 2021, the number of cybersecurity job vacancies in France doubled, and specialists predict that tens of thousands of jobs will be created in the very near future.

On the research side, alongside chairs dedicated to cybersecurity in partnership with the **Télécom Paris** and **Télécom SudParis** institutes, the region also boasts leading-edge organisations such as **CEA-List**, which brings together more than 70 cybersecurity experts in a platform that is unique in Europe. One of the region's brightest talents, **Florent Kirchner**, headed up the software safety and security laboratory and the cybersecurity programme for many years. Interdisciplinary institutes, one of the region's hallmarks, are also present, such as the Interdisciplinary Centre for Defence and Security (CIEDS) at the Institut Polytechnique de Paris and the SystemX Institute of Research and Technology (IRT), which aims to accelerate the digital transformation of the region's industry and services.

The Saint-Quentin-en-Yvelines Conurbation Community has developed specific expertise in cybersecurity.

Saint-Quentin-en-Yvelines Training the cybersecurity experts of tomorrow

As a number of companies concerned with cybersecurity issues have gradually set up in the area, Saint-Quentin-en-Yvelines has chosen to focus on this area of expertise. The Conurbation Community is now leading the way in the development of French areas known as "trust territories", territories that are more connected, more intelligent and more inclusive. In 2023, the Conurbation Community will also host the first regional cyberincident response centre (CSIRT) in partnership with ANSSI. In line with this economic development project, a large number of training organisations and dedicated schools have set up in Saint-Quentin-en-Yvelines and the surrounding area. Université Paris-Saclay in Versailles offers an M2 in Content, Network and Telecommunications Security. Ensitech trains students with 2 years' higher education (BTS digital systems), 3 years' higher education (cybersecurity and cloud computing) or 5 years' higher education (M2 cybersecurity and cloud expert). Esiee-IT prepares students for a bachelor's degree in IT with a security option. For its part, the EECS (European School of Cybersecurity), which opened in Versailles in 2021, focuses on 2-year higher education courses, under apprenticeship or as sandwich courses. The École 2600, set up the same year in Montigny-le-Bretonneux, offers a diploma in Data, System and Network Security (RNCP level 7/ Bac+5). And let us not forget the latest IPPSI campus, which offers training from BTS to master's (BTS SIO, Bachelor DevOps, SysOps, M2 Cybersecurity), including VAE (validation of acquired experience) and potential retraining. Finally, Saint-Quentin-en-Yvelines hopes to open a campus dedicated to cybersecurity training in the near future, linked to its SQYcub incubator.

Positioned on leading solutions for the industry of the future

Solutions for the industry of the future are based on a range of technologies such as **robotics, additive manufacturing, 5G, artificial intelligence,** the **cloud** and the **man-machine interface**, generating a range of products, services and intelligent industrial solutions designed to transform the production systems of all industries, from the agri-food and health sectors to automotive and aeronautics.

These digital technologies, which are now enabling industry to innovate in order to become more flexible and competitive, but also to meet new environmental and social requirements, are strongly supported, particularly in Europe, which alone accounts for 30% of the global industrial automation market. The **European Institute of Innovation and Technology (EIT)**, set up in 2008 to strengthen Europe's capacity for innovation in strategic sectors, has opened an EIT dedicated to Manufacturing, located at the heart of Paris-Saclay within the Nano-Innov Paris Région centre.

EUROPE REPRESENTS

30%

OF THE GLOBAL INDUSTRIAL AUTOMATION MARKET

Since 2015, France has had a programme dedicated to the industry of the future, aimed at modernising its production facilities and digitally transforming its industrial companies. In 2021, it created an industry based on solutions for the industry of the future, estimated by the Alliance Industrie du Futur at 32,000 companies and 500,000 direct and indirect jobs. This sector is once again being supported as part of the France 2030 investment plan.

Driven in particular by world-renowned groups and start-ups at the cutting edge of innovation, this move towards the industry of the future is within the innovations developed by the Paris-Saclay science and technology cluster. In terms of industry, Paris-Saclay is home to leading companies such as **Nokia, Ericsson, Air Liquide** and **Dassault Systèmes,** a company that is a real driving force in digital technologies and industrial solutions for the future. In terms of start-ups, the region is proving to be particularly dynamic, with start-ups operating in the fields of design (product design, manufacturing processes and production sites) such as **EikoSim,** control (traceability, flow management, logistics) such as **Dataswati, WIN MS and Inbolt**, and manufacturing (machines, tools, tooling) such as **Fabriq, Haption** and **Isybot.**

500,000

DIRECT AND INDIRECT JOBS

WOULD BE GENERATED BY THE SOLUTIONS FOR THE INDUSTRY OF THE FUTURE SECTOR IN FRANCE

• **Fig. 8** Automated robot with conveyor in a manufacturing plant for the food industry.

Solutions for the industry of the future

Industry 4.0 makes full use of the potential of all the digital technologies available. They are as much involved in the creation of projects and tools as they are in the operation of sites and/or the monitoring of manufacturing and the life cycle of equipment, etc.

BLOCKCHAIN

A file shared on a peer-to-peer network that is secure, tamper-proof and has no centralised control, enabling information to be shared, transactions to be carried out securely and trust to be created between remote players.

ARTIFICIAL INTELLIGENCE

Techniques that enable a "machine" to perform tasks usually associated with human intelligence, such as understanding, learning, adapting or reasoning.

BIG DATA

Tools for storing and analysing very large volumes of data.

DIGITAL CONFIDENCE

Tools and technologies for the security of computerised systems.

DIGITAL SIMULATION

Tools for virtually simulating a product in its final environment, facilitating the creation, optimisation and life-cycle management processes.

CLOUD COMPUTING

An IT model that provides easy, on-demand access via the network to a shared set of IT resources.

INTERNET OF THINGS

A set of physical or virtual objects communicating directly or indirectly.

ADDITIVE MANUFACTURING

Processes used to manufacture a physical object from a digital object, layer by layer, by adding material.

INTELLIGENT SENSORS

Instrumentation capable of collecting, processing and transmitting data autonomously.

PREDICTIVE MAINTENANCE

Maintenance designed to reduce the probability of failure or deterioration in the operation of an asset.

VIRTUAL REALITY

Techniques based on real-time interaction with a virtual world, using behavioural interfaces to immerse the user in this environment.

ROBOTICS

All the techniques used to design and build automatic machines or robots.

In terms of academic research, Paris-Saclay also occupies a prime position, with, alongside **CEA-List**, a leader in the field, numerous laboratories of excellence such as **LISN** (Interdisciplinary Laboratory of Digital Sciences), **LISV** (Versailles Systems Engineering Laboratory), **IBISC** (Computer Science, Bio-Informatics and Complex Systems) and **GEEPS** (Group of Electrical Engineering - Paris), a joint laboratory of the CNRS, CentraleSupélec, Université Paris-Saclay and Sorbonne University. Alongside these research institutes that are experts in their field, Paris-Saclay is also renowned for its collective and interdisciplinary initiatives. When it comes to solutions for the industry of the future, we should mention **Hi! Paris** and **DATAIA,** but also **H-CODE** (Human in the loop for control and decision), an interdisciplinary centre at Université Paris-Saclay aimed at bringing together communities of researchers and engineers working on control and decision theory concepts at different scales. Not forgetting cutting-edge facilities such as **CONTINUUM** (Continuité collaborative du numérique vers l'humain), an EquipEx+ project supported by the CNRS and led by **Michel Beaudoin-Lafon,** one of the region's top talents, which aims to create a collaborative research infrastructure bringing together 30 platforms located throughout France.

Paris-Saclay is renowned for its collective and interdisciplinary initiatives.

• **Fig. 9** Onboarding day at the CampusFab platform dedicated to Industry 4.0 training.

Through its many courses in this field, Paris-Saclay is also preparing future generations and training the talents of tomorrow. In this respect, **the University of Evry** in particular has made Industry 4.0 a key area for development. The University offers a master's degree in industrial robotics. It has also rolled out major education initiatives, such as the **Évry Innovation Centre,** a demonstration, training and research platform opened in June 2022 and the new flagship of the Campus des Métiers et des Qualifications Aéronautique et Spatial d'Île-de-France or **CampusFab**, an innovative and exemplary training platform offering a comprehensive range of courses to train the industry players of tomorrow. **Université Paris-Saclay** also offers a **Graduate School** dedicated to **Engineering and Systems Sciences**, for engineering and digital sciences at the service of the major challenges facing society, as well as a Master's Degree in Industry of the Future and Intelligent Systems.

Today, these digital technologies are within a revolution. Flexible and customisable, intelligent and connected, virtual and based on a high degree of human-machine collaboration, the factory of tomorrow will be largely digital and will incorporate future technologies such as generative artificial intelligence, programmable materials, autonomous twins and the metaverse. It's being invented today in Paris-Saclay!

The University of Evry has made Industry 4.0 a key area for development.

• **Fig. 10** Optical signal level measurement using a reflectometer in the server room of a data centre.

Smart manufacturing, start-ups at the heart of industry 4.0

Companies and start-ups based in Paris-Saclay specialising in smart manufacturing can be involved in all areas of Industry 4.0, from product design and quality control to the production line. Some examples? Dataswati and WiN MS, both founded in the mid-2010s, have gone from start-ups to fast-growing companies.

Dataswati, based in Massy, helps food manufacturers to optimise their performance (raw materials, energy, water, etc.) and reduce their carbon footprint. The company offers a digital twin, PowerOP, which uses artificial intelligence to analyse data. This "real-life" experience via the twin can help to reduce losses of raw materials, improve energy performance, and so on, but it can also considerably advance the R&D of companies in the sector by anticipating the physical and economic effects of any variations in recipes or components.

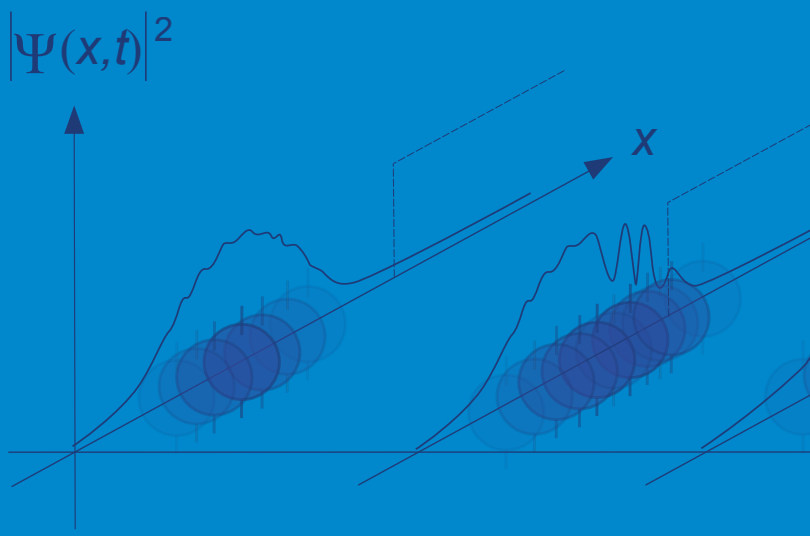
WiN MS (Wire Network Monitoring Solutions) enables manufacturers to detect and locate faults or anomalies in cable networks using reflectometry. It already has a wide range of applications, including aviation and space, the automotive sector, smart cities and their energy networks, and rail networks. WiN MS offers instant diagnostic tools for aviation as well as solutions for monitoring the most complex cable networks. Setting up the company in Gif-sur-Yvette seemed a natural move for the two founders, Marc Olivas, from CEA-List, and Arnault Peltier, from the Institut d'Optique Graduate School, who both describe themselves as "pure Paris-Saclay products". Founded in 2011, WiN MS already has subsidiaries in the USA and Singapore.

