June 15, 2026

The MVA is 30 years old

From CMLA to Deepika, via MVA and the Borelli Centre

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deepika.ai

Disclaimer . *This text was written by Jean-Michel Ghidaglia with, in particular, significant contributions from Nicolas Vayatis (Director of the Borelli Centre). However,* ***it represents the author's vision, and he alone is responsible for it*** .

On January 1, 1990, the Center for Mathematics and its Applications was established at the École Normale Supérieure de Cachan. Three years later, Robert Azencott joined this research laboratory with his team: the DIAM (Department of Artificial Intelligence and Mathematics), comprised of about twenty researchers, the vast majority of whom were under thirty. In 1996, the DEA MVA (Mathematics, Vision, Learning) program was created. We recount how AI has developed there since 1993.

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1. The creation of the Center for Mathematics and its Applications

On September 1, 1989, Jean-Michel Ghidaglia was appointed Professor at ENS Cachan with the mission of developing a mathematics research laboratory there in interaction with the economic world. A small probability research team collaborated with a research team from the École nationale des Ponts et Chaussées led by Nicolas Bouleau .

Jean-Michel Ghidaglia is a PDE specialist who works on the equations of fluid mechanics and, more generally, the equations of continuum physics. His work lies at the interface between the theory of nonlinear partial differential equations and their qualitative properties, such as those of dynamical systems theory, a rapidly developing field at the time. To strengthen the PDE research area, Jean-Michel Ghidaglia recruited two very bright young mathematicians in succession (1990 and 1991): Pierre Degond and then Frédéric Hélein .

On January 1, 1990, the Centre for Mathematics and its Applications was created as a research laboratory of the ENS de Cachan. It became an associated unit of the CNRS in 1991.

During its first three years, the CMLA developed along three lines within Partial Differential Equations (PDEs): theory with Frédéric Hélein, qualitative properties with Jean-Michel Ghidaglia, and numerical methods with Pierre Degond as scientific leaders. However, this segmentation remains somewhat abstract, as the three sub-themes led by these three university professors interacted very strongly. This interaction was particularly evident through their respective teams, which comprised a large number of people: doctoral students, research associates, lecturers, visiting scholars, and so on.

In 1992, the CMLA had the immense opportunity to welcome, on secondment to a position as Research Director at the CNRS, Jean-Michel Coron . A professor at Paris XI University (Orsay), Jean-Michel Coron was one of the most brilliant mathematicians of his generation (comparable to Jean-Christophe Yoccoz who died prematurely at the age of 59) and worked on control theory applied to nonlinear partial equations and their geometric methods. The presence of Jean-Michel Coron, who would go on to direct the CMLA for a time, brought renown to this laboratory and likely played a role in attracting another eminent scientist: Robert Azencott .

2. The arrival of the Department of Artificial Intelligence and Mathematics

In 1983, Robert Azencott attended a statistical physics seminar organized by IBM at the École de Physique des Houches (France) under the guidance of Marc Mézard and other physicists, in the presence of Sherrington and Kirkpatrick, the fathers of " simulated annealing ," a stochastic gradient descent method renowned for its universal properties in NP-hard combinatorial optimization. In the 1970s, Sherrington and Kirkpatrick became interested in "spin glasses." This is a disordered magnetic material where some interactions tend to align the spins, while others try to oppose them. This results in what is called frustration: there is no simple equilibrium state. The SK model, which they established in 1975, postulates that each spin interacts with all the others, and these interactions are random (positive or negative). This is a so-called mean-field (infinite -range) model: it is a disordered version of the Ising model . In the physics of the time, this model was revolutionary because, unlike the latter model, the energy landscape has an infinite number of local minima and the system has many metastable states, so the order is no longer simple (neither ferromagnetic nor paramagnetic).

Robert Azencott was struck by the self-organizing capacity of the random dynamics of large networks of interacting particles subjected to slow cooling, allowing them to stabilize in energy-minimizing configurations. After reading the seminal 1984 paper by the Geman brothers (Donald and Stuart) on

Markov random fields and digital image analysis, Robert Azencott immersed himself in this fascinating subject and devoured some 6,000 pages of articles on computer vision. In France, computer vision was then considered part of computer science, and the teams at INRIA, notably that of Olivier Faugeras , or the group of Henri Maitre at Télécom Paris, favored very "Cartesian" explicit algorithms.

In the United States, DARPA funding had significantly stimulated research on artificial neural networks and "brain-like" machine learning. This sparked the interest of physicists in France, such as Marc Mézard and his collaborators at the ENS rue d'Ulm, or in Grenoble with Christian Jutten and Jean Hérault , as well as the emergence of a broad, multidisciplinary "connectionist" front around Jean-Pierre Changeux and others.

In 1986, at the École Normale Supérieure (Ulm) in Paris, Robert Azencott launched a new research laboratory called DIAM: Department of Artificial Intelligence and Mathematics. His objective was to launch intensive research in two closely related mathematical fields: the analysis of digital images using Markov random field techniques and machine learning using stochastic artificial neural networks (Botzmann machines). Robert Azencott assembled a team of brilliant doctoral students in applied mathematics.

Initially, this team worked in three intertwined directions. The first, theoretical, focused on the theory of large deviations, notably through the work of Gérard Ben Arous (doctoral thesis under the supervision of Robert Azencott). The second related to the processing of satellite images (Defense), and finally the third related to the processing of medical images, co-led by Bernard Chalmond .

In 1993, Robert Azencott was recruited by the École Normale Supérieure (ENS) in Cachan. In 1989, he was one of the applied mathematics experts for the CAIMENS Association, an organization affiliated with the ENS on rue d'Ulm that provides training and expertise to industry professionals. Robert Azencott was assigned a project for SNECMA in the field of fluid mechanics. Two SNECMA engineers, nearing retirement, challenged management, arguing that the excessive use of numerical methods for approximate calculations of incompressible 2D flow solutions was unnecessary, since potential theory allowed these calculations to be reduced to holomorphic functions. Approximating flows based on these functions was relatively straightforward because they are sums of power series, resulting in very rapid calculations.

Robert Azencott met Jean-Michel Ghidaglia when he was a CNRS researcher and later a professor at the University of Orsay (Paris XI) and was familiar with his expertise in fluid mechanics. He therefore asked him to evaluate the report by the two SNECMA engineers. Jean-Michel Ghidaglia's expertise demonstrates that the proposed method based on holomorphic functions is not suited to SNECMA's needs. Indeed, this method relies on an ill-posed problem in the Hadamard sense . Most infinitesimal perturbations to the problem data lead to errors on the order of the desired solution. Thus, this method does not allow for numerical calculations.

