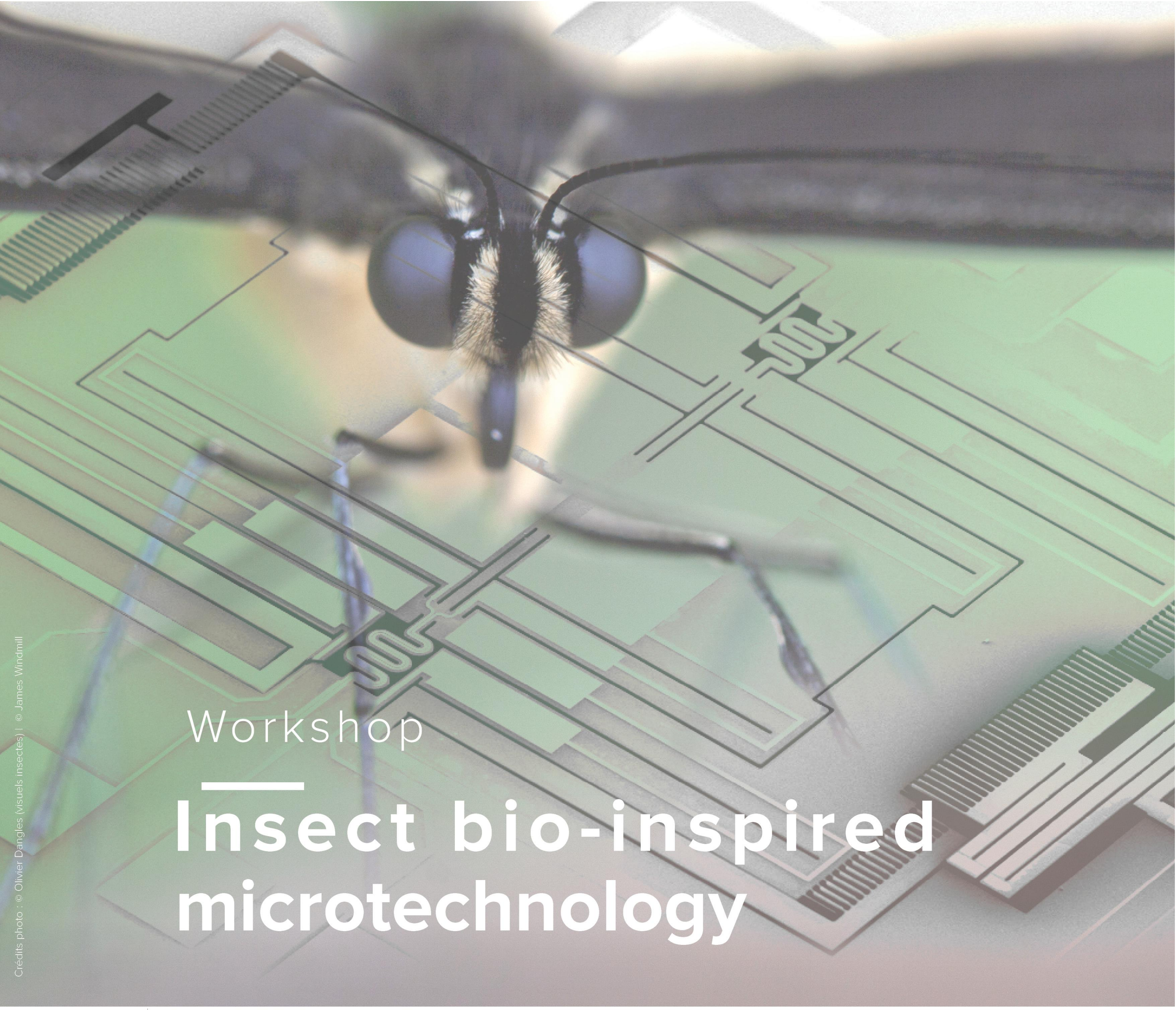
Crédits photo : © Olivier Dangles (visuels insectes) | © James Windmill

Workshop

Insect bio-inspired microtechnology

Thursday **30th November** & Friday **1st December 2017**

Chambre de Commerce et d'Industrie | Salle la Halle aux Draps
4 bis rue Jules Favre, 37000 Tours, France

Organized by

Jérôme CASAS, Professor, University of Tours – CNRS – Institut Universitaire de France
Barbara DE SALVO, Scientific Director of CEA – Leti of Grenoble, France

Intelligence des Patrimoines
Centre d'études supérieures de la Renaissance
59, rue Néricault-Destouches BP 12050 –
37020 Tours Cedex 1 - France
intelligencedespatrimoines@univ-tours.fr

Contact
intelligencedespatrimoines@univ-tours.fr
(+33) (0)2 47 36 77 97

Workshop

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Tours, France



Steering and Scientific committee

Jérôme CASAS
Professor, University of Tours – CNRS – Institut Universitaire de France and Chair holder in bioinspired technology at CEA-Leti of Grenoble, France

Barbara DE SALVO
Scientific Director of CEA-Leti of Grenoble, France

Benoist PIERRE
Director of the CESR and *Intelligence des Patrimoines* research Programme

Organizing committee

Morgane CHAUMIER
Research manager, *Intelligence des Patrimoines* research Programme

Emilie ROLLEAU
Events organizer, *Intelligence des Patrimoines* research Programme

Summary

Introduction

Jérôme CASAS
Professor, University of Tours – CNRS – Institut Universitaire de France and Chair holder in bioinspired technology at CEA-Leti of Grenoble

Barbara DE SALVO
Scientific Director of CEA-Leti of Grenoble, France

The international workshop "Insect bio-inspired microtechnology", funded by the CNRS INEE within the RTP (*réseau thématique pluridisciplinaire*) "Bioinspiration", and supported by the CEA-Leti Chair in "Bioinspired microtechnologies", is organised as part of *Intelligence des Patrimoines*, an interdisciplinary programme for research and innovation coordinated by the *Centre d'études supérieures de la Renaissance* (Centre for Advanced Renaissance Studies) for the *Université de Tours*. This programme, supported by the *Région Centre-Val de Loire*, seeks to understand the processes of heritage, whether cultural or natural, tangible or intangible, and organizes itself in interdisciplinary topic projects on major heritage items.