An exceptional research, education and innovation capacity

$$-\frac{\hbar^2}{2m}\cdot\frac{\mathrm{d}^2\psi(x)}{\mathrm{d}x^2}+U(x)\cdot\psi(x)=E\cdot\psi(x)$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2}+V\Psi=E\Psi$$

	$E-V(x)<0$	$E-V(x)>0$
$\Psi>0$	 $[E-V(x)]\Psi<0$ $\frac{\partial^2\Psi}{\partial x^2}>0 \quad T<0$	 $[E-V(x)]\Psi>0$ $\frac{\partial^2\Psi}{\partial x^2}<0 \quad T>0$
$\Psi<0$	 $[E-V(x)]\Psi>0$ $\frac{\partial^2\Psi}{\partial x^2}<0 \quad T>0$	 $[E-V(x)]\Psi<0$ $\frac{\partial^2\Psi}{\partial x^2}>0 \quad T<0$

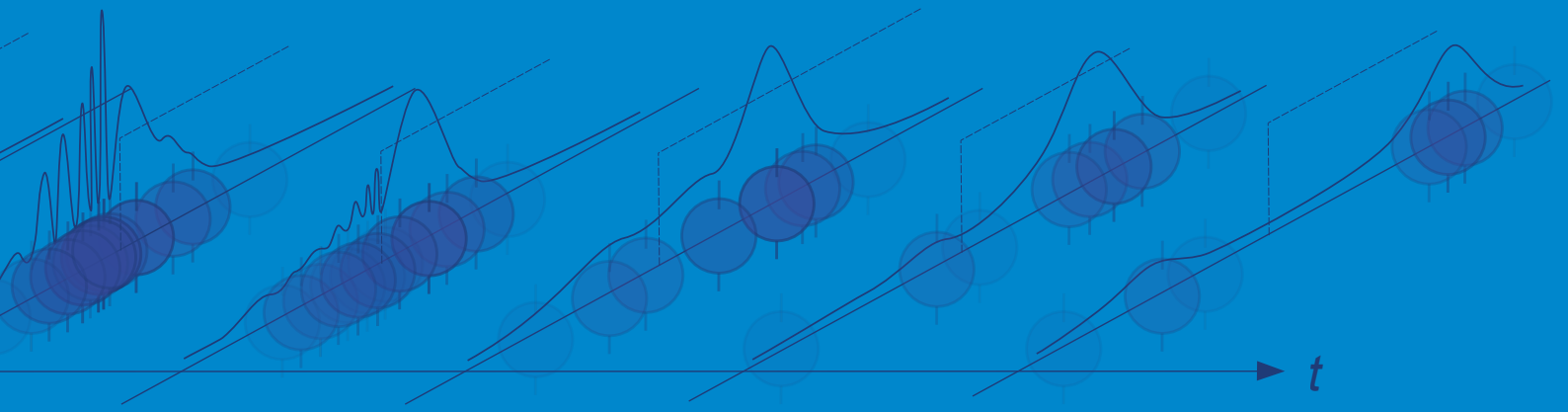


With world-class higher education establishments and research laboratories, internationally renowned talent and a breeding ground of high-tech start-ups, a sign of a strong innovation dynamic, Paris-Saclay benefits from a particularly rich ecosystem whose strength lies in the concentration of its players, the density of its skills, and the synergies deployed between disciplines, technologies and players.

As a result of these synergies, a growing number of exemplary interdisciplinary institutions and innovative collaborative programmes are being set up at the interface between academia and industry.

Today, the digital technology sector in the region includes 400 major establishments, more than 250 laboratories and technical platforms, 106 cutting-edge start-ups and represents around 32,000 jobs.

$$H(t)|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle$$



Academic research of excellence at the crossroads of scientific disciplines

Within Paris-Saclay's academic excellence: prestigious national research bodies such as **Inria** (National Institute for Research in Digital Science and Technology), France's leading research institute in artificial intelligence, **CEA-List**, dedicated to intelligent digital systems and a leader in cybersecurity research, and the **CNRS** (National Centre for Scientific Research). Paris-Saclay also boasts a large number of expert laboratories such as **LISN** (Interdisciplinary Laboratory of Digital Sciences), one of the best automatic language processing laboratories in France, the **LTCI** (Information Processing and Communications Laboratory) at Télécom Paris, the **IMSIA** (Institute of Mechanical Sciences and Industrial Applications) supported by ENSTA Paris and the **L2S** (Laboratory of Signals and Systems), jointly run by the CNRS, CentraleSupélec and Université Paris-Saclay.

Paris-Saclay is also a partner in priority research programmes and facilities (PEPR) such as the **DIADEM programme,** co-directed by the CEA and the CNRS, which aims to accelerate the deployment of innovative materials using artificial intelligence. In particular, it relies on major local facilities such as the **SOLEIL Synchrotron**.

Within Paris-Saclay's academic excellence are prestigious national research bodies such as Inria, CEA-List and the CNRS.

• **Fig. 11** Interior view of the main hall of the Alan Turing building at the Inria Saclay research centre.

Inria: France's digital bridgehead

Founded in 1984, the National Institute for Research in Digital Science and Technology has 215 project teams, 3,900 affiliated scientists and is behind more than 200 start-ups. The Institute's core missions are to maintain scientific excellence in the field, accelerate innovation, influence national and European public policy and drive growth in digital learning.
In addition to its numerous programmes – Artificial Intelligence, Education and the Digital Age, Digital Health, Cybersecurity, Quantum, Digital and the Environment – Inria has been entrusted, as part of the national strategy for artificial intelligence (SNIA), with coordinating all activities related to training in artificial intelligence, i.e. 190 chairs and 22 doctoral programmes. In this context, Inria also runs the four Interdisciplinary Artificial Intelligence Institutes (3AI), which are part of the national artificial intelligence research programme. The institute has also signed a partnership agreement with Université Paris-Saclay to build joint project teams (EPCs) and cooperation schemes. Their priority research areas are digital health, artificial intelligence and data sciences, cybersecurity, quantum sciences and human-machine interaction.

Other notable facilities at Paris-Saclay in the field of digital technologies include the CEA's **Très Grand Centre de Calcul** (TGCC), dedicated to intensive computing and high-performance simulation, and the **Jean Zay supercomputer,** the most powerful in France.

Alongside these fundamental and applied research activities, Paris-Saclay is also training the talents of tomorrow. One of the region's top courses is the **Mathematics, Vision and Learning (MVA) Master's Degree** at **ENS Paris-Saclay**, which each year trains the world's elite in artificial intelligence. Université Paris-Saclay offers **UDOPIA,** a cross-disciplinary doctoral programme dedicated to artificial intelligence, and recently opened **Quantum-Saclay**, an interdisciplinary centre dedicated to quantum science and technology, with the Institut Polytechnique de Paris. In the field of cybersecurity, the Saint-Quentin-en-Yvelines conurbation has specialised in this area, with dedicated schools such as the **École 2600, the European School of Cybersecurity** (EECS) and the **IPSSI campus**, alongside courses offered by the region's leading higher education establishments such as **Université Paris-Saclay, the Institut Polytechnique de Paris, ENSTA, CentraleSupélec, Télécom Paris and Télécom SudParis. The University of Evry**, for its part, has made Industry 4.0 a key focus for learning, with courses dedicated to industrial robotics and innovative training platforms such as **CampusFab** and the **Evry Innovation Centre**. A fantastic pool of future employees for local businesses.

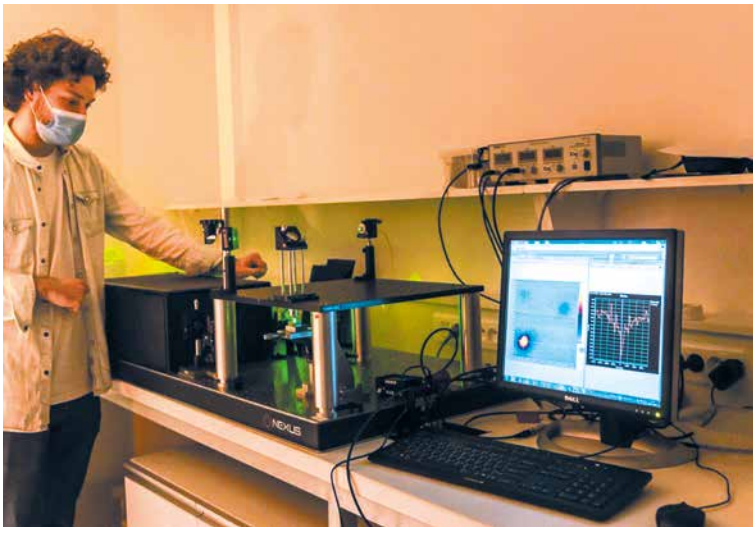
200

WORLD-CLASS *DATA SCIENTISTS*

TRAINED EACH YEAR BY THE MATHEMATICS, VISION AND LEARNING (MVA) MASTER'S PROGRAMME AT ENS PARIS-SACLAY.

Quantum-Saclay Centre: quantum under the microscope

Aware of the technological importance of the second quantum revolution, Université Paris-Saclay and the Institut Polytechnique de Paris have created Quantum-Saclay, the Paris-Saclay interdisciplinary centre for quantum science and technology. Working with the CNRS, CEA, Inria and ONERA, Quantum-Saclay brings together more than 80 teams from the region, with partnerships involving major industrial groups such as Thales, EDF, TotalEnergies, Air Liquide and IBM, as well as emblematic start-ups in the field such as Pasqal and Quandela. The research carried out by these teams covers the whole range of fields, from the most fundamental studies to development at high levels of technological maturity in quantum communications and photonics, quantum computers, quantum sensors, quantum simulation, quantum and topological matter, quantum computing, as well as the development of enabling technologies. The centre also federates training initiatives to meet the objective set by the national quantum plan of doubling the number of PhDs in quantum science and technology in the very near future. Paris-Saclay, which combines university courses with courses at some of the world's most prestigious engineering schools, is the only place where this challenge can be met in close interaction with industry.



• **Fig. 12** A PhD student explaining the manipulation of photon unbundling using a single emitter at the Quantum-Saclay Centre.

INTERVIEW WITH NICOLAS SABOURET, DIRECTOR OF THE *GRADUATE SCHOOL* OF COMPUTER SCIENCE OF UNIVERSITÉ PARIS-SACLAY

Training talent to meet the challenges of digital technology

The aim of the Graduate School of Computer Science at Université Paris-Saclay, which was launched in July 2020, is to train tomorrow's engineers and researchers to meet the major challenges of digital technology – big data, artificial intelligence, the Internet of Things, cybersecurity, quantum computing, etc. A specialist in artificial intelligence and human-machine interaction, professor of computer science at Université Paris-Saclay, lecturer at CentraleSupélec and researcher at the Interdisciplinary Laboratory of Digital Sciences (LISN – Université Paris-Saclay, CNRS, CentraleSupélec, Inria), its director, Nicolas Sabouret, tells us more, including the beneficial effects of enrolling some 22 laboratories participating in this Graduate School.

The challenges addressed by your Graduate School range from Big Data to AI, the Internet of Things, cybersecurity, quantum computing and more. How can you justify such a broad spectrum, which is reminiscent of an inventory à la Prévert?

NS All these challenges lie within computing and digital sciences today. For the record, computing is the science of automatic information processing, while the digital sciences are concerned with implementing this processing to develop tools and functions. It's therefore only natural to associate them, given that the digital sciences themselves cover challenges as varied as AI, quantum computing and automatic signal and image processing. So yes, it may sound like an inventory à la Prévert, but if you were to visit my colleagues at the Graduate School of Physics or the Graduate School of Mathematics, they would draw up at least as impressive a list of challenges that their disciplines are working hard to meet. Coming back to our own, I would add that we've been exploring them for a long time. Our laboratories have been working on this for years, and have built up an international reputation for their work in areas such as human-machine interaction, signal and image processing, telecommunication networks, automatic language processing, algorithms and formal methods.

What careers are your students aiming for?

NS They are destined to work as computer engineers or to continue in research. In reality, 80% do not go on to do a PhD. Not that research isn't attractive to them, but our students aspire to apply their knowledge very quickly by landing a job in industry. The context is particularly favourable: the IT and digital job market is dynamic, with prospects for well-paid jobs. Our students have no trouble finding jobs when they graduate.

To what extent are you preparing them to adapt to constantly changing professional environments?

NS This is an important point. Computing and the digital sciences are undergoing rapid change. Who would have thought 10 years ago that AI would attract such renewed interest from industry? And the courses offered by Université Paris-Saclay – and I can speak from experience as someone who has been involved in a number of different courses – are designed not just to train students to meet immediate needs, but also to ensure that they're capable of adapting to the new challenges of the coming years. This is, moreover, one of the University's primary missions and enables it to meet the challenges I've mentioned: to take AI as an example, the University has never ceased to take an interest in it and to offer courses in this field, even during the years when it seemed to have been neglected by industry. We're delighted about this, because it means we can meet the high demand for training today. It's in the same spirit that we continue to teach certain subjects, even if they seem less "fashionable", because there's nothing to say that they won't become so again. So no, we don't train students just to fit them into a mould, but so that they acquire skills that they can continue to develop. This is all the more necessary given that, as you know, digital technology is constantly evolving. Not a year goes by without the emergence of new applications and theoretical perspectives.

To what extent do your courses also teach them a critical sense and prepare them for the ethical issues involved in digital technology?

NS These are major issues that we're working to develop. But let's face it, it's not easy. Not that our teacher-researchers aren't aware of this. Quite the opposite. But we need to integrate them into our courses. In fairness, there are still very few modules dedicated to ethics and the ecological transition. We have an online course being set up on digital responsibility, and some of our training modules raise students' awareness of the need to design algorithms that are as economical as possible in terms of computing time (and therefore energy). But we have the same problem as other Graduate Schools: these modules are in addition to everything we already want to teach them. We ensure that students at least take the courses we offer, which they're happy to do, but I think this is an area where we could make progress. I'm confident that we'll succeed, given the way our Graduate Schools operate: we're fortunate to have teachers-researchers who are willing and able to adapt themselves as we go along.

