How has your professional background led you to your current position, and what is your area of research?

I have an MSc degree in electronics and telecommunications technology and received my PhD in computer science and electronic engineering in 2008 from the University of South Brittany, France. From 2010, I have been working on the development of embedded multicore architectures at CEA Tech. My main research interests lie in the design and development of hardware accelerators for vision processing. Recently, there has been renewed interest in the neural networks approach. This is largely driven by the excellent results it provides in image recognition of well-known benchmarks, as well as a move to more parallel architectures driven by the end of Dennard scaling and new technologies such as 3D stacking. These developments have led me to work on neural network hardware once more.

Can you describe the NEMESIS project and discuss its aims?

The aim of NEMESIS is to make steps towards designing an intelligent retina – that is, a solid-state, highly integrated system that outputs information based on the content of the images it ‘sees’ rather than outputting the images themselves. It is the combination of several domains. First, in terms of technology, 3D stacking allows the direct interface of a sensor to a grid of small processors, thus establishing a direct connection between each sensor and grid processor. Additionally, 3D stacking also enables the direct interconnection of ‘neuron processors’. Second, in terms of sensors, a back-side-illumination sensor increases the active area of the sensor. Finally, in terms of algorithms, the use of neural networks for image processing – and the use of ‘spikes’ for information coding in signal processing – differs to the use of binary representation in usual processors.

This project is predicated on exploring the potential of biologically inspired spike-based image processing. How does this work and why have you chosen to examine it?

Spikes are how biological neurons seem to communicate. It is different from classical computer communication, based on several bits organised in words that are exchanged. Spikes introduce a coding scheme so that a time interval and coincidence of spikes is key to carrying a message. Time correlation is the basic building block. Thanks to previous works, we have partnered with Simon Thorpe’s group, which is recognised for its results on spiking neurons. From a circuit point of view, spike coding has the promise of lowering the energy required to transmit information, compared to binary coding.

What have been the most challenging aspects of this project to date and how have you overcome them? Conversely, what has been your most rewarding experience?

All aspects of the project were challenging. When we started, we considered using an external company for the 3D assembly – but when it turned out that we could not guarantee the reliability of this solution, we decided to do this ourselves in our own assembly facilities. For cost reasons, we used a mature technology for the design of the dies – small blocks of semiconducting materials on which functional circuits are fabricated – which was also compatible for making image sensors. In the processing part, it proved difficult to fit this with the geometry of the sensor array. Moreover, the targeted applications also triggered a lot of discussion and debate within the project. As for the most rewarding experience, this is still to come: it will be when the first sign of life comes out of the system!

Has collaboration played a part in your research?

The project is inherently collaborative, involving four research groups with different areas of expertise that complement each other. For instance, one group specialises in spiking neural networks, one in the application of neural networks and board design, one in architecture and, finally, one in design and key technologies. This collaborative project was made possible thanks to the French National Research Agency (ANR) and its partial sponsoring of the project. The fact that we were able to draw on many people and resources enabled us to have deeper and more meaningful exchanges.
prototypes in the mid-20th Century, computers are highly efficient data-processing technology. Circuits require very high bandwidth and dense, Unsurprisingly, applications of smart vision encompassing robotics, medicine and security. To do this have multiple applications in fields from visual scenes. Systems with the capacity to understand images, they must have the ability of the most difficult functions is undoubtedly to understand natural, non-digital data. One able to cope with non-functional properties for example – means that they must now be essential for applications like self-driving cars, with the physical world – a function that is fact that computers must increasingly interact at our fingertips today. Of course, it is not only the size that has changed: the development of internet technology has fuelled the transition from centralised to distributed data and processing, as well as facilitating the linkage of different computers via networks.

However, the rapid and profound technological advances in recent years have also thrown up a series of pressing challenges. Indeed, the fact that computers must increasingly interact with the physical world – a function that is essential for applications like self-driving cars, for example – means that they must now be able to cope with non-functional properties such as time. Moreover, they must be able to understand natural, non-digital data. One of the most difficult functions is undoubtedly vision; for systems to recognise objects and understand images, they must have the ability to extract and process high-level information from visual scenes. Systems with the capacity to do this have multiple applications in fields encompassing robotics, medicine and security.