Bio-inspiration is taking off big times, worldwide: from hydrophobic surfaces, structural colors, neuromophic computing to a wild array of bio-inspired robots, just to name a few. Whole research institutes are now harboring this name, from China to Harvard. Insects are a fantastic source of ideas, tricks and system level solutions, in particular at the microtechnological scale. This is the realm of mechanics, material science and computing, again to name only a few. We have thus collated a series of speeches, balancing biology, physics and engineering which should be of highest interest to organismal biologists, microtechnologists and systems engineers.

Speakers

First session: material sciences and adhesion

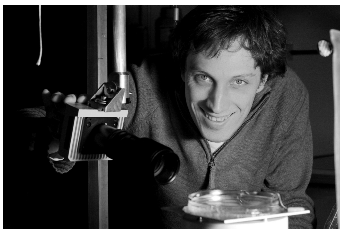
Stanislav GORB

Stanislav Gorb received his PhD degree in zoology and entomology at the Schmalhausen Institute of Zoology of the Ukrainian Academy of Sciences in Kiev, Ukraine. Gorb was a postdoctoral researcher at the University of Vienna, Austria, a research assistant at University of Jena, a group leader at the Max Planck Institutes for Developmental Biology in Tübingen and for Metals Research in Stuttgart, Germany. Gorb's research focuses on morphology, structure, biomechanics, and evolution of surface-related functional systems in animals and plants, as well as the development of biologically inspired technological surfaces and systems. Gorb has co-authored five books; more than 400 papers in peer-reviewed journals; and four patents. He is corresponding member of Academy of the Science and Literature Mainz (since 2010), and member of German National Academy of Sciences Leopoldina, (since 2011).

Contact: **sgorb@zoologie.uni-kiel.de**

Biologically inspired structure-based adhesives: Where are we now?

Biological hairy attachment systems found in flies, beetles, spiders and geckos demonstrate their excellent adhesion and high reliability of contact. The structural background of various functional effects of such systems is studied. Experimental studies show that the effective elastic moduli of fiber arrays and spatula-like terminal elements are low, and this is of fundamental importance for adhesion enhancement on rough substrata and for an increased tolerance to defects at the level of individual contacts. Based on the broad structural and experimental studies of biological attachment devices, the first industrial bioinspired reversible adhesive foil was developed, which adhesive properties were characterized using variety of measurement techniques and compared with the flat surface made of the same polymer. The microstructured foil demonstrates considerably higher pull off force per unit contact area. The foil is less sensitive to contamination by dust particles, and after washing with water, its adhesive properties can be completely recovered. This glue-free, reversible adhesive is applicable in dynamic pick-and-drop processes, climbing robots, and other systems even under vacuum conditions. The foil represents therefore a considerable step towards development of industrial dry adhesives based on the combination of several principles previously found in biological attachment devices.



Tristan GILET

Tristan Gilet obtained a MSc in Aerospace Engineering (ISAE, Toulouse) in 2004 and a MSc in Engineering Physics (ULiège) in 2005. He completed a PhD in Physics in 2009 (ULiège) on the manipulation of droplets. He was then appointed as an instructor at the Dept. of Mathematics at MIT (Cambridge, MA) for two years. Since 2011, he is assistant professor and the head of the Microfluidics Lab at the Department of Aerospace and Mechanical Engineering of the University of Liege (Belgium). The research of the Microfluidics Lab is focused on microscale flows involving surface tension, both in biological and engineering contexts. Current research projects include the rain-induced dispersal of foliar pathogens, the capillary-based terrestrial locomotion of insects, droplets in microfluidic channels, and droplet-based macroscopic quantum analogues.

Contact: **tristan.gilet@uliege.be**

The capillary adhesion of dock beetle tarsi:
a source of inspiration for microrobotic pick-and-place

Dock beetles can walk upside down on a wide variety of substrates thanks to arrays of micrometer-scaled setae present on their tarsi. A minute amount of liquid is found at the tip of each seta. In this talk, I will present several experimental measurements of the walk kinematics of living beetles. The observed phenomena range from the millimeter scale of the legs to the micrometer scale of individual seta tips. The theoretical models proposed to rationalize these observations reveal the importance of capillary forces, and their ability to deform the seta tips in order to potentially provide an optimal, controllable adhesion. This locomotion strategy is particularly inspiring for microrobotic pick-and-place applications for which robust and tunable adhesion mechanism is needed.

Maryam TADAYON

Maryam is a postdoctoral researcher in Max Planck Institute (MPI) of Colloids and Interfaces in Potsdam, Germany. Having the background in Materials Science and Engineering in her Bachelors and Masters from Shiraz University, Iran, Maryam was granted by Singapore International Graduate Award (SINGA scholarship) to pursue her PhD in Nanyang Technological University in Singapore under Prof. Ali Miserez's supervision. She received her doctoral degree from Materials Science and Engineering departments in 2016 and mainly on the mechanical and structural characterization of a cuticular spring-like structure in a marine crustacean. She was a postdoc in the same group for few months before joining the "Biological chitin-based tools and sensors" group in the department of biomaterials at the MPI in August 2016. Her research is focused on the structure – properties – function relationships in spider mechanosensors.