We carry out the maintenance in the Graduate School's offices in Building 640, which is located in front of the brand new Henri Moissan Biology-Pharmacy-Chemistry Centre, all in the Moulon district, which is home to many other higher education and research establishments, R&D centres, and so on. To what extent does your Graduate School's inclusion in such an ecosystem serve its ambitions?

NS The fact that we are physically located within the Paris-Saclay ecosystem, close to our colleagues in biology, pharmacy, chemistry and physics, is obviously an advantage. It's one thing to be able to interact remotely, it's quite another to do so face to face, especially when it's only a few minutes' walk from your office or laboratory. This changes the nature of the relationship, even if, following the periods of confinement and restrictions on meetings, we've got into the habit of using video more than before. But, needless to say, you can't do the same thing over video as you can face to face. It's true that you can exchange information remotely, but to build a project together over the long term, you need to be able to be present with others and take the time to see each other. What applies to teachers and researchers also applies to students: it's important that they don't stay within the confines of the PUIO [Pôle universitaire d'ingénierie d'Orsay] building where we are, but that they can meet students from across the street, or from CentraleSupélec or ENS Paris-Saclay, which are just a few minutes' walk away. That's how they can discover other ways of thinking and doing science.

Your own work focuses on human-machine interaction. A major challenge if ever there was one, given recent developments in AI...

NS These interactions are within society's concerns. People are concerned that technology is taking on an increasingly important role in society, sometimes to the point of having the impression that man is at the service of machines. My colleagues and I are working to ensure that machines adapt to humans rather than the other way round.

I can't resist evoking the philosopher of technology Gilbert Simondon, who urged us to "liberate the machine", by which he meant not to restrict it to functions defined once and for all, but to unleash its potential through new developments...

NS Be careful not to get it wrong. Too often, people imagine that machines are capable of doing everything, that any problem can be solved by designing a new machine capable of automating a particular physical or cognitive task. But I think that while machines can do a lot of things, in reality they can only do the same thing many times. A machine that can do everything, or many different things, is not for tomorrow. For the time being, humans are better able to adapt to different situations and carry out a wide variety of tasks. While each of these tasks can be reproduced by a machine, many different types of machine would have to be mobilised to cover most of the tasks carried out by a single human being, because of his capacity to adapt – we'll come back to this. Rather than asking how to "liberate the machine" so that it can do things beyond what humans can do, we should be asking how humans can be further liberated by machines, how they can contribute to their emancipation.

Interview by Sylvain Allemand

Exemplary interdisciplinary organisations

In addition to its scientific and technological excellence, the value of the Paris-Saclay cluster lies in its ability to facilitate bridges between scientific and technological disciplines and, more generally, in its collective dynamic, which encourages interdisciplinarity and cross-disciplinarity, one of its greatest assets.

A number of interdisciplinary and collective initiatives developed in recent years to promote the growth of digital technologies are particularly exemplary. This is the case of the **DATAIA Institute**, set up by Université Paris-Saclay and the **Hi! Paris Centre**, from the Institut Polytechnique de Paris, in the field of artificial intelligence. It is also the case for **H-CODE**, an interdisciplinary centre at Université Paris-Saclay that brings together communities of researchers and engineers working on the concepts of control and decision theory in the field of robotics, and **CONTINUUM**, an EquipEx + project led by the CNRS aimed at creating a collaborative research infrastructure bringing together 30 platforms working in the field of digital to human in France. The **CIEDS – Interdisciplinary Centre for Defence and Security** – initiated by the Institut Polytechnique de Paris to detect and develop breakthrough technologies for defence needs in the fields of digital security, robotics and artificial intelligence, quantum technology, imaging and modelling for systems engineering or defence innovation management, imaging and modelling for systems engineering and defence innovation management, and the SystemX Institute of Research and Technology (IRT), which is multiplying the connections between local players to accelerate the digital transformation of industries, services and regions, are equally exemplary.

Based on synergies between disciplines and skills and collaboration between academic and industrial players, these innovative collaborative and multidisciplinary initiatives are a true signature of the Paris-Saclay cluster.

These innovative collaborative and multi-disciplinary initiatives are a true signature of the Paris-Saclay cluster.

• **Fig. 13** Server cabinets in a data centre.

SystemX: accelerating digital transformation

An accelerator for the digital transformation of industry, services and regions: this is how the SystemX Institute of Research and Technology (IRT), created in 2012, defines itself. SystemX is one of the eight IRTs created under the national "Investissements d'avenir" programme and based on a public/private partnership. Its mission is to increase the number of connections between companies and the region's research and teaching facilities. It also provides its technological platforms – methodology, software, cyber-physical systems – and offers its expertise to all its public and private partners. Atos, Airbus, Air Liquide, EDF, Engie and Renault Group have all placed their trust in SystemX to help advance some of their research programmes. On the academic side, the IRT takes full advantage of its geographical proximity to the best schools and universities in France working in digital research. Agreements have been signed with Université Paris-Saclay, Université de Versailles-Saint-Quentin-en-Yvelines (UVSQ), the École polytechnique de Paris, ENSTA ParisTech and Mines Paris Tech. The Institute has also set up the SystemX Academy, which offers training related to Industry 4.0 (Industry of the Future Certificate). In addition, in the field of augmented engineering, IRT SystemX is piloting three programmes – Confiance.ai, IA2 – Intelligence Artificielle et Ingénierie Augmentée – and Jumeau numérique des systèmes industriels complexes – to deploy digital and artificial intelligence technologies more widely. Finally, it has stepped up its activity in cybersecurity, developing comprehensive solutions for a trusted digital economy.

The CIEDS: technology at the service of defence

The CIEDS (Interdisciplinary Centre for Defence and Security), one of the four interdisciplinary centres of the Institut Polytechnique de Paris, was set up in 2021. It operates across all five of the Institute's member schools, with two main missions: to develop breakthrough technologies for defence needs and to ensure that the Institut Polytechnique de Paris takes defence issues fully into account. The CIEDS is strongly supported by the French Ministry of Defence and the Defence Innovation Agency, in particular through the funding of research projects. The CIEDS conducts research in around 10 areas – robotics and artificial intelligence, imaging and modelling for intense laser systems engineering and applications, innovative materials and functionalisation, energy optimisation and propulsion, quantum technology, detection of biological and chemical threats and care for combatants, defence innovation management – in order to detect potential technological breakthroughs and integrate them into the Defence Industrial and Technological Base (DITB).
The Centre now has more than 120 researchers and teacher-researchers working in 25 laboratories at the Institut Polytechnique de Paris on around 50 defence-related studies.
It launches a dozen new projects a year, lasting 3 to 4 years.
Its second mission is to create a network of very long-term partnerships between researchers, students at the Institute, companies, funding structures and the Ministry of the Armed Forces. The CIEDS has set up an Industrial Partnerships Club that provides privileged access to its results and protected technologies.

Talent of international stature

Attracted by world-class research establishments and laboratories, as well as by the prospect of collaborating with both renowned researchers and leading industrialists, a growing number world-renowned scientists are joining the Paris-Saclay academic cluster.

The most emblematic of these talents is undoubtedly **Alain Aspect**, a researcher at ENS Paris-Saclay and the CNRS, lecturer at the Institut Polytechnique de Paris and the Institut d'Optique Graduate School, co-founder of the start-up Pasqal and, in 2022, **winner of the Nobel Prize in Physics** for his work on Bell's inequalities and quantum entanglement. In the same field, **Pascale Senellart**, director of research at the CNRS, professor of quantum mechanics at the École polytechnique and co-founder of the start-up Quandela, is another emblematic figure from Paris-Saclay. In 2021, she was awarded the **Grand Prix Mergier-Bourdeix by the Académie des Sciences**.

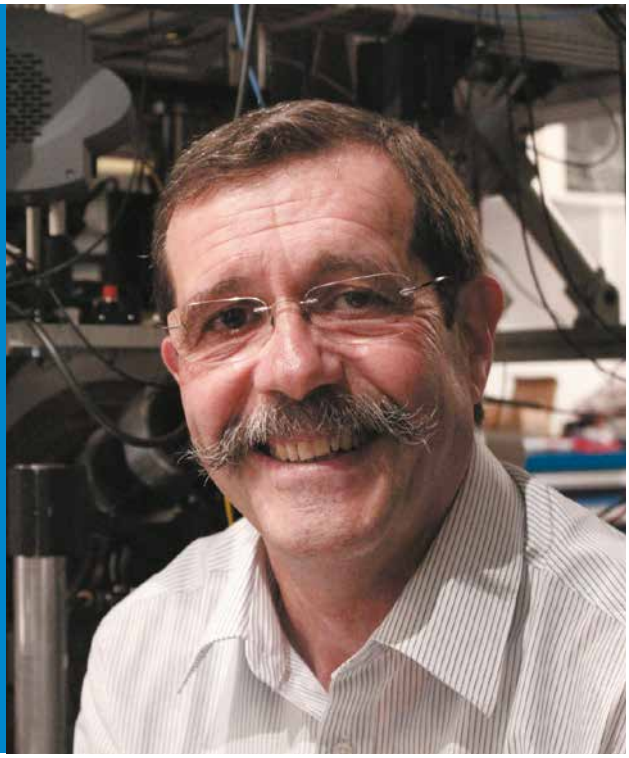
41%

OF THE TOP 200 FRENCH LEADERS IN ARTIFICIAL INTELLIGENCE ARE LINKED TO PARIS-SACLAY

Home to 41% of France's top 200 talents in the sector, Paris-Saclay is also the birthplace of many leaders in artificial intelligence. One of these is **Luc Julia**, who has returned to Paris-Saclay after spending many years in the United States, notably with the Apple Group, where he co-founded the Siri voice assistant, and is now Scientific Director for the Renault Group. **Jérôme Pesenti**, vice-president of artificial intelligence at Facebook and former head of the Watson programme at IBM, is another such talent, as is **Laurence Devillers**, a researcher in artificial intelligence at the Interdisciplinary Laboratory of Digital Sciences (LISN), a member of the DATAIA Institute and the National Steering Committee on Digital Ethics and Artificial Intelligence. In this field, we could also mention **Marc Schoenauer**, Director of Research at Inria, who in 2017 was commissioned by the Prime Minister along with Cédric Villani to define an artificial intelligence strategy for France, or **Julie Grollier**, CNRS Silver Medallist in 2018, **winner of the Irène Joliot-Curie 2021 Woman Scientist of the Year award** and head of the nanocomponents for cognitive information processing team at the CNRS/Thales Joint Physics Unit.

Alain Aspect, a quantum Nobel Prize winner

Born in 1947 in Agen, Alain Aspect is a Nobel Prize winner in physics "made in Paris-Saclay". Currently Emeritus Research Director at the CNRS, where he was awarded the gold medal in 2005, he took his doctorate at the Institut d'optique d'Orsay before spending most of his career in the laboratories of ENS Paris-Saclay and SupOptique. Today, he continues to pass on his knowledge by teaching at the Institut Polytechnique de Paris and the Institut d'Optique Graduate School, where he holds the Augustin Fresnel Chair. Always on the lookout for cutting-edge research in quantum physics, in 2019 he co-created Pasqal in Massy, a start-up specialising in quantum computers and systems. It was for his revolutionary and pioneering experiments on Bell inequalities and quantum entanglement, which paved the way for quantum computing and cryptography, that he was awarded the Nobel Prize, along with Jean Clauser and Anton Zeinlinger, in 2022. A member of a large number of science academies around the world, he was also awarded the Wolf Prize for Physics in 2010, the Balzan Prize for Quantum Computing in 2013, the Nels Bohr Gold Medal, as well as the Albert Einstein Medal and the Ives Medal from the Optical Society of America in the same year.



Luc Julia: Siri founder returns to his roots

An engineer and computer scientist, Luc Julia is best known to the general public for having co-invented the Siri voice assistant. He holds a doctorate in computer science from Télécom Paris. Based in the United States since the early 1990s, and a pioneer among pioneers, he was one of the founders of Nuance Communications in 1994, today the world leader in speech recognition.

After launching the project that would become Siri, he founded the Computer Human Interaction Center (CHIC) in 1998, a laboratory specialising in artificial intelligence that would produce the first connected objects and intelligent cars for BMW. In 2000, he founded Orb, a start-up specialising in transforming computers into multimedia servers, before spending almost 10 years with the Samsung Group. He joined the Renault Group in May 2021 as Chief Scientific Officer. A return to his roots for the man who trained at Paris-Saclay. There, with his teams, he created Reno, the avatar that will be integrated into the new R5. Luc Julia is a member of the Académie française des technologies. The author of several books, he is often presented by the media as the "pope" of predictive artificial intelligence.