**A STRONG SOLUTION**

Unsurprisingly, applications of smart vision circuits require very high bandwidth and dense, highly efficient data-processing technology derived from high levels of parallelism – a process that occurs when a set of processors work cooperatively to solve a computational problem. Because of this, it is essential that the detection components are closely integrated with the system’s processing capabilities. This automatically rules out the use of the majority of classical approaches, which are difficult to implement using parallelism and are characterised by high processing latencies and substantial power consumption. On the other hand, biological visual systems can perform complex recognition tasks using highly parallel ‘hardware’ – thus biologically inspired, spike-based neural networks represent promising technical solutions for the future. Despite this, currently available neural networks have limited interconnection options as the integrated circuits are purely 2D.

One researcher who is working on an innovative solution for the bandwidth and interconnection problems faced by neuromorphic vision chips is Dr Caaliph Andriamisaina, a member of the Embedded Computing Lab in the French Atomic Energy Commission’s Laboratory of Applied Research on Software-Intensive Technologies (CEA-LIST). In a project entitled NEMESIS – which is being jointly conducted with collaborators from computing research groups in various French research institutes (LEAD-CNRS-UB, CERCO-CNRS and INRIA) – Andriamisaina is attempting to develop a smart vision sensor that relies on neuromorphic hardware to perform image and video processing. “We are currently exploring the potential of biologically inspired spike-based image processing, supported by the realisation of massively parallel yet scalable hardware as a result of 3D stacking of integrated circuits,” he outlines. “Our aim is to design neuromorphic system architecture that has the ability to use 3D integrated circuit stacking technology.” As a proof-of-concept project, the hope is that the final representative demonstrator will have the potential to run multiple applications using this technology.

**PAIRING TECHNOLOGIES**

In their project, Andriamisaina and his collaborators are using a special type of 3D stacking technology whereby the active part of the silicon dies are placed face-to-face and connected by copper. While this means that only two dies can be stacked together, this approach is extremely cost-effective and presents fewer risks than standard 3D stacking based on Through Silicon Vias (TSVs) as it does not require the drilling of multiple holes in the silicon. “In contrast to TSV-based 3D stacking, in our approach only the last level of metal is impacted – and interconnects and transistors can be in the same position as when there is no die-to-die interconnect,”

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**The final product**

The final objective of the NEMESIS project is to use 3D integration of circuits to build a representative demonstrator, and then to run applications on this hardware to show that it works. The proposed hardware will be composed of four dies:

- A detection die, mainly composed of photodiodes
- An analogue-to-digital conversion die, including low-level image processing
- Two processing dies with embedded spiking neurons

The researchers will then use 3D stacking to connect the different layers together in order to maximise parallelism without decreasing the fill factor of the retina.
PROJECT NEMESIS

OBJECTIVE
To develop and build a smart vision sensor relying on neuromorphic hardware to perform image and/or video processing.

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Andriamisaina states. Essentially, because neural networks are inherently parallel they are highly suitable for silicon integration – and as an effective approach to real-world image recognition, they represent excellent building blocks for the design of an intelligent retina.

In addition, as Andriamisaina points out, a neuron can be processed in a tiny processor, meaning that there is no need to use complex floating-point operators: “We can therefore have a large grid of processors or neurons that match the topology of elementary sensors in an image sensor,” he elucidates. “The 3D stacking allows the direct connection of each elementary sensor to its corresponding processor, thus reducing the energy in the information transfer and drastically increasing the bandwidth.”

As a result, their system has the capacity to process 1,000 images per second.

TOWARDS COMMERCIALISATION
At present, Andriamisaina and his collaborators are applying their respective areas of knowledge and expertise to the construction of the various parts of their smart vision sensor system. Once the dies – which have already been tapped out – return from the foundry, this will lead to the next step: 3D assembly, packaging and testing. Importantly, this will enable the researchers to conduct a detailed assessment of their system in terms of its yield, power consumption and performance, as well as providing them with the tools to evaluate and validate the different approaches they applied throughout the course of the project.

Going forwards, the hope is that the researchers’ end-product will be successful, informing the wider development of low-cost intelligent retina systems that are able to process images directly. “It is our intention to build on the results of the project and to possibly team up with a company interested in transferring our technology to the marketplace,” Andriamisaina concludes. “Hopefully our innovative retina system will prove to be an excellent solution for a number of different applications with useful purposes that bring real benefits to the lives of real people.”

A cutting-edge research culture

With research activities spanning three main fields – information and health technologies, energy, and defence and national security – the French Atomic Energy Commission (CEA) is a public body that was established in 1945. It has a 15,000-strong workforce of researchers and engineers and an overarching multidisciplinary emphasis that is based on synergies between basic and technological studies. The CEA’s Division of Technological Research – which performs applied research on innovative technologies – is an important national technology and software systems research centre. The various institutes and laboratories it hosts are fuelling industrial advances with real-world societal and economic implications.