Contact: **maryam.tadayon@mpikg.mpg.de**

Materials level characterization of the spider *Cupiennius salei* metatarsal lyriform organ

The metatarsal lyriform organ of the Central American wandering spider *Cupiennius salei* is its most sensitive vibration detector. It is able to sense a wide range of vibration stimuli over four orders of magnitude in frequency between at least as low as 0.1 Hz and several kilohertz. The transmission of the vibrations to the slit organ is controlled by a cuticular pad in front of it. We have mapped the mechanism of high-frequency stimulus transfer (above *ca* 40 Hz) to the viscoelastic properties of the pad's epicuticle, while it low-frequency stimuli (less than 40 Hz) are transmitted via the pad's bulk. We used a variety of experimental techniques, such as X-ray micro-computed tomography for three-dimensional imaging, X-ray scattering for structural analysis, and atomic force microscopy and scanning electron microscopy for surface imaging. The mechanical properties were investigated using scanning acoustic microscopy and nanoindentation in hydrated state. Unraveling the structural arrangement in such specialized structures may provide conceptual ideas for the design of new materials capable of controlling a technical sensor's specificity and selectivity, which is so typical of biological sensors.

Walter FEDERLE

Walter Federle is a Reader in Comparative Biomechanics at the Department of Zoology, University of Cambridge, UK. Following his Diploma in Biology he obtained his PhD in 1998 from the University of Würzburg, Germany. He was a Postdoctoral Scholar at Harvard University, Cambridge, USA, and the University of California, Berkeley, USA, as well as at the University of Würzburg. Since joining the Department of Zoology at the University of Cambridge in 2005, his research has focused on insect ecology and animal biomechanics as well as on the biophysics of biological adhesion.

Contact: **wf222@cam.ac.uk**

Walking on the ceiling: biomechanics of surface adhesion in insects

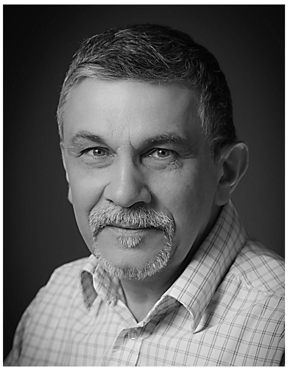
The ability of many insects, spiders and vertebrates to walk on the ceiling has fascinated biologists for centuries. Animal attachment devices have recently attracted renewed attention, as they outperform man-made adhesives and provide promising models for biomimetics.

During locomotion, foot adhesive structures can rapidly switch between firm attachment and detachment. Across all climbing animals, adhesion can be controlled by shear forces: pads stick when pulled towards the body but detach when pushed. Adhesion sharply increases for pull-off angles below ~30°, unexplained by peeling theory or changes in contact area. Instead, a key contribution may come from pad sliding, which thins out the fluid layer in the contact zone, thereby enhancing adhesion.

Many climbing and jumping insects also use their feet for pushing, against the normal direction-dependence of adhesive pads. They achieve this by engaging distinct "heel pads" which are not specialized for high adhesion but for strong friction forces when the foot is pressed against the substrate.

Adhesive structures are very soft, allowing insects to climb on most natural rough surfaces. However, many plants have developed insect-repellent surfaces which are slippery by wax crystals or lubricating films. Some insects have evolved striking counter-adaptations for climbing safely on slippery plants.

Second session: neuromorphic computing



Christian GAMRAT

Christian Gamrat received a degree in electrical engineering from the Université Joseph Fourier, Grenoble, France, in 1979 and a degree in information processing from the Ecole Nationale Supérieure d'électronique et de Radioélectricité, Grenoble, France, in 1993.
In 1981, he started his career at CEA, Grenoble, France, on the design of high-speed data acquisition systems for solid-state and nuclear physics experiments. He became involved in the study and design of neural networks computing machines in 1987, and led the team for the MIND-1024 neurocomputer project. In 1994 he joined the Parallel Computing Architecture Lab, CEA, near Paris, France, where he finalized the development of the SYMPHONIE embedded massively parallel computer for use on board military fighter aircraft. In 1997, he started a research on reconfigurable computing, and in 2003, he initiated a new research group on novel computing architectures aimed at nanotechnologies. Since 2010 and as of today he is CEA Fellow in the field of advanced computing architectures and chief scientist of the "Design, architecture and embedded software" division at CEA LIST, Gif-sur-Yvette, France.

Contact: **christian.gamrat@cea.fr**

From silkworms to bugs: Information processing toward new paradigms

In this talk, we will present the current trends toward new information processing paradigms with a particular focus on neuromorphic and cognitive computing. We will first give an overview of the strength and weaknesses of today's digital computers: how they came about and what are their limitations. We will then discuss possible ways toward the future of computing. In particular, we will see how novel nanotechnologies can contribute to better implementing future information processing systems and how bio-inspiration can give a new momentum to the architecture of future information processing systems. We will present new integrated circuits built around the concept of Deep Neural Network and their potential applications. Finally, we will discuss on the future of computers in the context of "Artificial Intelligence".

Sabina SPIGA

Sabina Spiga received the Degree in Physics from the Università di Bologna in 1995 and the PhD in Material Science in 2002 from Università di Milano. She is staff researcher at CNR-IMM–Unit of Agrate Brianza (Italy) since 2004, and she is currently leading a research team developing oxide-based resistive switching non-volatile memories and memristive devices for neuromorphic systems. She has experience in devices physics and electrical testing, synthesis of advanced materials and nanostructuring techniques for nanodevices. She is currently principal investigator for CNR of the European project-Horizo2020 NeuRAM^3-*NEUral computing aRchitectures in Advanced Monolithic 3D-VLSI nano-technologies* (2016-2018), and since 2014 she is also member of the Management Committee for Italy of the COST Action ICT 1401-"*Memristors-Devices, Models, Circuits, Systems and Applications*". S. Spiga is co-author of more than 100 publications on peer reviewed journals and proceedings, and she organized several symposia and workshops at international level.