CEA-List, a leading research laboratory in the region, also provides Paris-Saclay with a wealth of talent, such as **Florent Kirchner**, who for many years ran the laboratory for software safety and security and the cybersecurity programme, and who is now coordinator of the national cybersecurity strategy within the General Secretariat for Investment (SGPI) and the French representative on the Board of Directors of the European Cybersecurity Competence Centre (ECCC). **Gregorio Ameyugo**, also currently head of the Ambient Intelligence and Interactive Systems Department (DIASI), a 200-strong unit that ranks among the world's top teams in vision technologies, semantic artificial intelligence, collaborative robotics, human-machine interfaces, interactive simulation and network technologies, and formerly Director of Innovation at EIT Manufacturing. Or **Sara Tucci-Piergiovanni**, an international expert in blockchain.

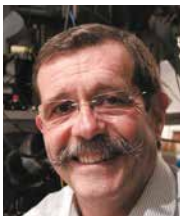
Other leading academic figures are also contributing to the prestige of Paris-Saclay, including **Christophe Tournier**, from ENS Paris-Saclay, who was responsible for launching an additive manufacturing platform of international scope in the region, or **Michel Beaudoin-Lafon**, CNRS silver medallist in 2022, who has been coordinating the network of 30 digital platforms in the national CONTINUUM programme since 2021. Not forgetting **Hugo Duminil-Copin**, professor at the Institut des hautes études scientifiques (IHES) and **Fields Medal winner in 2022**.

Laurence Devillers Making AI rhyme with ethics

Laurence Devillers is a researcher at the CNRS's Interdisciplinary Laboratory of Digital Sciences (LISN), where she leads the research team on Affective and Social Dimensions in Spoken Interaction. A member of the DATAIA Institute, she is also a professor of computer science specialising in artificial intelligence at Sorbonne University. Her main areas of research are human-machine interaction, emotion detection, spoken dialogue and affective and interactive robotics. She has taken part in a number of national projects, including ANR Tecsan Armen, FUI Romeo and BPI Romeo2, and European projects such as Rex Humaine, the first "bionic man". She also runs the human-machine co-evolution unit as part of the Digital Society Institute (Université Paris-Saclay). Ethics in the creation of robotics and artificial intelligence being her area of expertise, Laurence Devillers also took part in drafting the report on the ethics of robotics researchers for the Committee for the Ethics of Research in Information Sciences and Technologies (Cerna) of the Allistene alliance. Lastly, in 2017, she joined the National Steering Committee on Digital Ethics and Artificial Intelligence.

ALAIN ASPECT, NOBEL PRIZE IN PHYSICS 2022

A Nobel Prize in quantum physics at the heart of Paris-Saclay



Winner of the 2022 Nobel Prize in Physics (alongside American John Clauser and Austrian Anton Zeilinger) for his quantum physics experiments on the phenomenon of entanglement, Alain Aspect pursued his studies and career as a teacher-researcher in higher education and research establishments in the Paris-Saclay ecosystem. Here he highlights its virtues, including in terms of innovation. He has also contributed to the development of start-ups focused on quantum physics and computing, some of which were created by former doctoral students.

Your work on the phenomenon of entanglement, on the one hand, and atomic optics, on the other, has had concrete applications, including in the context of entrepreneurial projects that you have personally supported: Muquans, Pasqal, Quandela, and so on. How do you explain this commitment to innovative entrepreneurship, at a time when this was not so common, due to a strong division between basic research and applied research, not to say R&D? What does this say about the role you see for researchers, including in basic research?

AA I think that this commitment on the part of the researcher is important and should be valued. When I was still a student, and then at the start of my career, there was a tendency to think that basic researchers should not be interested in applications, that it was "getting their hands dirty", if I may use that expression. Until a turning point came in 1982-1983, when Laurent Fabius, then Minister for Research and Industry, encouraged researchers, as soon as they had an idea for an application, not to refrain from implementing it on the grounds that it could contribute to the country's development and help find additional funding for research. I kept this in the back of my mind. From there to launching my own entrepreneurial project... I'm afraid I was convinced too late to come up with my own ideas for applications. On the other hand, I've always recommended to my doctoral students that if they felt they had a good idea, they should not hesitate to embark on an entrepreneurial project. When, decades after my experiments on entanglement – and I say decades later because that's the time frame we're in when it comes to moving from basic research to applications – some students wanted to apply the results of my research, they asked me for my opinion and, on the good old principle that there's no love without proof of love, asked me if I could help them get their project off the ground. Naturally, I couldn't give up. That's how I ended up investing in my first project. It was Muquans, founded in 2010 by Bruno Desruelle and Arnaud Landragin, two of my former PhD students, and Philippe Bouyer, a direct collaborator in my atomic optics group. The absolute quantum gravimeter they developed has been so successful that their start-up has since been acquired by iXblue, which specialises in the design of navigation systems.

Then Quandela invited me, not to be one of its first investors, but to join its scientific committee, which I enthusiastically accepted. Since then, I've attended its two annual meetings with great pleasure and amazement at the progress that has been made. Quandela was able to capitalise on the ideas that Philippe Grangier, my first PhD student, and I had launched in 1985-86, by designing the world's first source of single photons. Quandela has become a world leader in this field. So you'll understand that I couldn't help but appreciate the invitation from its founders.
Finally, Pasqal, created in 2019 by another of my PhD students, Antoine Browaeys, with one of Philippe Grangier's PhD students – Georges-Olivier Reymond – whom I can therefore consider to be my scientific grandson, both having launched their project at the instigation of another of my former PhD students, Christophe Jurczak, who spent time in the United States and came back with a quantum investment fund. Pasqal offers one of the best quantum simulators in the world; it's based on the ability to entangle atoms by manipulating them with small optical "tweezers" developed in Philippe Grangier's group by Georges Reymond and another PhD student. This is yet another illustration of the perfect relationship between basic research and its applications, bearing in mind that several decades – and I stress this point – can pass in between.

Listening to you, we can't help noticing that entanglement doesn't just concern elementary particles. It is also needed between researchers – doctoral students, thesis supervisors – and investors, to give substance to an application through an entrepreneurial project...

AA (Smiling). That's right!

Coming back to your studies, it's clear that they are also very closely interwoven with the Paris-Saclay ecosystem: after graduating from ENS Cachan, which became ENS Paris-Saclay, you went on to study at Orsay University and then at Université Paris-Sud, the Institut d'Optique and so on. Could you say a few words about the role of the Paris-Saclay ecosystem?

AA I'd like to say more than a few words about this, firstly to say how invaluable the advice, and even the loans of equipment, from a number of laboratories on the university campus and also at the CEA have been. But I would also like to emphasise the key role played in my work by the Institut d'Optique, which has been closely associated with the university since the 1960s. In 1974, as an assistant professor at ENS Cachan, I was able to undertake an experiment on Bell inequalities thanks to a young professor at the Institut d'Optique, Christian Imbert. I remember the moment he handed me a set of texts on the phenomenon of entanglement, which was still little known at the time. A precious gesture: at the time, it wasn't easy to access the documentation we needed – the internet didn't yet exist! *"Look at this,"* he said, *"There might be something interesting for you."* These articles included the famous text by John Bell, in which he explained that the Einstein-Bohr controversy could be settled by experiments. When I read it, I immediately wanted to try and conduct them.
When I started telling colleagues about my intention to conduct an experiment on this subject, I immediately perceived resistance, not to say hostility, from many of them. Christian Imbert had the right attitude: he suggested I start by meeting John Bell. *"If he tells you that the experiment could be interesting, then you can conduct it within my research group."* What I did was to meet John Bell at CERN in Geneva. With his encouragement, I set up a team with two engineers, Gérard Roger and André Villing, to build the experiment from scratch. The rest is history. Eight years later, with two particularly brilliant postgraduate students, Philippe Grangier and Jean Dalibard, we obtained particularly significant results in favour of Bohr's position.
So I owe an infinite debt of gratitude to Christian Imbert and the Institut d'Optique for allowing me to carry out this experiment. I'm not sure that many laboratories would have allowed me to do it.
I'm all the more grateful to them because it was at the same Institut d'Optique that Philippe Grangier, who was starting his thesis under my supervision, and I managed to achieve another world first, the production of single photons. This provided convincing confirmation of another feature of quantum physics, the "wave particle" duality. To achieve this, we drew on the expertise that the Institut d'Optique had built up over the years in the field of interferometers.
Later, I was a fervent supporter of the creation of Université Paris-Saclay, especially as this university had the ambition of federating the university and the grandes écoles, an operation of which I had also been a strong supporter for a long time. The fact that ENS Cachan, the place where I did my initial training, also came out in favour of the Université Paris-Saclay project, to the point of joining the Saclay plateau, convinced me of the value of this project. Today, I'm delighted to be able to share the influence of the Nobel Prize with all the institutions that have played a part in my studies and my work.

Given that you are ecumenical and also teach at the École Polytechnique…

AA Absolutely. I won't comment on the fact that this school has chosen to withdraw from the Université Paris-Saclay project. On the other hand, I'd like to say that I made a point of keeping one foot in each camp. I'm involved in ARTeQ, a training programme on quantum technologies that combines the two. So, yes, in that sense, I am ecumenical in my approach to the Paris-Saclay ecosystem. Especially as I don't think it's a serious problem to have two separate entities: Université Paris-Saclay and the Institut Polytechnique de Paris (IPP). After all, in Boston, Harvard and MIT cohabit and, far from being detrimental, this cohabitation benefits both universities: my colleagues at MIT collaborate with those at Harvard and vice versa. There's no reason why it shouldn't be the same here.

We're conducting this interview in your office at IOGS, where you can see the Thales site and, a few hundred metres away, one of the entrances to the Polytechnique campus. These two entities are home to two other Nobel Prize winners in Physics: Albert Fert and Gérard Mourou. That's three Nobel Prizes in a particularly small area…

AA Yes, that's true, it's quite dense. Let me point out that in the case of Albert Fert and myself, the work that won us a Nobel Prize was carried out right here in France. Gérard Mourou carried out his work in the United States, which of course in no way detracts from its interest.

I can't resist the urge to end this interview by talking about your childhood village in Gascony. As much as you are keen to extol the merits of the Paris-Saclay science and technology cluster, in interviews you have given you are also keen to pay tribute to the teachers who gave you a taste for science, and to express your attachment to a school of the Republic that is present throughout the country, if I can sum it up in these words…

AA I wouldn't put it any differently. I'm lucky enough to have known these teachers, who were known as the "black hussars of the Republic". My own parents were among them. They had been trained before the Second World War in these teacher training colleges, which functioned as "secular seminaries". The great strength of these teachers was their versatility: they had just as good a grounding in mathematics, physics and the natural sciences as they did in French, geography and history. I still have fond memories of these teachers and their famous "lessons in things". I've had many opportunities to say how much they affected me, to the point where, when I entered secondary school, I wanted to take up physics. Through these lessons, the teachers instilled a taste for observing phenomena and trying to find an explanation for them.

Read the full version of the interview on the EPA Paris-Saclay website. Also read, by Alain Aspect: *Einstein et les révolutions quantiques, CNRS Éditions,* 2019

Interview by Sylvain Allemand

Start-ups at the cutting edge of innovation

Over the last 10 years, the number and pace of start-up creations in Paris-Saclay have continued to accelerate, illustrating the ecosystem's strong innovation dynamic in the field of digital technologies.

These start-ups are active in a wide range of fields, including data sciences, language processing, computer vision, modelling, quantum computing, high-performance computing,edge computing and blockchain technologies, with applications ranging from medical to space, energy, mobility and security.

Alongside the new European nuggets in quantum computing – **Pasqal**, **Quandela** and **Alice & Bob** – the region's most emblematic companies include cutting-edge start-ups such as **Therapanacea**, a genuine success story in French medtech, which brings the latest advances in artificial intelligence to radiotherapy, **TrustInSoft**, which specialises in cybersecurity and has been recognised by the US Department of Commerce's National Institute of Standards and Technology (NIST) for its ability to provide the highest level of mathematical guarantees for existing software, and two start-ups that are emblematic of the Paris-Saclay ecosystem: **Visionairy**, which came out of ENS Paris-Saclay and operates in the field of computer vision, and **Diota**, which came out of CEA-List and is now France's leading publisher of augmented reality software solutions for industry.

MORE THAN

40

INNOVATION CENTRES

IN THE PARIS-SACLAY REGION: INCUBATORS, ACCELERATORS, ILABS, FABLABS, CO-WORKING SPACES, BUSINESS INCUBATORS, ETC.

Snowpack makes internet exchanges invulnerable

Snowpack is a CEA spin-off set up in 2021 by two former CEA research engineers – Frédéric Laurent and Baptiste Polvé – and Sébastien Groyer. Hosted at the CEA Paris-Saclay Nano Innov integration centre, Snowpack develops and operates SNO (Snowpack Network Overlay), the first invisibility overlay network. SNO makes it impossible to exploit vulnerabilities on the network by preventing the identification of users, devices and the content of communications.