During this work, Robert Azencott and Jean-Michel Ghidaglia met at the École Normale Supérieure (ENS) on rue d'Ulm, where Robert Azencott had established the DIAM (Department of Artificial Intelligence and Mathematics). Jean-Michel Ghidaglia was surprised to find himself working with him in the coffee corner. There, Robert Azencott informed him that he only had two offices for a team of 20 researchers. The DIAM had a strong reputation in the field of probabilistic methods applied to image processing, and Jean-Michel Ghidaglia, who was developing the CMLA (Center for Mathematical Analysis and Analysis), was astonished that in France at that time, virtually no internationally renowned

laboratory combined Numerical Analysis and Probability-Statistics. He had the intuition to bring them together at the CMLA in order to dedicate himself to the major mathematical problems posed by other sciences and, more generally, by human activity (Economics, Industry, Medicine, etc.). Jean-Michel Ghidaglia then made an appointment with the Director of the ENS Cachan, Yves Malier . The latter is an eminent mechanic with a unique and exemplary career in many respects. His book, " Un pont vers d'autres mondes," published by Presses des Mines in 2024, describes his scientific journey. Jean-Michel Ghidaglia explains his project to Yves Malier: bringing the DIAM (Department of Artificial Intelligence and Mathematics) to the CMLA (Center for Mathematics and its Applications). A few days later, Yves Malier informs Jean-Michel Ghidaglia that he proposes (i) creating a Professorship at ENS Cachan for Robert Azencott and (ii) making 700 m² available to the CMLA for the integration of the DIAM. If Robert Azencott agrees to join ENS Cachan, he will first speak with the Director of the ENS on Rue d'Ulm, Etienne Guyon , to inform him. Thus, Robert Azencott was recruited to both ENS Cachan and the CMLA in 1993.

Let's hear from Robert Azencott (excerpt from a short text he wrote on the occasion of the 20th anniversary of the MVA Master's program).

> "DIAM has become a 10-year research adventure with very brilliant doctors such as Laurent Younes , Olivier Catoni , Alain Trouvé , Jérôme Lacaille , Isabelle Gaudron , Mathilde Mougeot , Oussama Chérif Idrissi El Ganouni , François Coldefy , Jiaping Wang , Jen Feng Yao , Michel Levy , Bernard Chalmond , Christine Graffigne , Charles -Albert Lehalle , Bruno Durand , Stéphane Herbin , Eric Lhomer , and several others .
>
> I had also identified massively parallel computing as a potentially fascinating tool for the stochastic relaxation of large networks of interacting " units " in quasi-synchronous Boltzmann machines, as well as for parallel simulated annealing. Between 1988 and 1995, the availability in France of a few massively parallel computers, such as the Connection Machine (64,000 processors) or the MASPAR (4,096 processors), offered DIAM fertile ground for exploration. This led to the massively parallel realization of artificial retinas built as synchronous Boltzmann machines, in collaboration with Jérôme Lacaille, Laurent Younes, and Oussama Chérif Idrissi El Ganouni, and to exciting collaborations with eminent specialists in parallel hardware (Patrick Garda and Éric Bellhaire).
>
> DIAM quickly became involved in the industrial applications of artificial intelligence techniques (with EDF, CNES, SNECMA, ARIANE Espace, etc.) and gradually moved from ENS Ulm to Paris 11 University. In 1993, JM Ghidaglia invited me and DIAM to join the CMLA laboratory at ENS Cachan, where in 1995 I launched the MVA program in mathematics/Vision/Learning. Thanks to collaborations with École Polytechnique, ENS Ulm, Télécom Paris, Paris 11 University, INRIA, and other partners, CMLA has become a leading innovation center in mathematics, dedicated to computer vision and machine learning. The arrival of renowned mathematicians such as Jean -Michel Morel and his team, the significant presence of Yves Meyer and the recruitment of Alain Trouvé enabled the CMLA to become a center of excellence in mathematics, specializing in computer vision and machine learning.
>
> In ten years, DIAM made considerable progress in the fields of parallel simulated annealing, Markov random fields for image segmentation, pattern identification, synchronous Boltzmann machines for artificial retinas, and more. By 1996, many of my former students

from DIAM had become accomplished researchers in their own right, and I suddenly lost my wife to lung cancer. A change was necessary.

With several former colleagues from DIAM, I created two consulting groups: MIRIAD (Neural Networks for Multi-Sensor Monitoring) and Sudimage (Digital Image Analysis). We successfully developed prototypes of artificial intelligence applications for Renault, CNES, CEA, Avantis, Saint-Gobain, SAT, Air Liquide, and others. At DIAM, I furthered the study of Vapnik's support vector machines and his machine learning theory through a detailed analysis of large deviations, conducted in collaboration with Nicolas Vayatis.

In 2000, I took a four-year sabbatical from ENS/CMLA, filed five patents in artificial intelligence, and heavily mortgaged my house to transform MIRIAD and Sudimage into two atypical start-ups. "American-style," as Jacques Tati used to say . But that's another story.

3. The creation of the Master's program in mathematics, vision, and learning

1995. At the time, it was called a DEA, a postgraduate diploma, and like any university degree, it required submitting an application to the Ministry of Higher Education. This was done in 1995. Robert Azencott submitted this application under the auspices of ENS Cachan, with university partners including Paris-Saclay University (formerly Paris XI University, Orsay) and Paris-Dauphine University, as well as prestigious engineering schools such as École Polytechnique (l'X) and École Nationale Supérieure des Télécommunications. In fact, Paris VI University (Jussieu) and École Nationale des Ponts et Chaussées (National School of Bridges and Roads) were involved from the outset in the MVA Master's program, focusing on mathematics, vision, and learning. These institutions provided instructors but, more importantly, doctoral students.

The Ministry approved this creation and thus the first class was recruited in October 1995 for the 1995/96 academic year.

Thirty years later, on January 9, 2026, the website of the newspaper Le Monde published a profile of one of the alumni of the MVA Master's program, Arthur Mensch , founder of Mistral (with Guillaume Lample and Timothée Lacroix). The profile reads, "The Master's in Mathematics, Vision, and Learning (MVA). A program sometimes nicknamed the ' ENA of AI,' known even in Silicon Valley. Californian tech companies poach researchers there at exorbitant prices." How far things have come since then! And this is certainly not the end of the story.