Contact: **sabina.spiga@mdm.imm.cnr.it**

Memristive devices for brain-inspired computing: From materials and devices to applications

Memristive systems represent a large class of emerging nanoscaled devices which exploit various physical mechanisms to achieve a controlled state-dependent and persistent conductance variation upon electrical stimuli. Most of the devices have a simple structure where an active organic or inorganic thin layer (e.g. an oxide as in our work) is sandwiched between two metal films and can be nanoscaled down to few nanometers. Memristive devices are today of large interested since they can be used to reproduce bio-inspired systems: for example they can act as dispersed memory elements mimicking the role of synapses in the nervous systems, or as stochastic and non-linear elements of neuronal units. Therefore, they can be used as new building blocks for brain-inspired computing technologies also thanks to their ease of integration within the processes of electronic industry. In this talk, I will present our work towards the development of metal/oxide/metal memristive electronic synapses, their characterization upon train of electrical stimuli and the demonstration of a spike timing dependent mechanisms for the update of the conductance values. Finally, I will show preliminary steps towards the realization of a bio-inspired spiking neural networks (SNNs) able to perform image recognition tasks.

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Marc DURANTON

Dr. Marc Duranton is a member of the Research and Technology Department of CEA (French Atomic Energy Commission). He previously spent more than 23 years in Philips and Philips Semiconductors where he worked on several video coprocessors for the VLIW processor TriMedia and for various Nexperia platforms. In NXP Semiconductors, he led the Ne-XVP project that targeted the design of the hardware and software of a multi-core processor for real-time applications and for consumer video processing. He also led the architecture of the family of L-Neuro chips, digital processors using artificial neural networks techniques. His interests include parallel architectures for high performance and real-time processing, Deep Learning, cognitive systems and emerging paradigms for computing systems, models of computation and communication with time guaranties, compiler technology. He has published more than 35 patents and several book chapters and he is in charge of the HiPEAC Vision (https://www.hipeac.net/publications/vision/).

Contact: **marc.duranton@cea.fr**

How bio-inspiration lead to the new hype on Artificial Intelligence

There is a high hype today about Deep Learning and its applications. This technology originated from the 50's from a simplification of the observations done by neurophysiologists and vision specialists that tried to understand how the neurons interact with each other and how the brain is structured for vision. This talk will come back to the history of the connectionist approach and will show how bio-inspiration lead to a new approach in computing science.

Eric MÜLLER

Eric Müller received his Ph.D. degree in physics from Heidelberg University, Germany, in 2014. He is a postdoctoral researcher at the Kirchhoff-Institute for Physics in Heidelberg, and directs software development in the Electronic Visions group. He started working on neuromorphic hardware in 2007 and has been working on the "Spikey", "BrainScaleS" and group's latest prototype microchips. His research interests focus on applications for neuromorphic hardware systems and, in particular, information processing in closed-loop environments.

Contact: **mueller@kip.uni-heidelberg.de**

Simulating without a computer - Physical models of neural circuits

The brain is a universe of 100 billion cells interacting through a constantly changing network of 1000 trillion synaptic connections. It runs on a power budget of 20 Watts and carries a rather complete model of our physical world. Understanding fundamental principles of the brain is among the key challenges for science. Traditional simulation approaches are mostly hindered by a huge energy gap of 14 orders of magnitude between supercomputer simulations and biological reality. In the lecture, I will discuss an approach to build a physical model of the brain as a tool for experimental tests of theories that attempt to describe the storage and processing of information in the brain.

Daniel ROBERT

Daniel Robert studied sensory biology at the University of Basel Switzerland (PhD). He enjoyed postdoctoral fellowships in Odense, Denmark and at Cornell University, USA where he gathered experience in the sensory ecology, biophysics and evolution of sensory systems. He was a research professorial fellow at the University of Zurich, awarded by the Swiss Science Foundation and the Schering Fellowship at the Institute of Advanced Study in Berlin. Since 2003, he is a professor of bionanoscience at the School of Biological Sciences at the University of Bristol. In 2008, he was awarded a Royal Society Wolfson Research Merit Award. His investigations of insects auditory biophysics of hearing have contributed fundamental insights into nanoscale biomechanics. Along with co-workers, he discovered the third principle of directional hearing in small parasitoid Ormia flies, prompting the development of bio-inspired microphones. Other contributions include revealing active auditory mechanics in invertebrates and nanoscale neuronal motility. Recently, he and his group have unveiled the capacity of bumblebees to detect and learn about weak electric fields.

Contact: **d.robert@bristol.ac.uk**

The bee, the flower and the Coulomb force: towards an electric ecology of pollination

Flowers and bees have a fascinating co-evolutionary history, working together to exchange nutritious nectar for pollination services. Bee-flower interactions rely on vision, olfaction, humidity sensing and touch. Yet, recent evidence has revealed a rather unconventional interaction - the generation and detection of weak electric fields. Bees can detect and learn about the weak electric field arising between themselves and flowers. This electric field arises as a result of a Coulomb interaction between a positively charged bee and a negatively charged flower, against the background of the atmospheric potential gradient. Potentially interesting for bio-inspired sensor technology, a putative mechanism for electroreception in bees and possibly insects will be presented and discussed in an electric ecological context.

James WINDMILL

Prof James Windmill is an engineer with nearly 20 years research experience. His formal degree and PhD training was electronics engineering. After his PhD Prof Windmill joined the School of Biological Sciences, University of Bristol, where his work concentrated on exploring the nanoscale mechanics of insect auditory systems using engineering techniques. In 2008 he joined the University of Strathclyde as a junior academic in the Department of Electronic and Electrical Engineering. At Strathclyde he has built up a large team of researchers, helped in part by the award of an ERC Consolidator Grant in 2014. In 2017 he was promoted to full professor at Strathclyde. As a senior member of Strathclyde's Centre for Ultrasonic Engineering, his main research interest is combining his ongoing exploration into insect hearing with the conception, development and application of new biologically inspired transducer and sensor systems.