It is based on the mutual reinforcement of anonymity and security and the distribution of exit nodes. Its services are offered via a range of subscriptions, depending on customers' needs and the complexity of the anonymisation request. The company also offers publishers and developers the opportunity to integrate a layer of invisibility into their own applications, and is already working on Cloud and IoT offerings. In order to pursue its development,

Snowpack had raised over €2 million by the end of 2022. The funds will be used in particular to roll out SNO worldwide and expand its user community. The I-Lab prizewinning company is currently working on Brightnet, an integrated cybersecurity solution upstream of the antivirus. Finally, it is involved in SCRED, a unique collaborative project in the field of cybersecurity, in partnership with Thales, Atos and the Institut Mines-Télécom.

• **Fig. 14** Baptiste Polvé, Frédéric Laurent and Sébastien Groyer, the three co-founders of the start-up Snowpack, at the International Cybersecurity Forum (FIC) held in Lille on 5, 6 and 7 April 2023.

• **Fig. 15** The Playground Paris-Saclay, opened in 2021, is a new 6,000 m² business incubator-hotel (IPHE) in the Paris-Saclay region.

These start-ups have been able to take advantage of the many facilities dedicated to innovation and the creation of innovative businesses in Paris-Saclay. Incubators are run throughout the region by the schools, such as the **X-UP** and **Pépinières X-Tech** incubators at the École Polytechnique, the **503 Entrepreneurship and Innovation Centre** at the Institut d'Optique and the **CentraleSupélec incubator**. Accelerators and incubators have also been set up by public and private bodies such as **IncubAlliance, WILCO, Hardware Accelerator, SATT Paris-Saclay** and **Playground Paris-Saclay,** the new innovation cluster for the region. iLabs, fablabs and experimentation centres such as **Software République** are also dedicated to developing innovative technologies. Finally, events such as the **Paris-Saclay SPRING**, organised every year since 2019 and now a real showcase for scientific and technological innovation in the Paris Region.

NEARLY
110
CUTTING-EDGE START-UPS
LISTED IN DIGITAL TECHNOLOGIES

In all, almost **110 high-tech digital start-ups** have been launched, incubated or set up in the region. This creative dynamism is largely the result of the structuring of the industry over the last 10 years. Higher education establishments, cutting-edge research laboratories, leading companies, innovative collaborative programmes – the exceptional concentration of resources and partners present here makes Paris-Saclay one of the most attractive innovation clusters for investors, innovators and entrepreneurs from all over the world.

Start-ups benefit from a number of facilities dedicated to innovation or to the creation of innovative companies within Paris-Saclay.

EikoSim, a trajectory at the heart of Paris-Saclay

Physical and/or mechanical tests to validate digital simulations are time-consuming and costly for manufacturers. EikoSim helps their engineers to make the most of mechanical testing by offering innovative software that integrates test data into the digital design chain, mainly at test level. EikoSim is involved wherever complex industrial mechanisms need to be tested: aerospace and defence, automotive and rail, energy and civil engineering. The company, founded in 2016 by two ENS Paris-Saclay alumni, now offers concrete, practical solutions: test specification, sensor processing, data analysis, model recalibration. This R&D is sometimes carried out in cooperation with major industrial groups, such as Ariane Group for the RAPID R&D project (dual innovation support scheme) or the Mutation industrial test-simulation dialogue platform, or Dassault Systèmes with EikoTwin. EikoSim is also working with the Laboratoire de Mécanique et Technologie (LMT), in particular the Eikologie team, to create the measurement and identification methods of the future.
The company is supported by SATT Paris-Saclay and the Institut Polytechnique de Paris.

INTERVIEW WITH ZUZANNA STAMIROWSKA, CEO OF PATHWAY

Data sciences at the service of logistics

This start-up, currently housed at La Fibre entrepreneur – Drahi – X Novation Center, aims to provide a programming framework for automatically managing data updates in streaming architectures. The first uses are in the world of logistics, where real-time analytics are now possible. But there are many other possible applications for this tool, designed for all developers. Explanations from its co-founder and CEO, Zuzanna Stamirowska, who has a CNRS thesis in complexity science.

If you had to start by pitching Pathway?

zs We've observed that the world of Machine Learning offers promising models for static point data. At Pathway, we set out to develop models capable of running on constantly changing data, reflecting new events and process updates, in real time and to the nearest millisecond for the financial sector. Designed for developers, our tool is aimed at anyone who generates data and needs to process it in real time. Pathway enables them to develop and deploy applications linked to event stream data, i.e. streams of event data generated by different systems. In concrete terms, our product is installed in the customer's private cloud and enables data to be processed to provide real-time analysis and high added-value information thanks to Machine Learning.

What use cases have you worked on?

zs We started by looking at logistics. Our industrial partners include the La Poste Group and DB Schenker, the world's third-largest freight forwarder. Why this area? Because, generally speaking, supply chains require a complex data processing logic to determine what's "normal", "abnormal" and "the new normal". This is a reality that COVID-19 and other events such as the blocking of the Suez Canal have recently highlighted. But strange as it may seem, there's a lot of mystery surrounding how supply chains work. There's still a lack of understanding of the actual processes in relation to the data.

How do you explain this?

zs The major players in the logistics sector have developed through the acquisition of entities with their own more or less interoperable databases. It's a very chaotic world, because of the diversity of data flows relating to events. We find events relating to physical activities for which we have spatio-temporal data; on the other hand, we observe events relating to commercial transactions. Logistics thus combines a dual physical and business process and, as a result, different types of data, making it all the more complex to understand. The volumes of data are so massive that it is becoming very difficult to monitor processes at a global level, to know where to focus our attention.

How did you become interested in this field?

zs I became interested in this subject during my thesis on complexity science at the CNRS. It focused specifically on maritime trade forecasting, which enabled me to familiarise myself with the sector, one of whose main characteristics is its high degree of concentration. Even before I defended my thesis, I was able to develop the model that's now used as a reference for forecasting maritime trade – it was published by the American National Academy of Sciences (PNAS).
As a reminder, 80% of international trade is carried out by ships, so much so that we talk of maritime trade as the lifeblood of the global economy. It has to be said, however, that the digitisation of the logistics sector has been slowed by the lack of a software infrastructure capable of performing automated reasoning on data flows in real time. However, a better understanding of the processes that underpin their operation is critical to identifying areas for improvement – even before devising optimisation tools. For example, by changing processes, getting a player in the chain to work differently, improving asset management, you can reduce the number of transport days, or avoid acquiring additional containers by optimising the existing fleet. The problems encountered by shipowners sometimes stem not from a lack of capacity, but from a poorly managed fleet, with containers that are underutilised or stored somewhere without anyone knowing where exactly!

Given the role of logistics in the globalisation process and its economic weight, we can imagine that other start-ups have positioned themselves in this real-time data analysis market. What makes you different? What is your added value?

zs Our aim is not to position ourselves solely in the logistics market. Our tool is designed to be horizontal and there are many possible applications. After all, from one sector to another, the same difficulty is encountered: the ability to reason on the basis of event flows and therefore to understand what the process looks like. And that's before we even talk about optimisation or forecasting. The idea is to start from the processes at work, from concrete use cases, to better understand the logic behind them.
Our "competitors" are more data processing engines, such as Spark or Apache Flink.
Our ambition is for our technology to become the benchmark in Business Intelligence for real-time data, and for Pathway to enable the creation of innovative data products far beyond what we'd imagined. To do this, we've opened up our source code to our users, who can then concentrate on developing the logic of the code, without having to worry about how the data evolves over time.

How do you see AI in the future? What do you say to those who see this as a risk of replacing the physical and cognitive tasks carried out by humans? To what extent do you combine AI with human expertise, if only to interpret massive data in a relevant way?

zs We need to distinguish between real-time Machine Learning and so-called reactive applications, in the sense that they allow feedback loops with their users. We saw it with logistics. This type of application is essential in environments where the complexity of the system makes it impossible to integrate all the information. So AI as we see it is not there to replace human intelligence, but to enhance it. Pathway's vocation is to help professionals stay "on top of the flow", to ensure that they have the best possible command of a situation in a changing context.
To achieve this, Pathway doesn't impose any decisions, but rather informs them.

What kind of expertise did you call on?

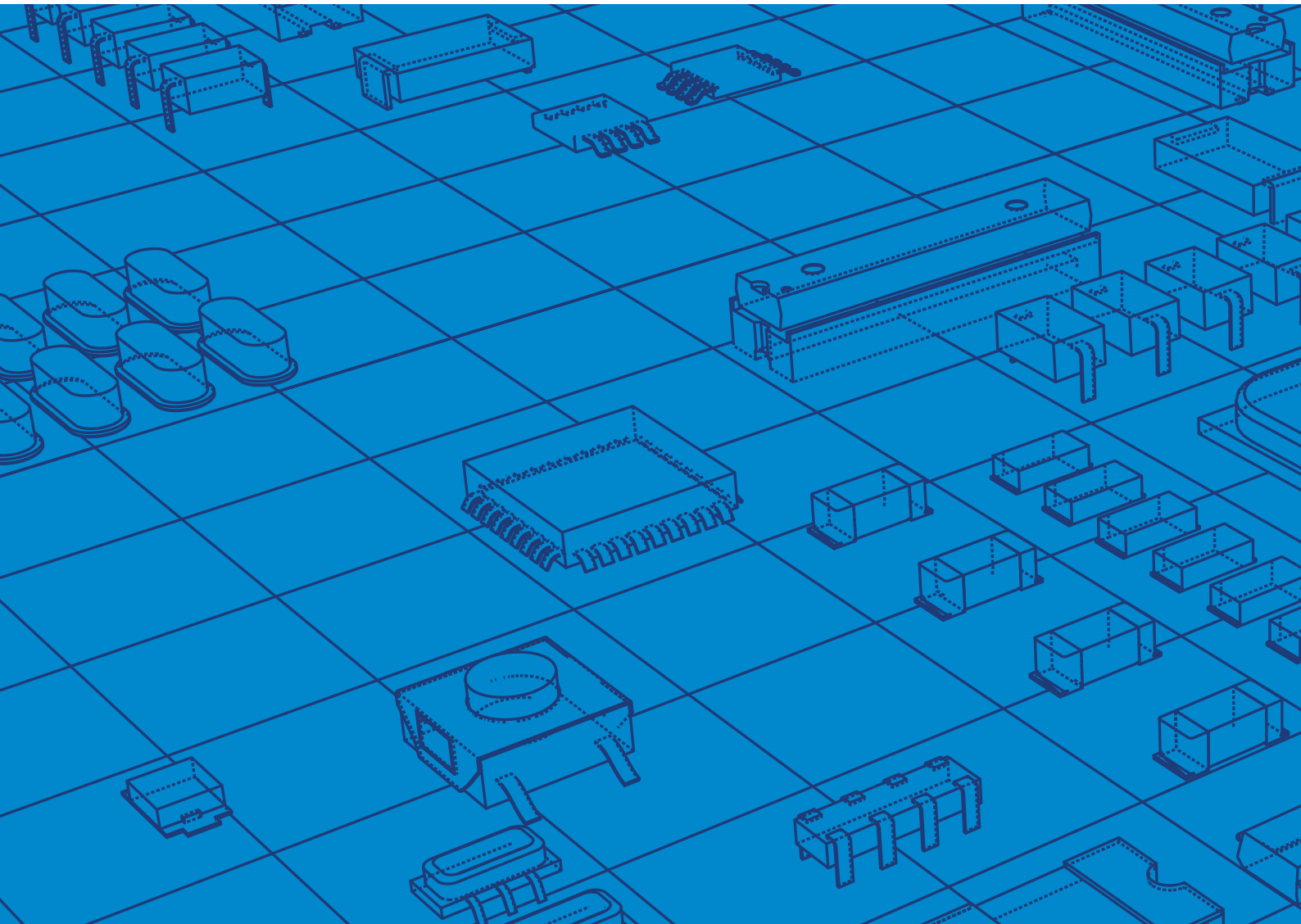
zs Pathway was co-founded with Jan Chorowski, our CTO, who is a leading figure in AI. What makes him special is that he also has skills in hardware (he has a degree in electrical engineering), so he has a detailed knowledge of how the sensors that collect the data work! I met him when I was finishing my thesis; he was returning to Europe after working for Google Brain [Google's deep learning research team].
The opportunity to get involved in an entrepreneurial project came just at the right time. As for our product manager, Adrian Kosowski, I met him when I was doing an internship with the start-up he founded in 2004 – Spoj.com, the first platform for competitive programmers [programmers who engage in competitive programming to improve their performance in learning computer programming].
This entrepreneurial experience has given him access to some of the best programmers in the world. He is recognised as one of the people who have contributed to the development of the discipline and, by extension, the community. This was extremely useful for the launch of Pathway. A professor at X, he also coaches the school's team of competitive programmers.
Finally, my co-founder and COO, Claire Nouet, is a graduate of HEC Paris and Sciences Po, where I was her teacher a few years ago.
Born and raised in Le Havre, she has always understood the challenges of the first vertical market we serve – logistics.