The early 2020s dramatically altered the role of mathematics in society. The COVID-19 pandemic and the AI revolution brought mathematical modeling to the forefront, transforming it into a topic of social debate. Mathematics and AI researchers gained media attention, appearing on television programs, while columnists suddenly became science enthusiasts, sharing sometimes outlandish ideas about the future of AI: AI is everywhere, AI is frightening, AI sells. In particular, the commercial advances of generative AI tools prompted many countries, including France, to launch more aggressive and specific policies, especially in research and education. All universities and engineering schools created their own AI programs, and the number of AI master's degrees increased dramatically. Faced with this surge, the MVA, by virtue of its long history, served as a beacon, maintaining a strong identity based precisely on the values and foundations established at its inception. First, AI is not a research discipline, but a melting pot of numerous disciplines, and as such, constitutes a new common ground. There are therefore countless perspectives (computer science, computational aspects, etc.), and the MVA's is clear: it is that of mathematics. In particular, many courses (still) focus on modeling aspects that are sometimes rightly considered obsolete in the age of AI and big data. We believe, on the contrary, that

"useful" AI will be frugal, specific, and therefore largely based on refined mathematical work in information representation, and thus in modeling. Furthermore, it is also necessary to distinguish the rationale behind the programs . Here again, the MVA has a clear position. It is a research master's program, and we train researchers who will contribute to the world of academic research or industry. This greatly influences the content of the courses. We don't train students to use current AI techniques, but to design them. Furthermore, the goal isn't to equip them with the tools to design today's AI, but rather the AI of tomorrow. This implies returning to the fundamentals. It's therefore not surprising that in recent years, while all programs have created courses in LLM or generative AI, we have also introduced courses in geometry, statistics, and so on, and that there are still (popular!) master's level courses focusing on Fourier and wavelet analysis tools or "classical" image processing. For example, we deliberately waited several years before launching a (much-anticipated) course on LLM. This required both finding instructors and, more importantly, ensuring that this technology, initially developed by companies for the general public, would become widely integrated into research and offer a viable avenue for mathematical inquiry. For its 30th anniversary, the MVA Master's program welcomes nearly 280 students with 65 elective modules offered by over one hundred instructors. Specific tracks have been developed over the years: a health track grouping courses related to this field; an "industry & engineering" track designed to redirect students from specialized engineering schools (electrical engineering, mechanical engineering, computer science, bioengineering, etc.) towards mathematics and research careers; and a "reproducible research" track to equip students with the tools of open-source software and best research practices. In addition to these tracks, the program offers introductory scientific courses on subjects such as ethics, law, the environment, and even… art history!

Driven by the undiminished vision that gave rise to its creation, the MVA master's program has been able to stand the test of time and, despite its status as a benchmark in the French landscape, has been able to develop and evolve freely.

4. The Maturity of the Centre for Mathematics and its Applications (1995-2012)

a. Yves Meyer arrived in Cachan in September 1995

Let's give him the floor:

> “Professor Georges Mathé was one of the greatest French cancer specialists of the 20th century, a pioneer in bone marrow transplantation and a major figure in oncology research. He wrote: *‘ A researcher who leaves his laboratory after ten years does as much good for the laboratory he leaves as for the laboratory he joins .’*”
>
> Thus, after spending ten years at Cérémade (Paris-Dauphine University), I looked for a new home. I had already become an applied mathematician. Without consulting me, the CNU (National Council of Universities) had transferred me from the twenty-fifth section (fundamental mathematics) to the twenty-sixth (applied mathematics). It was then that Jean-Michel Ghidaglia offered me a position at the CMLA (Center for Applied Mathematics and Applied Mathematics), which he was finalizing. I resigned from the IUF (Institut Universitaire de France), where I had been a senior member since 1991 (the IUF prohibited mobility at that time), and obtained a secondment to the CNRS (National Center for Scientific Research). There I was in Cachan, in September 1995. Ghidaglia and his colleagues (Robert Azencott, etc.) had created the MVA (Mathematics, Vision, Learning) program, which became a revolutionary postgraduate course.

The MVA laid the foundations of AI. I made a point of attending Azencott's prodigious course on statistical learning. I carefully kept my notes and often reread them.

Today we can say that Azencott was announcing artificial intelligence.

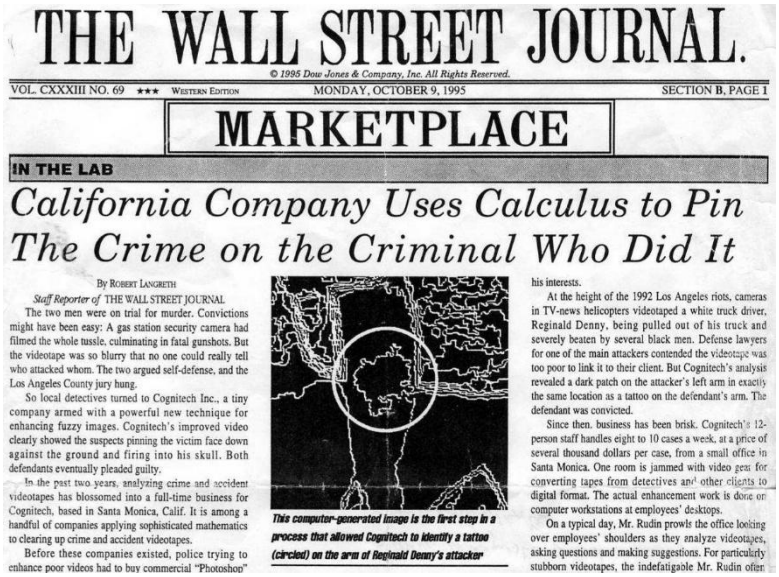
As an aside: It's interesting to note that I also worked for DARPA. I collaborated with Louis Auslander , the head of mathematics at DARPA.

I also took Donald Geman's course. Quite different from Azencott, but just as exceptional. Donald Geman made me understand the pitfalls of expert systems applied to machine translation. For me, those years at CMLA were extraordinary. In 1999, I applied for a professorship at ENS-Cachan. It was difficult. I had to prove, among other administrative hurdles, that I had indeed obtained a doctorate in mathematics... But finally, I was accepted, and I am still an emeritus professor at ENS Paris-Saclay today. I finally broke Georges Mathè's rule. Sometimes you have to know when to disobey.

Need we remind you that Yves Meyer is one of the greatest living mathematicians? He has received countless awards, including the Abel Prize in 2017. One of his greatest achievements is the development of the mathematical theory of wavelets .

b. In 1997, Jean-Michel Morel was recruited to the CMLA.

After founding the image processing team at Cérémade (Paris-Dauphine University), he was naturally drawn to the presence of Robert Azencott and Yves Meyer at CMLA. Jean-Michel Morel initially trained in partial differential equations, variational models , and nonlinear analysis under Haïm Brezis. In 1989, impressed by the work of two world-renowned mathematicians, David Mumford and Yves Meyer, he turned to image processing. His method consists of re-examining the theories and algorithms of image science, analyzing their numerous variants through mathematical analysis in order to deduce the most relevant algorithms. Jean-Michel Morel is generally recognized for having clarified, through an axiomatic method, the role of partial differential equations in image processing and for having invented new ones. He also contributed to the mathematical development and algorithms of four crucial questions in image processing and analysis: image segmentation, image denoising, invariant image matching, and image detection with false alarm control.