Contact: **james.windmill@strath.ac.uk**

Biologically Inspired Acoustic Sensors – From Insect Ear to 3D Device

Taking inspiration from insect ears to develop an acoustic device is not new. Ongoing research to take inspiration from the highly directional, sub-wavelength *Ormia* fly's ear to produce miniature directional microphones is a well-known example. Since the 1990's researchers have tried to implement *Ormia* based micro-electro-mechanical systems devices, typically using standard silicon or similar microfabrication. Much of this time has been spent trying to circumvent the fact that *Ormia* evolved to hear one specific frequency, that of a calling cricket, and so is not a broadband system as you would require for an audio microphone. Further, building a silicon system inspired by the mechanics of insect cuticle leads to various compromises.

This talk will discuss ongoing work in Strathclyde on silicon microfabrication of acoustic devices inspired by the *Ormia* system. It will also describe research by the Strathclyde team into the application of 3D polymer microfabrication for the development of bio-inspired acoustic devices. This will include work to produce wide bandwidth ultrasonic devices, passive mechanical frequency analyzers, and the recent progress made to 3D print a complete miniature microphone system. Finally, research into the use of active feedback in acoustic systems, inspired by auditory hearing mechanisms, will be presented.

Claire RIND

Dr F Claire Rind is a Reader in Invertebrate Neurobiology at the Institute of Neuroscience/Centre for Behaviour and Evolution at the Newcastle University, United Kingdom.

Contact: **claire.rind@ncl.ac.uk**

Raising the alarm: a bioinspired circuit for looming detection

How does circuit architecture in the visual system permit the rapid detection of looming stimuli in a field of view? Our labs have for years studied object detection in the visual system of the locust. Looming specific detectors have been identified in the visual systems of many species: *Drosophila*, pigeon, frog, fish and mouse. The first and best understood are the Lobula Giant Movement Detectors, LGMD 1 and 2, in the locust visual system. The locust LGMDs are able to detect the looming image of a colliding object and, within minutes of the locust's hatching, co-ordinate appropriate escape behaviors that enable the locust to escape or hide and survive. My recent focus is on the neurons providing excitatory inputs to the LGMDs in the lobula complex in the locust. They are Trans-medullary afferent (TmA) cells. As both LGMDs are looming detectors we looked at shared features of their inputs and found connections between the input TmA neurons and the LGMDs occur at in astonishingly high numbers: 131,000 to 186,000 and their spatial density the highest described in any nervous system so far. We find one TmA per facet connected with each LGMD, but the signals these convey do not come from just one facet: reciprocal connections amongst the TmAs are the rule, for both LGMDs, with up to six neighbors connected in this way. Adapting a previous Neural Network Model of the LGMD to incorporate these findings gave evidence that inhibitory, reciprocal connections between the input neurons sharpens the LGMD's looming detection, giving a more rapid distinction between objects on a collision course and those merely passing by. In future models this can greatly increase their power to predict collision.

Gijs J.M. KRIJNEN

Prof. dr. ir. Gijs Krijnen’s interests are in bio-inspired transducers, parametric sensing schemes and additive manufacturing (embedded sensing). He has (co-) authored over 100 refereed journal papers, 10 book chapters and 235 conference contributions on a variety of subjects including nonlinear integrated optics, micromechanical sensors and actuators, biomimetic flow and inertial sensors and parametric and nonlinear transduction.
He holds a PhD (cumlaude) fromthe University of Twente, has been a fellow of the Royal Netherlands Academy of Arts and Sciences and was awarded a VICI grant by the Netherlands Organisation for Scientific Research in 2005 for research on bio-inspired flow-sensors (BioEARS). He currently is with the Robotics and Mechatronics group of the University of Twente.

Contact: **gijs.krijnen@utwente.nl**

In Search of Fabrication Tools for Insect-Inspired Transducers

In our work on micro-fabricated hair-sensors, inspired by the flow-sensitive hair-sensors found on crickets, over the years we have made great progress. Initially delivering mediocre performance compared to their natural counter parts they have evolved into capable sensors with flow-velocity thresholds roughly a factor of 30 larger than of their natural equivalents. Due to this disparity, and also instigated by our work on flyhalteres inspired rotation rate sensors and desert locust ear-drum mimicking membrane structures, we have analysed the differences in performance between natural and man-made sensors.We conclude that two major drawbacks of main-stream micro-fabrication are the lack of easily applicable soft materials, as well as the limitations imposed by photolithography based fabrication with respect to freeform3D shaping of structures.
Currently we are targeting additivemanufacturing for bio-inspired sensor systems and in this contribution we report on initial results of these activities.

Fourth session: bio-inspiration: new techniques and approaches

Thomas ALAVA

Thomas Alava graduated in micro and nanotechnologies for integrated systems, with a master's degree jointly delivered by Politecnico of Turin (Italy), Ecole polytechnique fédérale of Lausanne (Switzerland) and Institut National Polytechnique of Grenoble (France) in 2006. He received his Ph.D. from University of Toulouse in 2010 for his works on resonant MEMS systems for biological detection. Between 2010 and 2013, he joined Professor Harold Craighead research group at Cornell University as a postdoctoral associate. In 2013, he joined the microsensors laboratory at LETI as a full-time researcher. He currently works on various sensors for environmental and biochemical analysis applications and leads the global effort on microsensors for environnemental monitoring at the Microsensors Laboratory within LETI.

Contact: **thomas.alava@cea.fr**

Yves FOUILLET

Yves Fouillet received the "Agregation de mecanique" in 1987. He received his PhD degree from Institut National Polytechnique de Grenoble, France, in 1992 (Numerical simulation of compressible shear flow). In 1992, he joined CEA-LETI for Micro-Electro-Mechanical-Systems (Mems) development and was in charge of projects concerning micro-sensors or micro-actuators. Since 1998, he has worked on microfluidic in DTBS-labs (Mirco-Technologies for Biology and Health Division). His current research interests include fluid control in lab on a chip application, microfluidic design and architecture, liquid handling by electrowetting (digital microfluidic), Mems micropumps and microvalves, stretchable microfluidic.