Where does Pathway stand in terms of growth? I'd like to ask you to say a few words about your recent fundraising...

zs We raised an initial pre-seed round of 4.5 million dollars. Over and above the amount, it demonstrates the confidence of investors in Pathway's potential.
Our product is already available in a beta version. Since January 2023, you've been able to access it from our pathway.com website and use the code to develop your own applications. We now need to make this product more widely known to developers, solution architects and data engineers, and give them the opportunity to test Pathway with the aim of integrating it into their projects. A step that the fundraising will enable us to take.

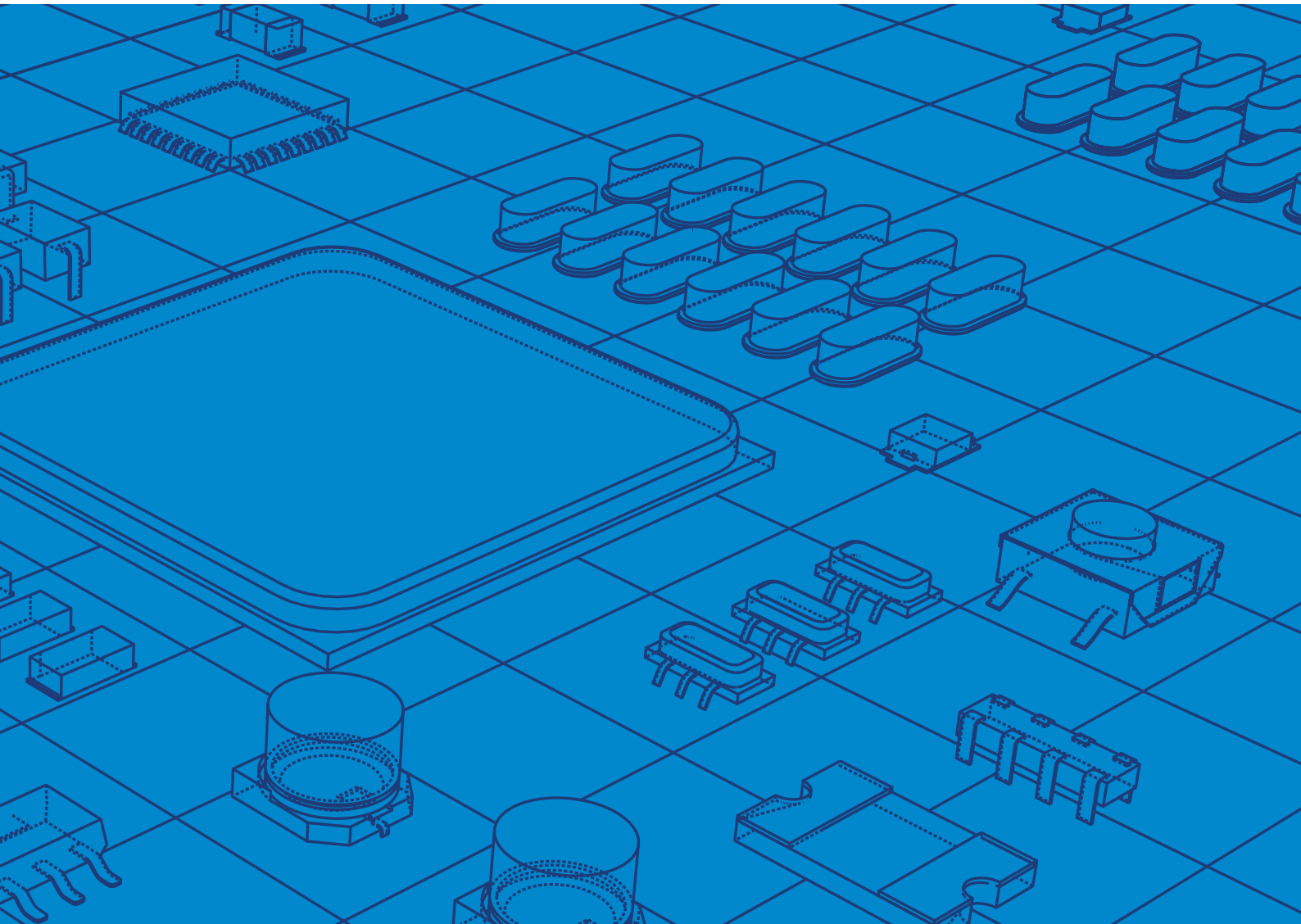
Interview by Sylvain Allemand

A land of industry, a laboratory for experimentation in digital technologies



This impressive growth trajectory for digital technologies is also the result of the presence, within the region's strategic industries, of a high concentration of manufacturers, including world leaders in their sectors. Interacting with the region's research and education players, as well as innovative start-ups, they contribute to the innovation and development of these digital technologies, in particular through prestigious research and development centres located in the heart of Paris-Saclay. They also apply and experiment with them within their production and manufacturing processes.

Symbolising this dynamic, an increasing number of collaborative projects combining research, training and industry are being set up in the region. They are at the origin of major innovations and make Paris-Saclay a unique testing ground for the technologies of the future, an open-air laboratory for the industry of the future.



A concentration of major industrial groups

Attracted by the presence of internationally renowned research organisations and leading engineering schools, stimulated by major facilities open to industrial R&D and innovative collaborative programmes, many companies, including world leaders in their fields, have over the years established themselves at the heart of the Paris-Saclay science and technology cluster.

As an essential link in the innovation chain, these companies are making a major contribution to the development of these cutting-edge digital technologies, in particular through the prestigious research and development centres based in the region. Among the international digital leaders based in the heart of Paris-Saclay are IBM, which opened an innovation centre dedicated to artificial intelligence in 2021, and Atos, which opened its new global R&D laboratory for quantum computing, cybersecurity and artificial intelligence in Clayes-sous-Bois the same year, Fujitsu, whose centre of excellence in artificial intelligence is based on the campus of the École polytechnique, Nokia and Ericsson, which have set up research centres in the region, and Thales, which is working on these subjects as part of its Software République programme. Other groups that have developed specific expertise in cybersecurity have chosen to set up in the Saint-Quentin-en-Yvelines Conurbation Community, which has developed a leading cluster in the field bringing together research, training and industry.

Over the years, many companies, including world leaders, have established themselves within the Paris-Saclay science and technology cluster.

IBM, the choice of co-innovation

In 2021, IBM opened a co-innovation centre dedicated to artificial intelligence in the heart of Paris-Saclay, the largest IBM R&D centre in France. Its software development teams, as well as a research and consulting team, are based here. This innovative approach enables the company to bring together the entire value chain – basic research, software development and application services – in a single location, with a view to producing unique innovations and solutions.

The centre now has 200 researchers, developers, product managers, designers, data scientists and consultants working on applications in banking, transport, route optimisation, security, finance and medical diagnostics. Its teams work in three main areas: artificial intelligence-assisted decision-making, business process automation and mainframe development tools. In concrete terms, the innovations developed relate to the development of tools for the automatic analysis of medical images, in particular for the analysis of certain cancers, means of detecting bank card fraud, and on-board solutions for the Mayflower, an autonomous ship sailing the Atlantic Ocean without a pilot to collect data on the impact of climate change. With a view to accelerating collaboration between public and private partners within an ecosystem rich in research bodies and leading educational establishments, IBM is increasing the number of tripartite projects. The partnership developed with Université Paris-Saclay, Softeam, Decisionbrain and STET is a good example. Together they have co-created the AIDA platform, aimed at boosting the competitiveness of participating French companies and positioning France as a leader in operational artificial intelligence.

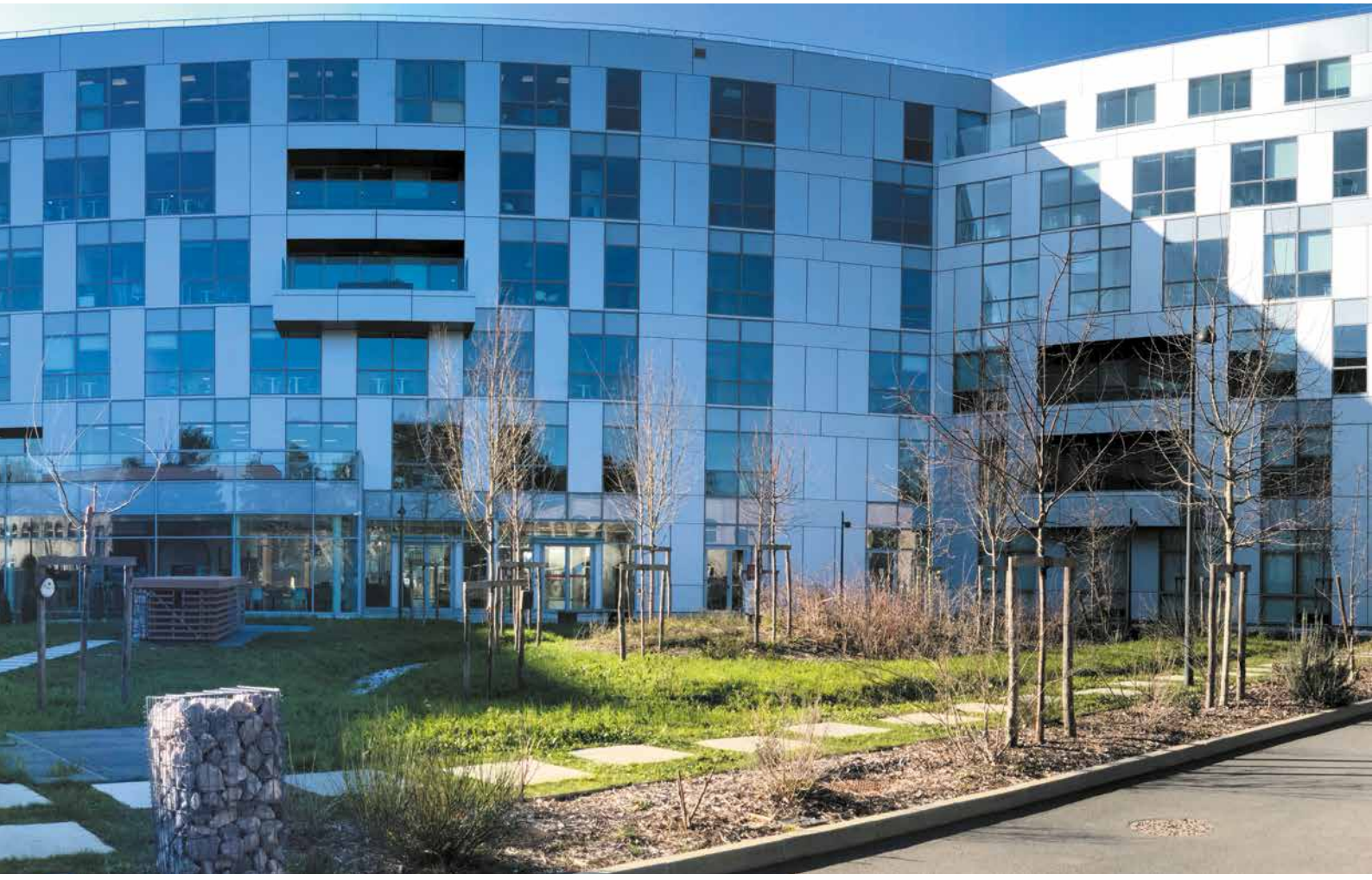
This is the case for **Airbus Defense and Space, Airbus CyberSecurity, C2S Bouygues, Orange Cyberdefense** and the public electricity transmission network operator, RTE, with its national operational centre for monitoring IS-Telecom and cybersecurity infrastructures based at Montigny-le-Bretonneux.

Paris-Saclay's core competencies in artificial intelligence, quantum computing, cybersecurity and smart manufacturing are also highly sought-after by many of the leading industrial groups in the region's sectors of excellence, such as health, energy, mobility and aerospace-security-defence.

Some have set up their research and development centres here, so that they can benefit from the region's research laboratories, higher education establishments, engineering schools and talent on a daily basis. In this respect, the **Servier** group chose Paris-Saclay as the location for its brand-new research institute in 2022, as did **GE Healthcare** in the same health sector, whose international site of excellence brings together 600 R&D researchers and engineers in Buc, and **Oncodesign**, which arrived on the Saclay plateau in 2016 after acquiring GSK's R&D centre and then Bertin Pharma's pharmaceutical and biotechnology services and is now heavily involved in the field of precision medicine, based in particular on predictive models and the analysis of patient data.

As an essential link in the innovation chain, businesses make a major contribution to the development of cutting-edge digital technologies.

• **Fig. 16** IBM's new co-innovation and research centre dedicated to artificial intelligence, which opened in 2021 in the heart of Paris-Saclay.