THE WALL STREET JOURNAL.

VOL. CXXXIII NO. 69 ★★★ WESTERN EDITION MONDAY, OCTOBER 9, 1995 SECTION B, PAGE 1

MARKETPLACE

IN THE LAB

California Company Uses Calculus to Pin The Crime on the Criminal Who Did It

By Robert Langreth
Staff Reporter of THE WALL STREET JOURNAL

The two men were on trial for murder. Convictions might have been easy: A gas station security camera had filmed the whole tussle, culminating in fatal gunshots. But the videotape was so blurry that no one could really tell who attacked whom. The two argued self-defense, and the Los Angeles County jury hung.

So local detectives turned to Cognitech Inc., a tiny company armed with a powerful new technique for enhancing fuzzy images. Cognitech's improved video clearly showed the suspects pinning the victim face down against the ground and firing into his skull. Both defendants eventually pleaded guilty.

In the past two years, analyzing crime and accident videotapes has blossomed into a full-time business for Cognitech, based in Santa Monica, Calif. It is among a handful of companies applying sophisticated mathematics to clearing up crime and accident videotapes.

Before these companies existed, police trying to enhance poor videos had to buy commercial "Photoshop"

This computer-generated image is the first step in a process that allowed Cognitech to identify a tattoo (circled) on the arm of Reginald Denny's attacker

his interests.

At the height of the 1992 Los Angeles riots, cameras in TV-news helicopters videotaped a white truck driver, Reginald Denny, being pulled out of his truck and severely beaten by several black men. Defense lawyers for one of the main attackers contended the videotape was too poor to link it to their client. But Cognitech's analysis revealed a dark patch on the attacker's left arm in exactly the same location as a tattoo on the defendant's arm. The defendant was convicted.

Since then, business has been brisk. Cognitech's 12-person staff handles eight to 10 cases a week, at a price of several thousand dollars per case, from a small office in Santa Monica. One room is jammed with video gear for converting tapes from detectives and other clients to digital format. The actual enhancement work is done on computer workstations at employees' desktops.

On a typical day, Mr. Rudin prowls the office looking over employees' shoulders as they analyze videotapes, asking questions and making suggestions. For particularly stubborn videotapes, the indefatigable Mr. Rudin often

Image segmentation . In 1995, the image segmentation algorithm discovered by Jean-Michel Morel and his collaborators Georges Koepfler and Sergio Solimini was the first image processing algorithm used and validated in a US criminal court during the trials related to the Los Angeles riots. The segmentation result, obtained by Lenny Rudin, a collaborator of Jean-Michel Morel and CEO of Cognitech , was published on the front page (section B) of the Wall Street Journal on October 9, 1995 (see figure above). This algorithm was described in the book by Jean-Michel Morel and Solimini published in 1994 (Variational) . methods in image segmentation, with seven image processing experiments , Springer Science & Business Media, 2012).

Image denoising at CMLA . In 2005, Jean-Michel Morel and his colleagues at CMLA and the University of the Balearic Islands defined a new mathematical method for image denoising, "nonlocal averaging," often referred to today as "nonlocal methods" or "patch methods." Their two articles presenting nonlocal averaging and its mathematical theory received two international awards for best paper and have garnered over 10,000 and 5,800 citations, respectively. Nonlocal averaging quickly became accessible to photographers worldwide thanks to DxO software. OpticsPro by DxO Labs . DxO Labs integrated this denoising method into the processing chain of over 700 million camera-equipped mobile phones. It was the first digital signal processor (DSP) to incorporate such a sophisticated image processing algorithm. Its quality contributed to the widespread use of phones as high-quality cameras. Today, most high-end smartphones incorporate non-local image processing. Phone manufacturers are currently preparing the next generation, based on neural networks. The transition from "handmade" denoising algorithms to autonomously trained deep neural networks requires a thorough understanding of the state of the art in deep learning. Understanding and guiding the development of efficient and unbiased neural networks is crucial. This is why Jean-Michel Morel addresses this transition in his 2020 lecture notes, "Image denoising: the human-machine challenge" (Pablo Arias, Gabriele Facciolo, and Jean-Michel Morel. Image denoising: the human -machine con-test, Lecture notes, Ecole Normale Supérieure Paris-Saclay. 2020), where the two approaches are compared.

Perspective-invariant image matching at CMLA . The impact of parameter-free online algorithms can be considerable. The most influential computer vision algorithm is probably the parameter-free SIFT method (David G. Lowe. Object recognition from local scale-invariant features. In Proceedings of the seventh IEEE international conference on computer vision, volume 2, pages 1150–1157. IEEE , 1999.), published in 2004, already cited more than 60,000 times and used in all areas of imaging and robotics. This method can be applied to any image pair with your eyes closed. It is an ingenious method: recognizing objects at different distances involves identifying and compensating for different blur kernels.

Although perfectly scale-invariant, SIFT was only partially perspective-invariant. Jean-Michel Morel's team discovered, through in-depth mathematical and numerical analysis conducted in 2010, that it was possible to extend it to a fully perspective-invariant method. This fact is clearly illustrated in the IPOL article, accompanied by an online demonstration. The experimental public archive for this article lists over 78,000 experiments. The method is optimally described in the first review report for the article (Jean-Michel Morel and Guoshen Yu. Asift : A new framework for fully affine invariant image com-parison. SIAM journal on imaging sciences, 2(2): 438–469, 2009), published in the SIAM Journal of Imaging Science, which now has 2,000 citations. The work described in this article proposes a completely different paradigm for extending Lowe's descriptor (...).

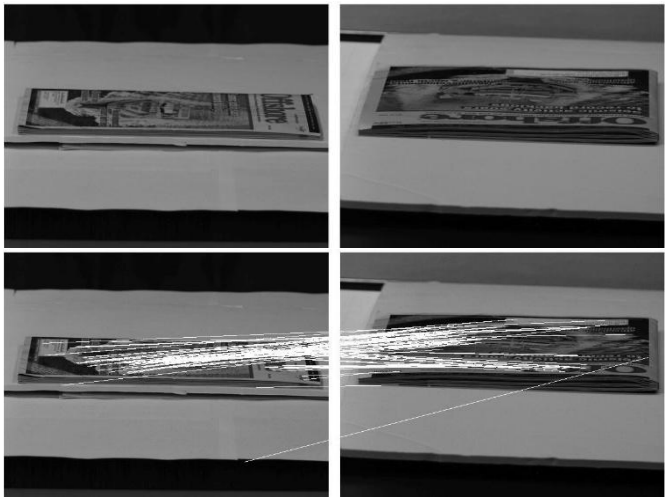


Figure 1: Top: Pair of snapshots of the same object with a transition tilt t ≈ 36. (SIFT, Harris-Affine, Hessian-Affine, and MSER all fail completely.) Bottom: ASIFT finds 120 matches, only 4 of which are incorrect. See comments in the text.