Contact: **yves.fouillet@cea.fr**

Opportunities offered by the biomimetic approach for the development of microsensors and microfluidic circuits and vice versa

Microfluidic and microsensor refer to technologies using microsystems to manipulate small amounts of fluids and to detect bio-chemical compounds within them. The behavior of fluids at the microscale (low Reynolds numbers, confinement, interfaces, diffusion…) differ from "macroworld" behavior. Especially, interfacial forces become predominant, thus many microsystems are based on capillarity forces such as droplet based microfluidics. Likewise, numerous systems are fabricated in soft material and deformability of the fluidic networks is designed in order to actuate the fluid. Similar mechanisms can be observed in nature. More generally, microfluidic and microsensor technologies can benefit from the observation and the understanding of how the nature works at microscale (blood vessel, fluidic in leaf etc…). Indeed nature performances often surpass those of microsystems (animal olfaction, tactile plant...). In turn, these new technologies may give useful tools for researchers in biology. In this talk, different microfluidic and sensors technologies developed in our lab for biological and/or biomedical applications will be presented. Physical aspects and design consequences of working at the microscale will be discussed regarding the opportunities offered by the biomimetic approach.

Jérôme CASAS

Jérôme Casas obtained his Ph.D. from the ETH Zurich in 1989. After a short post-doc at Strathclyde University (Glasgow) he was hired assistant professor at the ETH Zurich. He migrated to the US in 1993, working at the University of California, Santa Barbara, and returned to Europe as full Professor in 1995 in Tours. One notable feature of his approach is the blending of natural history with both state-of-the-art technology and modeling. His group is composed of applied mathematicians, engineers and biologists. He was awarded the ETH medal for a thesis in the University's top 10%, was nominated both junior and subsequently senior member of the IUF (*Institut Universitaire Français*) and was the Distinguished Invited Professor of the Center for Insect Science at the University of Arizona in Tucson in 2006. Jérôme Casas holds the chair in bioinspired technology at CEA-Leti in Grenoble.

Contact: **casas@univ-tours.fr**

The contribution of physical ecology to insect-inspired micro-technology

After a short dash in the definition of physical ecology and a brief survey of other current research in my group on physical ecology of insects, I will dwell into the hair-based flow sensing of insects and report on our journey, with collaborators, in the implementation in a flow sensing MEMS and flow camera. While the technological implementation and difficulties of the biomimetic approach will be highlighted in the talk of Prof. G. Krijnen, I will pay special attention to the biological understanding which "co-evolved" during the continuous interaction with engineers. A deep understanding of biological functions and of the reasons for the top performance sometimes seen in biological sensors and actuators – which is driving the desire for a biomimetic approach - can be achieved only when the context in which these functions operate has been mastered. For insects, this means understanding their daily life and outside the lab, even if most of our time is spent dissecting the processes in a highly controlled laboratory environment.

Thomas VAN DE KAMP

Thomas van de Kamp is an entomologist working at the Laboratory for Applications of Synchrotron Radiation (LAS) of Karlsruhe Institute of Technology (KIT), Germany. Focus of his research is insect functional morphology and evolutionary biology, covering both extant and fossil specimens. Further, he contributes to the development of X-ray imaging techniques to study arthropod morphology and morphodynamics. He is responsible for biological imaging at KIT's Synchrotron Radiation Facility, head of the associated BioLab, and project leader of the research area "In-house research Life Sciences". He is member of the interdisciplinary ASTOR and NOVA collaborations – two leading analysis platforms of arthropod morphology studies based on large scale photon facilities and cloud technology.

Contact: **thomas.vandekamp@kit.edu**

Fast X-ray imaging and semi-automated analysis of insects

Synchrotron-based X-ray imaging became an established method for the examination of small animals and X-ray microtomography in particular is an important tool for non-destructive 3D imaging of insects. The imaging station of KIT's Synchrotron Radiation Facility is optimized for fast X-ray imaging and includes a high speed detector system and a sample change robot. The setup facilitates high throughput experiments and digitization of large numbers of insects in a single experiment.

Despite faster acquisition times, image analysis is often still time-consuming. Especially the manual segmentation of tomographic volumes is extensive and its results often show unwanted artifacts. By employing semi-automated tools, however, image analysis can be substantially accelerated and improved.

Recent experiments demonstrate the value of fast X-ray imaging for the digitization and 3D analysis of insects. Interactive 3D reconstructions based on tomography data allowed analyzing motion systems and the elytra of beetles proved to be interesting role models for biomimetic design. When studying 30-million-year old fossil insects from the fissure fillings of the Quercy region in France, we found that also insects from non-amber collections may contain detailed internal anatomical characters, thus allowing species descriptions and phylogenetic analyses as done for extant specimens.

Pascal BRIOIST

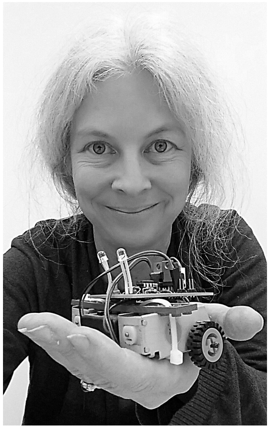
Pascal Brioist is Professor in History and researcher at the CESR since 1994. Specialized in cultural history and history of England (PhD of the European University Institute of Florence in 1992), his work has dealt mainly with techniques and sciences history for numerous years, especially through the study of Leonardo de Vinci. Co-author with Hervé Drévillon and Pierre Serna of a book about the history of the sword violence, *Croiser le Fer* (2002), he has also written two books intended to Capes and Agregation examinations: *La Renaissance 1470-1570* and *Les Européens et les Espaces maritimes au XVIII^{e} siècle*. He has also published numerous books about Léonard de Vinci : *Da Vinci Touch* (2014), work dedicated to blind people, *Léonard de Vinci, homme de guerre* (2013), *Léonard de Vinci : Arts, sciences et techniques* (2011) or *Léonard de Vinci, ingénieur et savant* (2008). He has organized three exhibitions about Leonardo da Vinci (Rombas, Nancy and Romorantin) and in 2015 he staged in Amboise and Romorantin a Renaissance pageant commemorating Marignan. Pascal Brioist has also created two web series, one about Marignan 2015 and another one "On the tracks of Leonardo da Vinci".