In the energy sector, France's three industrial giants have also chosen Paris-Saclay as the location for their industrial research centres. In 2015, **EDF** set up **EDF Lab**, the world's largest R&D centre. **Air Liquide** opened the **Campus Innovation Paris** there, which houses the Group's first R&D centre. Finally, **TotalEnergies** opened its new research and development centre here in 2022.

Others have manufacturing and production sites there, enabling them to experiment with these new technologies. These include **LFB** in the healthcare sector, **Elogen** in the energy sector, **Valeo** in the mobility sector and **Safran** and **Dassault Systèmes** in the aerospace-security-defence sector.

The presence of these industrial leaders is a particularly structuring force for Paris-Saclay, facilitating the process of transforming knowledge into applications along the innovation chain. Paris-Saclay offers companies in all of the region's industrial sectors the most advanced skills in digital technologies, enabling them to make a successful transition to the industry of the future.

Paris-Saclay offers companies in all industrial sectors the most advanced skills in digital technologies, enabling them to make the transition to the industry of the future.

• Fig. 17
Thales laboratory in Palaiseau.

Airbus, applied research in space and cybersecurity

Airbus is one of the leading industrial groups in digital research in the fields of cybersecurity, aviation and aerospace. The Group has been based in Élancourt since 2007. In 2014, Airbus Defence and Space (ADS) - one of the Group's three divisions, specialising in military aircraft, drones, missiles, space launchers and artificial satellites – and Airbus CyberSecurity were relocated there. In addition to its work on radio communications, the various implications of digital technology and network security, Airbus is involved in a number of projects with various local organisations. Télécom SudParis and Airbus thus launched a joint laboratory in 2021: Intelligence in Networks. This enables teams of professionals and doctoral, postdoctoral and research students to tackle practical problems faced by industry. The joint work focuses on the introduction of artificial intelligence into networks and the flexibility provided by machine learning. Airbus is also helping to develop activities in the region. UMS (United Monolithic Semiconductors), a Franco-German company and European leader in RF MMIC (monolithic microwave integrated circuit) products for specific markets such as defence, space, telecommunications, industrial sensors, etc., based in Villebon-sur-Yvette, was created by combining the activities of Thales and Airbus Defence and Space in this sector. Similarly, the Airbus CyberSecurity cybertraining centre is located on the premises of the École 2600 in Saint-Quentin-en-Yvelines.

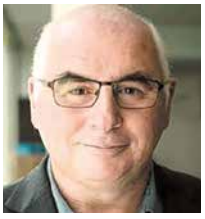
Thales, historic leader in cybersecurity

Thales, a world leader in cybersecurity, set up one of its largest research sites in Palaiseau in 2005, as a member of the Thales Research & Technology network. Built on the École polytechnique site, it is home to more than 300 researchers and around 250 doctoral students, working on the security of military communications, space systems, air traffic management and the on-board electronics of major government IT networks. Latest successes: Vertigo, a high-power optical data transmission system from Thales Alenia Space.
In addition, Thales has chosen to set up joint laboratories with leading research institutes, while building framework agreements with leading researchers. The Group is also behind the prestigious CNRS/Thales – Université Paris-Saclay Joint Physics Unit dedicated to nanoelectronics, microfabrication, high-temperature superconductors and bio-inspired electronic circuits, and is one of the industrial partners of Frama-C (CEA/Inria), an open-source platform dedicated to analysing the source code of C software. Finally, Thales is funding the new Connected Cars and Cybersecurity Chair at Télécom Paris. The Group also wants to take full advantage of the benefits offered by the innovation ecosystem that is Paris-Saclay. For example, in 2020, in partnership with EDF and TotalEnergies, it took part in the creation of the first joint artificial intelligence laboratory, SINCLAIR, as part of the national #AIforhumanity strategy.

Based at EDF Lab in Palaiseau, this laboratory studies the maintenance of industrial production resources and forecasting in design and production, the improvement of control, monitoring and alarm systems and the development of digital twins. On a more industrial level, Thales, in partnership with Alcatel, is also behind the creation of the III-V Lab, one of the outposts of the European III-V semiconductor industry.

INTERVIEW WITH BERTRAND BRAUNSCHWEIG,
SCIENTIFIC COORDINATOR OF THE CONFIANCE.AI PROGRAMME

Pooling skills for trusted artificial intelligence



It is a word that was not spontaneously associated with artificial intelligence (AI), so much did AI appear to be primarily a set of technological challenges to be met – those of massive data processing, deep learning, etc. Yet it is on the ability of these technologies to inspire confidence that the next stage in a story that began in the 1940s and 50s will depend, a story that has already endured "winters" that seemed to doom it. As its name suggests, the Confiance.ai programme, launched in 2021, aims to develop and test technologies based on trusted AI for critical systems engineering. Its scientific coordinator, Bertrand Braunschweig, tells us more.

Although the title is self-explanatory, could you start by outlining the aims of the Confiance.ai programme...

BB Everyone agrees on the need to accelerate the very large-scale deployment of industrial systems incorporating AI. This is a crucial issue in terms of industrial and economic competitiveness and national sovereignty. We still need systems that are safe, robust, secure and controllable – in other words, AI needs to inspire confidence, be explainable and even certifiable. This is precisely the ambition of this programme, led by the SystemX IRT, which is the technological pillar of the Grand Défi "Securing, certifying and making reliable systems based on artificial intelligence", launched by the French government.

Which players are involved?

BB The programme brings together a group of academic and industrial players in the fields of defence, aeronautics, transport, manufacturing and energy, who have agreed to pool their know-how. Its originality lies in this integrative strategy: it addresses the scientific challenges relating to trusted AI and provides tangible solutions that can be applied in the real world and industrialised. The partners are working to remove a number of scientific and technological barriers, such as the construction of AI components with controlled confidence, the construction of data/knowledge to increase confidence in learning, and the interaction that generates confidence between the user and the AI-based system. A review of the state of the art focused on five areas of engineering where we needed to pool our skills: algorithmic engineering, data engineering, security engineering, systems engineering and human and cognitive factors engineering.

What about the humanities and social sciences? To what extent do you involve them?

BB Let's face it, when this programme was launched, the HSS were still not very prominent. Confiance.ai is primarily focused on the world of engineering. But we recognised that the HSS could be useful, if only to enable our engineers to take a step back. With the CNRS – its Institute of Human and Social Sciences (INSHS) and its Internet and Society Centre – we launched a call for expressions of interest, aimed at the HSS community, following which no fewer than four laboratories were selected. They are mobilised to observe the way in which we engineers go about things, and possibly to alert us to factors that we might otherwise overlook, starting with the human factor. I won't hide how impatient we are to learn their conclusions, which should be communicated to us in a few months' time.

What are the benefits of being part of a regional ecosystem like Paris-Saclay? After all, doesn't it allow the stakeholders to meet, get to know each other and find out who does what within the AI sector?

BB Your question is an opportunity to point out that Confiance.ai is actually part of two ecosystems: the Paris-Saclay ecosystem and the Toulouse ecosystem, with which we are in constant interaction. Two ecosystems identified during the Grand Défi that I mentioned, as the best placed to work on the national programme dedicated to trusted AI. Now, if your question is about the interest for academic and industrial partners in seeing each other in real life, even though the technologies they are developing are part of a virtual world, then yes, I would say that this also contributes to the creation of such AI.

How far have you got with the programme?

BB The programme formally started in January 2021 and will run for four years. So we're halfway there. Every year, we organise Confiance.ai Days to take stock of the situation. The most recent were held in October 2022 at CentraleSupélec. In the space of two years, we have already developed and tested a very large number of components – around 120 – based on quite diverse use cases – image and signal recognition and processing, tabulated data processing, and so on. Admittedly, not all these components are at the same level of maturity, nor are they of the same interest, but their diversity gives us an overview of what can contribute to trusted AI.
We are now embarking on a second phase, the maturation of these components, so that when the programme ends we will have robust solutions that can be implemented in various industrial engineering structures.

Our two ecosystems, Paris-Saclay and Toulouse, were among the first in the world to launch a large-scale programme on trusted AI.

By trying to design technologies to make AI more reliable, aren't you just postponing the problem by relying on other technological solutions? Don't we need to strike the right balance between confidence in new technologies and confidence in the stakeholders involved in their development?

BB Your question provides an opportunity to clarify the factors of confidence, the subject of an article I published last year in *Le Monde*'s Binaire blog and in the March 2023 issue of *Futuribles* magazine. I distinguish four categories: technological factors – robustness, absence of bias, etc.; factors relating to interaction with users, i.e. humans – explicability, the possibility of supervision, transparency, etc., i.e. characteristics that relate more to our relationship with the system; ethical factors – we'll come back to this – inclusion, diversity, voluntarism; finally, the fourth category: the existence of a trusted third party – a certification body, for example.

Confiance.ai is first and foremost aimed at the problems faced by manufacturers. But what about AI for more mainstream applications?

BB In fact, the question also arises about this AI. We're all familiar with the problems posed by the biases inherent in algorithms or, more recently, the errors made by new conversational agents such as GPT Chat – the latter is already known to produce what are known as "hallucinations", in other words things invented out of thin air (for example, imaginary bibliographical references, or a degree that the person has never obtained), so that it can't yet be completely trusted. What's more, even Chat GPT takes care to invite users to check what they are saying at the end of each session, as it acknowledges that it isn't 100% reliable. That said, the question of trust is less acute in the case of consumer applications – after all, if someone makes a mistake by misdirecting a consumer in a purchasing choice, the error isn't harmful; all the user has to do is not validate the choice. On the other hand, if AI is used to assist the automatic piloting of a vehicle or a nuclear power plant, or to carry out a medical diagnosis, it's clear that we have every right to expect it to be as reliable as possible. However, AI technologies don't yet meet this requirement.

What made you personally decide to join the programme as scientific coordinator?

BB Naturally, it's the prospect of taking part in the AI adventure, which reached a new stage in 2012 with the beginnings of deep learning, which is increasing the capacity of image processing algorithms. Since the mid-2010s, it's been within the news – Microsoft even proclaimed 2016 the year of AI. Personally, I'd already been interested in this subject for a long time; I'd given many lectures on it. Each time, I stressed that the key point was confidence! If this isn't forthcoming, AI could well experience its third "winter", a drop in public and private funding dedicated to research in this field, since its appearance on the research agenda after the Second World War (the first two winters were 1974-1980 and 1987-1993). So much so that, when I left Inria at the end of my assignment as coordinator of the national AI research programme, my colleagues at IRT SystemX asked me to give them a hand with their Confiance.ai programme. Naturally, I accepted enthusiastically. All the more so as our two ecosystems, Paris-Saclay and Toulouse, were among the first in the world to launch a large-scale programme on this subject.

Interview by Sylvain Allemand

Collective initiatives in application sectors

Interdisciplinarity, collaboration and synergy are among the hallmarks of Paris-Saclay. Among the innovative projects that will shape the industry of tomorrow, the SINCLAIR and LabCom intelligence in networks joint laboratories are exemplary, particularly for their collective dynamic combining research, teaching and industry.

The first, **SINCLAIR** (Saclay INdustrial Collaborative Laboratory for Artificial Intelligence Research), created in 2020, is the first joint industrial laboratory in artificial intelligence to be based in Paris-Saclay. Shared by three of the region's leading companies – **Thales, TotalEnergies** and **EDF** – it is developing, in partnership with several institutions at Université Paris-Saclay and the Institut Polytechnique de Paris, research programmes dedicated to the control of production units, alarm systems and digital twins with the shared aim of optimising engineering. The **LabCom intelligence in networks** was created in 2021 by **Airbus Defence and Space** and **Télécom SudParis** around the themes of combinatorial optimisation, machine learning and network modelling, the aim being to use artificial intelligence to design networks that are more agile, programmable and controllable.

In the field of artificial intelligence, the **LNE** (Laboratoire national de métrologie et d'essais), based in the Saint-Quentin-en-Yvelines Conurbation Community, supports all the region's manufacturers in their competitiveness and innovation strategy by providing measurement, metrology, testing and certification services.

Interdisciplinarity, collaboration and synergy are among the hallmarks of Paris-Saclay.

• **Fig. 18** *Team Building Jet Fighter* at CampusFab, a training platform for the industry of the future.

CampusFab: a new approach to Industry 4.0 training

CampusFab is the fruit of the collaborative work of a consortium of more than ten entities, made up of industrial and technology companies, and institutional and training players. Over an area of 2,000 m², it showcases the state of the art in production digitisation. An experiential journey for professionals, students and schoolchildren alike. CampusFab is attempting to provide a response to the problems of industrial sovereignty by training both students and current employees in digital continuity and the digitisation of industrialisation. The newly trained young people will be able to meet the needs of the industrial fabric of the Paris Region. For their part, the employees, in possession of this new knowledge, will support the change within their company to make them more competitive. CampusFab targets companies of all sizes. The machines and processes on display cover digital continuity, machining, additive manufacturing, assembly, robotic assembly and maintenance. A way of showcasing all the solutions and technologies available. In addition to this presentation, CampusFab offers customised training modules and services on request. This approach is supported by the France Relance plan, the Programme d'investissements d'Avenir (PIA), the Paris Region and Grand Paris Sud.