Contrary to David Lowe's claims, the authors demonstrate that judicious sampling of affine space makes extending SIFT to the affine frame entirely feasible. Furthermore, they propose a multi-resolution method with a computational complexity approximately 1.5 times greater than that of SIFT. The authors have thus developed a method with impressive results, far surpassing all current leading methods for the local description of affine images. Figure 1 illustrates perspective invariance in practice: the same object, viewed from different angles, can undergo significant geometric distortions (called transition inclination) of up to 40°. In the example presented, this object has a transition inclination of 36° and is nevertheless recognized with high reliability (116 features correctly identified).

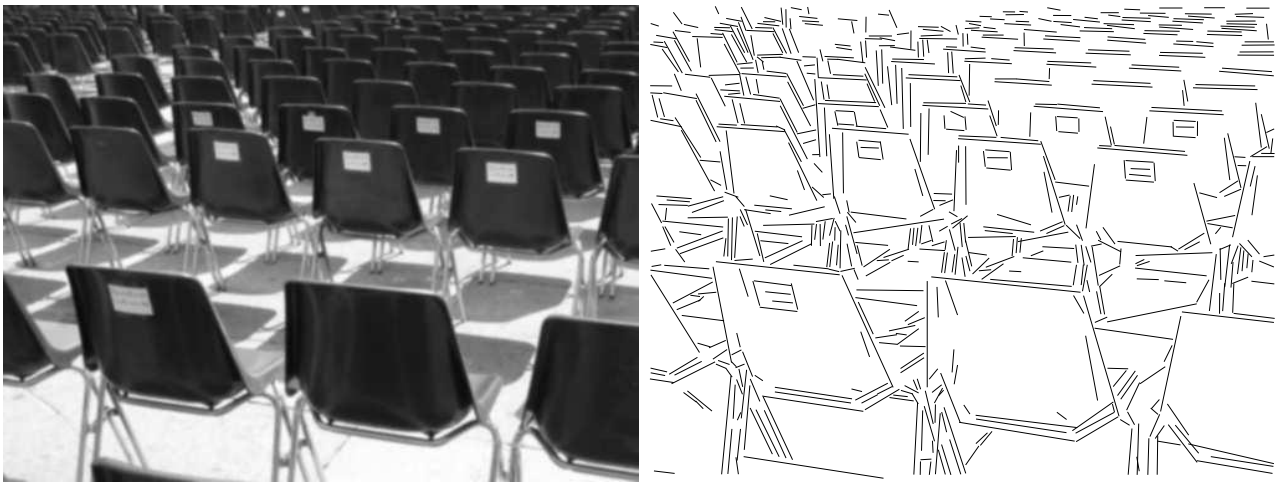


Figure 2: Result of our zero-parameter line segment detector. The experimental public archive for this article contains over 44,700 experiments.

Contrario detection theory at CMLA . Over the past 13 years, Jean-Michel Morel and his team have developed a statistical theory adapted to image processing, enabling the design of parameter-free algorithms. This theory, generally called contrario detection theory, is the subject of a monograph (Agnes Desolneux, Lionel Moisan, and Jean-Michel Morel. From gestalt theory to image analysis: a probabilistic approach, volume 34. Springer Science & Business Media, 2007) (720 citations). The flagship algorithm from this theory is the line segment detector (Rafael Grompone Von Gioi, Jérémie Jakubowicz, Jean-Michel Morel, and Gregory Randall. Lsd : A fast line segment detector with a false detection control. IEEE transactions on pattern analysis and machine intelligence, 32(4): 722–732, 2008) (2300 citations), tested by thousands of scientists and engineers during the online demonstration of the IPOL paper (Rafael Grompone Von Gioi, Jérémie Jakubowicz, Jean-Michel Morel, and Gregory Randall. Lsd : a line segment detector. Image Processing On Line, 2:35–55, 2012) (1100 citations). The theory has extremely diverse applications, such as the detection of methane emission sources (in collaboration with Kayrros) in satellite imagery or the detection of falsified images (Tina Nikoukhah, Rafael Grompone von Gioi , Miguel Colom, and Jean-Michel Morel. Automatic jpeg grid detection with controlled false alarms, and its image forensic applications. In 2018 IEEE Conference on Multimedia Information Processing and Retrieval (MIPR), pages 378–383. IEEE, 2018) (in collaboration with Agence France-Presse).

Anomaly detection , industrial applications . A large part of Jean-Michel Morel's current work is dedicated to anomaly detection in optical images or image sequences, videos, synthetic aperture radar images, and hyperspectral images . This is because digital images and videos are now ubiquitous in scientific, technical, and societal applications. At the same time, their number is considerable. Any image analysis application must be automated. Anomaly detection was recently addressed by Jean-Michel Morel in (Axel Davy, Thibaud Ehret, Jean-Michel Morel, and Mauricio Delbracio. Reducing anomaly detection in images to detection in noise. In 2018 25th IEEE International Conference on Image Processing (ICIP), pages 1058–1062. IEEE, 2018) and (Thibaud Ehret, Axel Davy, Jean-Michel Morel, and Mauricio Delbracio. Image anomalies: A review and synthesis of detection methods. Journal of Mathematical Imaging and Vision, 61(5): 710–743, 2019). This unified theory allows for the

elimination of extraneous data and focuses on relevant data. It associates a number of false alarms (FNAs) with each detected anomaly. This allows industrial, scientific, law enforcement, press and medical users to sort the data and use only the relevant data, with relevance controlled by the NFA.

Software and reproducible research

DxO Bonus OpticsPro has been the most recognized raw image denoiser[1] for many years , and is based on a denoising method developed by Jean-Michel Morel. Its hardware version was installed by DxO in over 700 million mobile phones between 2007 and 2017.