Contact: **pascal.brioist@univ-tours.fr**

Leonardo da Vinci and bio-inspiration

As such bio inspiration is not totally an invention of our present; in the Renaissance, engineers looked at natural shapes and were convinced that mimicking nature offered technical solutions to their own problems. Around 1580, Mathew Baker, for instance, a Tudor shipbuilder, produced the drawing of a galleon hull about to transform itself into a giant fish and Maximilian armours, with their decorative fluting, offered strange similarities with the belly of a Rhinoceros drawn by Albrecht Dürer. Nevertheless Leonardo da Vinci was certainly the most careful observer of nature of his time and as a result, it has become a common evidence to assess that he was using biomimetism as a way to find inspiration. Recently, for an exhibition at the *Cité des Sciences* in La Villette, scientists claimed that Leonardo was some kind of precursor for bionics. The exhibition displayed different kinds of animatronics like an elephant trump, a robot-gecko, a robot-lobster or a robot-insect and showed posters about the property of squale-skin or bee-hives alveolas. The intellectual process of imitation adopted by Leonardo da Vinci was however not fully investigated. This paper proposes to get deeper into this enquiry looking especially at the imitation of birds, insects and flying fishes to study the possibilities of flying available to humans.

Fifth session: locomotion



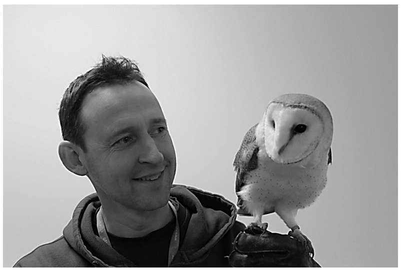
Barbara WEBB

Barbara Webb completed a BSc in Psychology at the University of Sydney then a PhD in Artificial Intelligence at the University of Edinburgh. Her PhD research on building a robot model of cricket sound localization was featured in Scientific American. She held lectureships at the University of Nottingham and University of Stirling before returning to a faculty position in the School of Informatics at Edinburgh in 2003. She was appointed to a personal chair as Professor of Biorobotics in 2010.

Contact: **bwebb@inf.ed.ac.uk**

How insects exploit physics for efficient locomotion and navigation

One way in which technology can learn from insects is to appreciate the ways in which their evolution has found clever physical solutions to simplify behavioural control problems. I will discuss two particular examples we have recently investigated. By visual filtering for ultraviolet and polarised light, combined with a wide field of view, ants are particularly sensitive to the boundary between sky and ground. We have shown this approach can be highly effective for robust selflocalisation under a range of natural conditions. The passive mechanics of the soft body of a maggot (a larval fly) support the maintenance of travelling waves and produce spontaneous bending. The addition of minimal local feedback control circuits can produce a system capable of exploration and steering to a sensory source. Both examples have the potential to be applied in developing novel microtechnology.



Richard BOMPHREY

Richard Bomphrey joined the RVC in 2013. He read biological sciences at the University of Exeter followed by a DPhil (PhD) in biomechanics at the University of Oxford. After postdoctoral positions in Oxford and the Department of Mechanical Engineering at the University of Bath, he was awarded an EPSRC Fellowship held in Oxford's Department of Zoology, during which he moved his group to the RVC.

Richard Bomphrey uses biomechanics as a tool to investigate evolutionary biology and, specifically, how the physical environment determines the morphology of flying insects and birds. He has an active interest in the neurobiological mechanisms that insects use to stay aloft, including flow-sensing and load-sensing, and the phenomenon of optic flow and how that can be used to control flight. He also has an interest in internal flows and the haemodynamics of abdominal aortic aneurysms.

Contact: **rbomphrey@rvc.ac.uk**

Aerial sense-and-avoid technology based on a nocturnal mosquito model

Flying animals must perceive and avoid obstacles, often in environments deprived of sensory cues. In particular, nocturnal mosquitoes must divert away from surfaces or land gently when visual cues are unavailable, indicating a short-range, non-visual collision avoidance mechanism. This is likely to be mediated by mechanosensory feedback, with mosquitoes detecting and reacting to modulations of their own induced aerodynamic and acoustic fields as they enter ground- or wall-effect. We investigated the sensory information available for sensing obstacles through computational fluid dynamics and aeroacoustic simulations of low-altitude and near-wall mosquito flight. Our simulations are based on detailed wing kinematics extracted from high-speed recordings of free flying *Culex quinquefasciatus* mosquitoes. Areas of relative pressure changes associated with close proximity to the ground and wall planes could provide crucial information to the flight controller: a mechanism we term 'aerodynamic imaging'. Using computational aeroacoustics, we also calculated sound pressure levels around the mosquito in the near and far fields. The simulations suggest a strong directionality in the magnitude and dominant frequencies of the acoustic signature that could be encoded to detect surface proximity and directional vectors, or for intraspecific communication. Finally, we built and flew a robotic prototype carrying the bio-inspired sensor.



Ramiro GODOY-DIANA

Dr. Godoy-Diana is a CNRS research scientist at the *Physique et Mécanique des Milieux Hétérogènes* laboratory (PMMH) at ESPCI in Paris, France. Physical engineer from the Tec de Monterrey (México, 1994), he holds a Master in Physics from the UNAM (México, 1999) and a PhD in fluid dynamics from *École Polytechnique* (France, 2004). His experimental fluid dynamics work has included research on ocean wave energy, geophysical fluid dynamics, wake instabilities, fluid-structure interaction and bio-inspired propulsion. He co-heads the Biomimetics and fluid-structure interaction group at PMMH.