As part of this, it has developed a service for evaluating artificial intelligence systems and, in 2022, launched **LEIA** (Laboratory for the Evaluation of Artificial Intelligence), the world's first platform for evaluating artificial intelligence.

Collaboration between industry and research at Paris-Saclay has also given rise to collaborative programmes around the industry of the future. This is the case of **FactoryLab,** an industrial and academic consortium including the **CEA,** manufacturers **Safran, Dassault Systèmes, Naval Group** and start-ups **Diota** and **Isybot,** which aims to accelerate the digital transformation of industrial companies through the development of a dozen projects a year, and **Additive Factory Hub,** an additive manufacturing platform bringing together leading players such as the **CEA,** the **CNRS, LNE** and **ONERA** for research, and **EDF, Air Liquide** and **Safran** for industry.

Software République: sharing knowledge for sustainable and safe mobility

Launched in 2021, Software République is a collaborative Open Innovation ecosystem dedicated to intelligent and sustainable mobility. Co-created by Renault, Atos, Dassault Systèmes, Thales, Orange and STMicroelectronics, its aim is to bring together the expertise of these major groups, in their respective and complementary fields (artificial intelligence, cybersecurity, digital twins, connectivity, on-board electronics) to develop new systems and software for the benefit of users. Its members meet at the Renault Technocentre in Guyancourt. Software République's aim is to provide complete solutions, from user interfaces to energy management, integrating vehicle systems, service platforms and network operating tools. Two areas of research were launched as soon as it opened: the management of mobility flows by local authorities via a journey simulation tool offered to users, and Plug and Charge, a digital tool essential for easy charging of electric vehicle batteries. In order to increase the number of experiments, Software République opened an incubator in 2022 to host projects around three themes: energy, new mobility and connected vehicles. Five organisations were selected in the first call for projects and are now being supported by the founding members: Angoka (hardware solutions to safeguard the integrity of machine-to-machine (M2M) communications), Geoflex (high-precision satellite positioning service), Parcoor (threat detection), Vianova (a solution for aggregating mobility data and modelling public policies) and WattPark (a sharing and leasing solution for owners of charging stations). A new call for projects was launched in January 2023.

• **Fig. 19** From left to right: Jean-Philippe Poirault, CEO Atos Big Data and Cyber-Security, Bernard Charlès, Vice Chairman and CEO Dassault Systèmes, Aliette Mousnier-Lompre, CEO Orange Business Services, Luca De Meo, CEO Groupe Renault, Frédérique Le Grevès, CEO STMicroelectronics France and Patrice Caine, CEO Thales, at VivaTech 2022.

INTERVIEW WITH PIERRE-FRANÇOIS LAVALLÉE,
CNRS RESEARCH ENGINEER AND DIRECTOR OF IDRIS

A major facility at the heart of the Paris-Saclay ecosystem

The fight against COVID-19, research into climate or astrophysics, learning large AI models... the Jean Zay supercomputer, operated by the CNRS's Institute for Development and Resources in Intensive Scientific Computing (IDRIS), is opening up new prospects by offering powerful computing capacity to the scientific community as well as to industry, SMEs and start-ups. Details from the director of IDRIS, Pierre-François Lavallée, who hosts it in its premises in building 506 on the Orsay campus.

Maintenance is carried out in building 506 on the Orsay campus, which houses IDRIS and the Jean Zay supercomputer that you operate. Its physical appearance is reminiscent of the very first computers..

P-F L In fact, the Jean Zay supercomputer occupies a surface area of 320 m^2 and weighs 70 tonnes... but its computing capacity is incomparable! Since it was commissioned in 2019, its power in PFlop/s has risen from around 14 to almost 37 in January 2022 (1 PFlop/s = 1 million billion operations per second). Until recently, it was the most powerful supercomputer in France, before being overtaken by the supercomputer belonging to our colleagues at CINES in Montpellier. However, it still managed to feature in the TOP20 of the November 2022 ranking of the 500 most powerful supercomputers in the world.

This isn't the first supercomputer you've operated..

P-F L No, since 2008, this is the third generation of machine. The first two were IBM Blue Gene-type massively parallel architectures (Babel BG/P in 2008 then Turing BG/Q in 2012), whereas Jean Zay is a hybrid parallel architecture accelerated with GPUs [computer graphics units]. In 12 years, computing power has increased 33-fold, from 1.2 to 36.8 PFlop/s. But that's not all: storage capacity also needs to correlate with the way the machine is used. We've gone from 2 PB to 37 PB of disk storage. Memory – in other words, the capacity to temporarily store the data you're going to work on at a given moment – increases from 106 to 457 TB.

So there's a before and an after for the Jean Zay supercomputer...

P-F L Yes, the number of users has risen from 1,200 to 2,700, and the number of projects from 410 to 1,450, mainly thanks to the arrival of the artificial intelligence research community on the Jean Zay dedicated national infrastructure. In fact, this supercomputer is converged in the sense that as well as being able to meet the needs of numerical simulation, it also enables extensive AI training, a major change compared with previous supercomputers.

Advances that have been achieved, as some might imagine, at the cost of an even higher energy bill...

P-F L No, quite the opposite! Its electricity consumption has only increased by a factor of 8 to around 2,400 kWh. The supercomputer's eco-responsible architecture is one of the most efficient in production. Some of the heat produced by the supercomputer is already used to heat buildings – the IDRIS building and another nearby building. In the spring of this year, the supercomputer will be interconnected to the EPA Paris-Saclay heating and cooling network, further reducing its energy impact by supplying the equivalent of the heating consumption of a thousand homes. More than ever, an HPC simulation or AI training carried out on the Jean Zay supercomputer will be a guarantee of a limited carbon footprint.

What about users? What are their profiles?

P-F L These are engineers or researchers working either for academic research, within the framework of the major public research agencies (CNRS, CEA, Inria, etc.) or universities; or for manufacturers, SMEs or start-ups on condition that the scientific results are published. Of all the projects we select, 8% are led by private companies.

In practical terms, what steps do you need to take to access the Jean Zay supercomputer?

P-F L It couldn't be simpler! All you have to do is visit the eDari portal. A single form is required to apply for either type of access – regular or dynamic. This is the same procedure as for the other national centres.

This is where users define their project by submitting initial technical information. If it's a small request and doesn't require too much calculation or training, then it's assessed quickly, within a fortnight. If not, you will have to wait for one of the two annual project evaluation sessions.

In 12 years, computing power has increased 33-fold, from 1.2 to 36.8 PFlop/s.

What disciplines are involved in using supercomputers?

P-F L They are varied. In terms of uses for modelling or simulation, they range from the environment – modelling climate change – to chemistry – simulating molecular dynamics with a view to finding new drugs or discovering and classifying new viruses –, astrophysics – to study solar eruptions or dark matter – geophysics – earthquakes or tsunamis – materials science – to increase battery storage capacity and reduce weight – theoretical physics – for plasma modelling, for example – and so on. As for AI learning capabilities, they are being mobilised in areas ranging from very large language models such as the BigScience project – automatic translation, human-machine interaction, bots, text summarisation, information extraction – to cybersecurity, via medicine – diagnostic assistance, clinical surgery –, image and video analysis, shape and movement recognition, autonomous driving, etc.
The absence of the HSS community cannot be denied. We're just beginning to see it emerge through AI-related projects. I'd therefore like to take this opportunity to invite researchers in these disciplines to find out more about the potential of the supercomputer.
That said, the notable fact is the large community of AI users. Until then, as I mentioned, we only worked with the HPC community. Today, the vast majority of small projects involve AI (91%).

An expansion you had anticipated?

P-F L Yes, but not on this scale. When we launched the call for tenders announcing the possibility of training for AI learning, the French Ministry of Higher Education and Research allocated us, as part of the AI for Humanity plan, a specific budget so that part of the computing power could be reserved for the AI research community.
At first, we had a few problems getting it onto our supercomputer. Clearly, its researchers weren't used to using this type of tool. So we took the time to go and meet them, to visit the laboratories and present the machine. As a result, more and more users came forward. In less than three years, we've reached 1,500 users.

And, as you might imagine, with a great deal of support from your teams...

P-F L Our HPC and AI support teams each employ 12-13 people, doubling our workforce in three years. They provide round-the-clock assistance by telephone or email, Monday to Friday, as well as managing incident tickets. We also provide a significant amount of training, taking on between 200 and 350 trainees each year.

There's a lot of talk about ChatGPT. What about the AI applications that your supercomputer will have taught you?

P-F L We're participating in the BigScience project, a programme run by a private company, Hugging Face, as part of an international public-private collaboration involving 800 researchers from around 60 countries, with a view to training a very large language model, the same size as GPT3 on which ChatGPT is based. These researchers were given an allocation of some 5 million GPU hours of computing time and dedicated access for 117 days to the latest extension we acquired for the final training of the Bloom model. Articles have already been published and IDRIS, GENCI and Hugging Face have won prizes at SuperComputing, the world conference in this field.

How will the Paris-Saclay ecosystem benefit in terms of visibility?

P-F L Our projects come from all over France and abroad. Having said that, I anticipated your question. After verification, projects led by Paris-Saclay laboratories or companies represent around 35% of the total, a significant proportion if ever there was one.
In addition, IDRIS may be called upon to play a leading role in the training provided here on our Orsay campus. The majority of our trainees come from this campus, if not from the Paris Region. We also have a strong local presence, hosting part of the MesoUPSaclay mesocentre of Université Paris-Saclay at IDRIS. Finally, we have a close relationship with Inria Saclay and the DATAIA Institute, as part of the AI for Humanity Plan: the Institute entrusts us with a large number of calculations for its projects.

Interview by Sylvain Allemand

Photo credits

Cover: © Shutterstock
P3: © Shutterstock
P4-5: © EPA Paris-Saclay
P6-7: © EPA Paris-Saclay/
© CEA-List/Cyrille Dupont (Fig. 1)
P12-13: © Shutterstock
P14-15: © CEA-List/Cyrille
Dupont (Fig. 2)
P16-17: © Inria/B.Fourrier
(Fig. 3)/© DATAIA/Guillaume
Malle (Fig. 4)
P18-19: © Telecom Paris,
Institut Polytechnique de Paris/
Nicolas Gonthier (Fig. 5)
P20: © Quandela/Matt La Prod
(Fig. 6)
P22-23: DR
P24-25: © CEA-List/
Cyrille Dupont (Fig. 7)
P26: © Shutterstock (Fig. 8)
P28-29: © CampusFab (Fig. 9)/
© Shutterstock (Fig. 10)
P30-31: © Shutterstock
P32-33: © Inria/S.Erôme –
Signatures (Fig. 11)/
© Quantum-Saclay (Fig. 12)
P34-35: DR
P36-37: © Shutterstock
(Fig. 13)/© IRT SystemX
P38-39: © Jean-François
Dars/© Yves Forestier –
Alkama photo/© Olivier Ezratty
P40-41: DR
P42-43: © Snowpack (Fig. 14)/
© Playground Paris-Saclay/
Carlos Ayesta (Fig. 15)
P44-45: DR
P46-47: © Shutterstock
P48-49: © IBM/© IBM (Fig. 16)
P50-51: © EPA Paris-Saclay/
Adeline Bommart (Fig. 17)
P52-53: DR
P54-55: © CampusFab (Fig. 18)/
© Renault Group (Fig. 19)
P56-57: DR
P59: © Shutterstock
P60: © Shutterstock

Already published

Praxis No. 1 - Satory Ouest Versailles Charter/March 2013
Praxis No. 2 - Water management/July 2013
Praxis No. 3 - Mobility/October 2014
Praxis No. 4 - Biodiversity primer/January 2016
Praxis No. 5 - Innovation for all time/January 2019
Praxis No. 6 - Paris-Saclay, health excellence/December 2022
Praxis No. 7 - Paris-Saclay, a player in the energy transition/March 2023

PARIS-SACLAY

Établissement public
d'aménagement Paris-Saclay
6 boulevard Dubreuil
91400 Orsay
+33 (0)1 64 54 36 50
contact@oin-paris-saclay.fr

www.epa-paris-saclay.fr
www.paris-saclay.business
a programme: Paris-Saclay TV
on TV78

facebook.com/ParisSaclay
@parisSaclay
paris_saclay
Établissement public
d'aménagement Paris-Saclay
youtube.com/ParisSaclay
Paris-Saclay Innovation
Playground
inno_playground

Editorial
La mécanique du sens

Conduct and preparation
of interviews
Sylvain Allemand

Graphic design
La mécanique du sens

Print
CIA Graphic

Print run: 1,500 copies
2023