• The flagship project of Jean-Michel Morel's group, IPOL (Image Processing on Line, www.ipol.im), is a journal that promotes reproducible research in image processing. Each published algorithm must include an online demonstration that can be run on any image uploaded by the user. Founded in 2011, it has published 290 algorithms with mathematical descriptions, source code, online demonstrations, and a public experimental archive containing over 450,000 online experiments conducted by users from more than 2,000 academic and industrial centers across five continents. Jean-Michel Morel has contributed to 29 IPOL articles. The CNRS Innovation Prize was awarded to Jean-Michel Morel and his team for the development of IPOL.

c. The Partial Differential Equations team is being strengthened during this period

Between 1997 and 1999, three major scientists joined the EDP team: Claude Bardos on secondment from the CNRS (1997-2000), Laurent Desvillettes as Professor (1998-2015) and Frédéric Dias in 1999. In 2005, Frédéric Pascal joined the CMLA as well as Florian de Vuyst in 2010.

d. Alain Trouvé joined the CMLA in 2003

That year, Alain Trouvé left his position as Professor at the University of Paris 13 (Villetaneuse) to join the CMLA. Alain Trouvé, who had completed his PhD under the supervision of Robert Azencott ten years earlier, was the most mathematically inclined member of the image processing team. He was a world-renowned specialist in computational anatomy for neuroimaging.

e. Nicolas Vayatis joined CMLA in 2007

That year, Nicolas Vayatis was recruited to the laboratory. What profoundly surprised him was that one of the smallest mathematics departments in the world (with only about ten tenured staff) could so clearly reflect the universality of mathematics and its applications. Nicolas Vayatis was engaged in a period of intense work on developing new machine learning algorithms for ranking / scoring (and their theoretical foundations) through a highly fruitful collaboration with Stéphan Clémençon. Their attempts to commercialize their work encountered several setbacks, and to reassure themselves, they told themselves they were too far ahead of their time. However, they realized that AI algorithms were just one ingredient among many for implementing information processing solutions for real-world applications. What was lacking in the theory and methods derived from statistical learning was a data culture, a culture that permeated both the imagery team and the physical modeling team, his new colleagues in the PDE team were immersed in.

The years 2007-2019 of the machine learning team around Nicolas Vayatis.

The Beginnings (2007-2016). From a scientific standpoint, the early years followed a surge in ranking / scoring research . Initial steps in collaborations with companies were opportunistic. Digital marketing was developing, and machine learning found a natural field of application: there was massive amounts

of data, no critical issues at stake, and financial resources to support research. This was also the period of the Netflix Prize , which sparked the interest of brilliant mathematicians like Terrence Tao and Emmanuel Candès in modeling the recommendation systems that would bring fame to Amazon, Netflix, and their ilk. But the Netflix Prize also marked the origin of the star system surrounding machine learning researchers , which began to permeate the R&D teams of Big Tech companies in Silicon Valley. In France, Thibaut Munier , co-founder of the company 1000mercis, was one of the very first partners with whom Nicolas Vayatis forged fruitful research collaborations. In addition to high-quality CIFRE theses (Emile Richard, Rémi Lemonnier), modeling questions naturally lead to inference problems on graph-structured data, resulting in a rich scientific field that continues to be explored today from various angles. Simultaneously, Nicolas Vayatis is fully involved in a FUI -funded project for the aeronautics industry, led by Michel Ravachol, which brings together numerous academic laboratories and companies working on AI-assisted system design. This collaboration did not produce anything interesting from a research point of view in the immediate future, except for application openings which, on this inspiration, would give rise to achievements at CMLA many years later with the theses in active learning of Steven Masfaraud (co-founder of the company DessIA), Emile Contal (co-founder of the company Crossing Minds, acquired in 2025 by OpenAI) and Themis Stefanakis (which earned articles in MIT Tech and The Economist).

Outreach and structuring of Maths&IA around the CMLA (2016-2020)

In 2016, the CMLA (Centre for Mathematics and Applied Mathematics) had a very strong reputation in the field of Mathematics & AI. Following the subprime mortgage crisis , the MVA (Mathematics and Visual Analysis) Master's program doubled its enrollment to approximately 150 students per year and dethroned the Paris 6 Mathematical Finance Master's program as the most sought-after Master's in Applied Mathematics. The program boasts a faculty of leading figures in machine learning research and image and signal processing in France: Yves Meyer, Jean-Michel Morel, Stéphane Mallat, Jean-Philippe Vert, Francis Bach, Alessandro Lazaric, Michal Valko, Emmanuel Bacry, Olivier Faugeras, and others. As director of the MVA Master's program, Nicolas Vayatis was asked by the State Secretariat for Digital Affairs (Axelle Lemaire) to lead a working group on AI training as part of the " FranceIA " mission, whose report was submitted to President François Hollande towards the end of his term in 2017.

At the same time, the CMLA recruited Vianney Perchet and Alain Durmus. In terms of industrial collaborations, it was a tsunami; the phone rang almost daily with requests for partnerships with companies. Many of them wanted to develop deep learning. Learning represents the resurgence of neural networks, but we are cautious. We must first understand the industrial problem before adopting a solution method. Furthermore, our potential partners are French companies operating in B2B markets with critical stakes; we cannot afford to commit to methodologies with low technological maturity because mastery is essential. This message resonates with some industry leaders, including Hubert Tardieu, special advisor to Thierry Breton, CEO of ATOS. Nicolas Vayatis meets with Daniel Le Coguic , former CEO of Bull and VP of ATOS's Defense and Security division. In the office of CEA program director Jean-Philippe Bourgoin, Nicolas Vayatis participates in a meeting focused on supporting AI efforts for industry, moving beyond the hype, and where the importance of fostering interaction between national industrial players and academic research centers appears to be taken seriously. A partnership chair was then established, bringing together several large and medium-sized companies around the challenges of AI for industry (transfer) learning , physically inspired AI, etc.). A chair holder was identified in Mathilde Mougeot , who possesses a rare talent that could be described as a mastery of the interfaces between academic research and industrial R&D. This endeavor continues today with Michelin, SNCF, and CEA. The chair was also mobilized during the Covid-19 pandemic, as ATOS, along

with other major French companies, intervened pro bono to assist the government in managing the health crisis, particularly for the Ministry of the Interior, which was responsible for implementing the population lockdown measures. The CMLA, which at that time became the Borelli Center, thus provided support for both operational and strategic aspects (at the level of certain interministerial units), notably for model qualification by providing reproducible versions of the epidemic models developed urgently by epidemiologists.

f. Agnès Desolneux joined the CMLA in 2011

Agnès Desolneux began a thesis on the statistical analysis of geometric event detection in images, supervised by Jean-Michel Morel. She defended it in 2000 at the Centre for Mathematics and their Applications (CMLA) at ENS Cachan (now ENS Paris-Saclay).

During a thematic term organized at the Henri Poincaré Institute, Agnès Desolneux met the American researcher David Mumford, Fields Medalist in 1974. “While he was dedicated to pure mathematics at the beginning of his career, I had the good fortune to meet him just as he was becoming interested in image modeling.” The mathematician took her on as his teaching assistant and suggested she write a book based on her notes. After numerous trips back and forth between France and the United States, the book was published in 2010.

Meanwhile, Agnès Desolneux was recruited by the CNRS in 2001 as a research fellow at the applied mathematics laboratory at Paris 5 (MAP5 – CNRS/Univ. Paris Cité). She remained there for ten years before returning to the CMLA in 2011 following her promotion to CNRS research director.

At the intersection of probability and the physics of imaging systems, mathematical models allow us to test the behavior of the objects under study. "I consider images as mathematical objects. From there, I ask myself questions such as: how to restore poor quality images? How to perform detection in images, or even how to generate new ones for various applications?" explains Agnès Desolneux.

Among the potential applications of this research, medical imaging holds a special place, particularly regarding the early detection of breast cancer. "Using mammograms, we model what constitutes detectable structures: we aim to show what is detectable and what is not," explains Agnès Desolneux, who collaborates with GE Healthcare on this topic. She also creates synthetic images for conducting virtual clinical trials. "For example, we simulate lesions or calcifications on these images. We then perform statistical estimations to determine if they can be detected and, if so, at what size."

Other applications exist, such as enhancing the images of video games and animated films, which are constantly demanding greater realism. Conversely, there is also image restoration: this involves, for example, removing the effects of chemical degradation from old film stock in digitized older movies.

Identifying the composition of very old materials

Today, Agnès Desolneux collaborates with the Major Area of Interest (DIM) for Material Heritage – Innovation, Experimentation and Resilience (PAMIR) in the Île-de-France region. The research conducted contributes to the development of the "data, modeling, statistics" component of the analysis of materials in historical heritage. "Using spectral images of materials obtained through the electron and energy flux of the SOLEIL synchrotron, we model the physical phenomenon to analyze the chemical composition of these materials, for example," explains Agnès Desolneux.

Agnès Desolneux is also a member of the Mathematics of Image Processing, Learning and Stochastic Geometry Thematic Network (RT MAIAGES), which brings together the entire national scientific community of mathematics for image processing. "Generally speaking, my work consists of finding a

balance between the complexity of the mathematical models developed (to be as realistic as possible and closely reflect the physical phenomenon) and simplicity (to be as computable as possible)," explains Agnès Desolneux.

5. The creation of the Cognac G laboratory

The CMLA-Cognac G adventure (2012-2019)

Alongside the previously mentioned developments in Maths & AI for industry, another branch emerged in 2012 with new interactions between behavioral neuroscience and medicine. The genesis of this new research area was a phone call Nicolas Vayatis received from Pierre-Paul Vidal in the fall of 2012. He explained that medicine was about to undergo a revolution due to inexpensive sensors and machine learning algorithms, and that there was therefore an urgent need to bring medicine, neurophysiology, and mathematics closer together by merging our two units. I wasn't quite sure how to interpret this proposal, but we quickly explored its potential by setting up a student engineering project from ENSTA in the spring of 2013 within the neurology department of the Val-de-Grâce military hospital, under the watchful eye of Damien Ricard, a graduate of École Polytechnique, a military physician, and head of that same department. The collaboration is smooth and very promising, and it's the beginning of a human adventure of a scale rarely seen in a career. From there, everything fell into place: funding from SATT IDF INNOV, headed by Christian Estève, and the crucial support of Robert Marino; the "Smart-something" projects, all inherently "smart"; the recruitment of brilliant young people who accepted the immense risks associated with this venture—doctoral students (Rémi Barrois, Clément Dubost, Pierre Humbert, Thomas Moreau, Alice Nicolaï, Charles Truong) and postdoctoral researchers (Julien Audiffren, Laurent Oudre, Ioannis Bargiotas); and the creation in 2015 of the UMR COGNAC G, a precursor to the creation of the Borelli Center, thanks to the discreet benevolence, like wise men, of key figures in the management of our supervisory bodies: Christoph Sorger and Bernard Poulain (CNRS), Frédéric Dardel and Stefano Marullo (Paris-Descartes), Pierre-Paul Zalio (ENS Cachan), not forgetting General Dominique Felten (director of the Val-de-Grâce). Among the bittersweet institutional anecdotes, the pillars of the COGNAC G initiative will remember their exploration of the inner workings of the General Investment Council (CGI, now SGPI). A small delegation composed of COGNAC G executives and the management of SATT IDF INNOV, in their great naiveté, presented themselves to CGI advisors and introduced an ambitious project for an interdisciplinary research institute focused on the study of regular and pathological human behavior. Our interlocutors found the idea so good that a few months later they announced the call for projects for the "Convergence" institutes, a call in which, of course, our project was not selected. Indeed, as is often the case, institutional logic overrides scientific merit…

In parallel, the Partial Differential Equations team saw the arrival of Thomas Alazard at the CMLA in 2016. François Alouges, for his part, will join the Borelli Centre in 2022.

6. The creation of the Borelli Centre

Following the completion of the institutional process, the Borelli Center, UMR 9010, a merger of UMR CMLA and COGNAC G, was established on January 1, 2020, and its existence was immediately apparent, which in itself was a remarkable event. The idea was so natural that the supervisory bodies proposed integrating new teams: the INSERM team of Jean-Luc Martinot , specializing in mental health and the monitoring of international cohorts of children and adolescents in psychiatry, and a computer science research team led by Professors Mohamed Nadif and Ahmed Mehaoua. The first few months of the new center's existence were anything but typical for a research unit: the health crisis erupted, and,

moreover, part of the unit had to relocate from Cachan to the new ENS Paris-Saclay campus on the Moulon plateau . The administrative team is under pressure because, in addition to organizing the administrative merger of units, it must also cope with remote work and staff reductions following the relocation. Véronique Almadovar, who has risen through the ranks since the creation of the CMLA, is asserting herself as the unit's executive director, a role for which she will be awarded a CNRS Crystal Medal in 2025. During this unusual period, she is ensuring continuity of service for both teaching and research. Thanks to the unparalleled commitment of Véronique and her team, including Alina Muller and Gwladys Stouvenel , the unit is able to continue its intense activity smoothly. In February 2020, the researchers faced a new challenge, as their hospital colleagues alerted modelers to the need to support the organization of services during periods of staff attrition. Around twenty researchers from the Borelli Centre, including many young doctoral and postdoctoral students, mobilized, setting aside their core research to support this demand, which encompassed several aspects, from the most operational to the most strategic. Very quickly, the Borelli Centre focused on the reproducibility and transparency of the epidemiological models developed urgently by specialized teams from the Pasteur Institute and the University of Montpellier. Partner companies like Atos volunteered their time to assist prefects in the practical implementation of lockdowns and also relied on the expertise of Borelli Centre researchers. This period proved to be a formative experience, bringing together different generations of researchers, civilians and military personnel, hospital practitioners, and mathematics researchers. New vocations emerged, students from the ENS Paris-Saclay's "Passerelles" program pursued doctoral theses in science, and mathematics PhDs began medical studies. This period also saw emblematic researchers from the CMLA, such as Yves Meyer, Jean-Michel Ghidaglia, and Jean-Michel Morel, leave the unit. The MVA Master's program experienced a revival under the leadership of the young professor, Laurent Oudre, recently recruited as the new architect of the interfaces between mathematics, signal processing, and biomedical applications. Laurent assembled a research team in record time to investigate physiological signals from every angle, taking on the challenge of working with real-world signals collected in hospital settings. He also became involved in other forms of AI training. Indeed, while the MVA Master's program trains AI leaders at the global level, other skills development needs were identified for non-expert audiences. Thus, the Borelli Center is in charge of the AI Research Year (ARIA), the first (and only) training program open to all teaching and research departments at ENS Paris-Saclay: engineering sciences, physics, chemistry, humanities and social sciences, design sciences, and languages, among others. Within the framework of the call for proposals on skills and professions of the future (CMA), Laurent Oudre is working to raise awareness of AI among all higher education students through the BrevetAI platform , which is based on the principle of learning by doing. BrevetAI will be open to all students and staff of Université Paris-Saclay (several tens of thousands of people) starting in the fall of 2026, and other universities are ready to implement it. It will also be offered on the national FunMooc platform . The Borelli Centre's adventures in scientific AI training continue with the ClusterIA Paris-Saclay project, FormIA, which is aimed at teachers of all disciplines to support them in integrating AI-related concepts into all teaching at all levels. The IDAML Chair is strengthened with the continuation of the partnership with Michelin, SNCF, and CEA, under the leadership of Mathilde Mougeot. Finally, anticipating the psychological and organizational impacts of AI, the Borelli Centre is exploring scientific themes such as mental health, ergonomics, and the humanities. In this last area, further expansion is made possible by the recruitment of Julien Randon- Furling to a junior professorship; he is another expert in the interfaces between random processes, statistical physics, agent-based modeling, arts, and society. The initiative is off to a flying start with numerous collaborations and other funding (ANR, PEPR, etc.). In general, all subjects are approached with the same prism: to meet the concrete problems of field actors, to contribute to the back-and-forth between science and technology based on models, simulations and empirical data, to approach from a scientific

angle the question of the adoption of algorithmic tools by experts in the field, to explore beyond the physiological and psychological mechanisms, the decision-making mechanisms and the related risks.

7. Contributions to Innovation

Math & Interaction laboratories , the CMLA and later Borelli research centers sourced their scientific output through multidisciplinary and industrial collaborations. This is evident from the preceding paragraphs. These collaborations with companies were, of course, conducted under contracts involving substantial financial flows. From this perspective, the CMLA and later Borelli are leading institutions within ENS Paris-Saclay, as well as nationally and internationally.

This fertile melting pot has seen the growth of numerous Startups and Robert Azencott, ahead of the curve in the mathematical community, founded several companies: SUDIMAGE, EASYGLIDER and then MIRIAD TECHNOLOGIES.

a. Startups from CMLA and Borelli

Please note : This list cannot be exhaustive, as these companies appeared spontaneously. Feel free to contact Jean-Michel Ghidaglia if you have any suggestions for companies to include in this list.

Name	Website	Domain	Year of creation	Founders from CMLA / Borelli
DxO Labs	https://www.dxo.com/fr/	Image processing	2003	Frédéric Guichard
DxOMARK	https://www.dxomark.fr/	Equipment quality assessment	2017	Spin Off of DxO Labs Frédéric Guichard
Poseidon	https://poseidon-tech.com/fr-FR/	computer vision for drowning detection	1999	Frédéric Guichard
Dessia Technologies	https://fr.dessia.tech/	AI to improve engineering processes	2017	Steven Masfaraud
Scibids Technology	https://scibids.com/	AI for marketing	2016	Rémi Lemonnier
Crossing Minds	https://www.crossingminds.com/	Recommendation engine	2016	Emile Contal

b. The creation of deepika

In 2019, Walid Ben Youssef , Arnaud Salomon , Nicolas Vayatis, and Jean-Michel Ghidaglia began to consider the possibility of creating a fund to finance deep tech companies in the AI sector with a strong scientific and technical background. All four had been asked, mostly individually, to provide their opinions as part of due diligence on funding applications from startups that relied heavily on AI technologies to establish their businesses. It became clear to them that, in general, deep tech

investment funds had become adept at evaluating the human (team) and economic (business plan) aspects, but on the technological side, some were simply following trends and were easily impressed by buzzwords and prestigious CVs.

Walid Ben Youssef, a graduate of the École Normale Supérieure de Cachan, holds a doctorate in mathematics and has been a senior consultant in territorial innovation for many years. He then suggests we consider the "Startup Studio" model. These innovation structures emerged in Silicon Valley in the 2010s. The precursor was Idealab, founded in 1996 by Bill Gross in Pasadena , California. In France, Thibau d' Elzière and Quentin Nickmans founded the first Startup Studio in 2011: eFounders . Renamed HEXA at the end of 2022, this Startup Studio remains active and productive (3 unicorns out of some forty companies created).

After a thorough study of the model, Walid Ben Youssef, Arnaud Salomon, Nicolas Vayatis, and Jean-Michel Ghidaglia decided to initiate the creation of an AI startup studio. This studio was scheduled to launch its initial funding round in the spring of 2020 when the COVID-19 pandemic caused the widespread disruptions. This development project was then put on hold until the end of the pandemic.

In the fall of 2022, the team resumed operations, updated the project, and decided to present it to a few potential founders. The company Kannon For Deep Tech was thus created by 29 founders on March 29, 2023. It adopted the commercial name "deepika" and highlighted its intellectual connection with the Borelli Centre, https://deepika.ventures/

Presenting itself more as a " deep tech venture studio" than as a classic SaaS startup studio like Hexa, deepika works on more scientific or sovereign topics around responsible AI.

Deepika has invented a new model for creating startups: the "nouvelle vague" model, which is centered on the co-creation of scientific and business expertise. It is based on a product studio, deepika.ai .

deepika is backed by around ten Business Angels and relies on an "Ethical, Economic, Technological and Scientific Council" comprising 65 Senior experts in numerous fields.