Contact: **ramiro@pmmh.espci.fr**

Insect-inspired flapping wings

Insect wings impress by their versatility and have been a recurrent source of inspiration for engineering devices. I will discuss our recent work on flapping wings inspired from insects considering two aspects: On the one hand the non-trivial mechanisms that rule the performance of a flexible wing, in terms of aerodynamic force production; and on the other hand the conception of simplified models to study the biomechanical consequences of wing venation in insects.

Stéphane VIOLLET

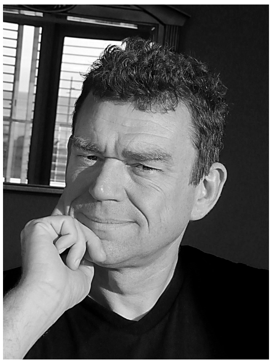
Stéphane VIOLLET, 45, is a CNRS researcher director at the Institute of Movement Sciences, Aix-Marseille Université and head of the Biorobotics team. He received the master's degree in control engineering from the University of Bordeaux 1, France, and the Ph.D. degree from the National Polytechnic Institute, Grenoble, France, in September 2001. He obtained a CNRS permanent position in 2003. His interests include sensory-motor reflexes in flies, retinal micro- movements and bio-inspired control strategies for aerial robots. He is the leader of the development of autonomous robots and innovative visual sensors for robotics (artificial compound eye, hyperacute sensors and artificial retinas) and involved in several national and european projects on these topics. He is the author of more than 60 publications, 8 patents and recipient of several best paper awards and nominations (Journal La Recherche in 2005, IEEE ICAR, IEEE Sensors and Living Machines conf.).

Contact: **stephane.viollet@univ-amu.fr**

From fly to robot and vice versa

The Biorobotic approach is a meeting point where robotics and neuroscience are used to try to explain the behaviour of animals, especially winged insects (fly, bee, wasp...) and to model the processing of the sensory modalities at work in these outstanding animals. The neurophysiology is also used to better understand the sensorimotor reflexes at work in insects. The robots are a kind of embodiment of this insect-based knowledge to validate our models. Recent studies carried out at our laboratory focused on the graviception in fly, i.e., the ability of the animal to assess its orientation with respect to gravity. Would it be possible that a fly, able to achieve exquisite manoeuvres, could not have any clue of its body tilt with respect to gravity during flight? Could future robotic applications could take a great benefit of this lack of graviception? Several fly-inspired visuals sensors as well as bio-inspired robots will be presented in this talk.

Sixth session: towards the future



Paul VERSCHURE

Paul Verschure is Catalan Institute of Advanced Studies (ICREA) Research Professor, Director of the Center for Autonomous Systems and Neurorobotics at Universitat Pompeu Fabra and Director of the neuro-engineering programme at the Institute for Bioengineering of Catalunya where he runs the Synthetic Perceptive, Emotive and Cognitive Systems (SPECS) Laboratory (specs.upf.edu). He is founder/CEO of Eodyne Systems S.L. (Eodyne.com), which is commercializing advanced science grounded neurorehabilitation and education technologies.
Paul is founder/Chairman of the Future Memory Foundation (futurememoryfoundation.org) which aims at supporting the development of new tools and paradigms for the conservation, presentation, and education of the history of the Holocaust and Nazi crimes. He received his MA and Ph.D. in Psychology, and Paul's scientific aim is to find a unified theory of mind and brain using synthetic methods and to apply it to the quality of life enhancing technologies. His theory of mind and brain, Distributed Adaptive Control, has been generalized to a range of brain structures and robotic systems and has laid the foundation for a novel neurorehabilitation approach called the Rehabilitation Gaming System.

Contact: **pverschure@ibecbarcelona.eu**

Towards a system level model of the insect nervous system

Traditionally the design principles of insect brains have been seen as distinctly different from those governing the mammalian brain. This notion has recently been questioned by the demonstration that invertebrate and mammalian brains show distinct homologues as defined by distinct genetic and anatomical signatures (Strausfeld & Hirth 2013). Based on this fundamental insight I will explore the theoretical consequences of this important observation. Starting from the Distributed Adaptive Control theory of mind and brain. Starting from the view of developing an architecture of the brain, I will identify distinct architectural features of mammalian and invertebrate brains that would provide a good starting point to validate the notion of homologues. Here I will emphasize the view that at the heart of an architecture stand principles allow to resolve distinct trade-offs that support survival such as speed, robustness and bandwidth. I will analyse specific examples from our own work on robot based models of perception, memory, motor learning and action selection.

Metin SITTI

Metin Sitti received the BSc and MSc degrees in electrical and electronics engineering from Bogazici University, Istanbul, Turkey, in 1992 and 1994, respectively, and the PhD degree in electrical engineering from the University of Tokyo, Tokyo, Japan, in 1999. He was a research scientist at UC Berkeley during 1999-2002. He is currently a director in Max-Planck Institute for Intelligent Systems, Stuttgart, Germany and a professor in Department of Mechanical Engineering and Robotics Institute at Carnegie Mellon University, Pittsburgh, USA. His research interests include small-scale mobile robotics, advanced functional micro/nanomaterials, medical soft robotics, and programmable self-assembly. He is an IEEE Fellow. He received the SPIE Nanoengineering Pioneer Award in 2011 and NSF CAREER Award in 2005. He received many best paper and video awards in major robotics and adhesion conferences. He is the editor-in-chief of Journal of Micro-Bio Robotics.

Contact: **sitti@is.mpg.de**

Insect-inspired attachment materials and small-scale mobile robots

Insects have developed very robust and efficient attachment mechanisms on a wide range of complex surfaces for climbing and jumping. Beetles use micron-scale foot-hairs with a liquid coating to attach and detach on complex surfaces. We study dock beetles to understand how they clean their sticky foot-hairs while they are climbing, when they are contaminated with particles. Also, we fabricate synthetic micro-fiber adhesives to create new reversible attachment materials, and demonstrate their use in small-scale climbing robots and robotic soft grippers. As the second study, we work on crickets to understand how they can robustly jump on different complex surfaces, where slip can occur. Cricket's feet have both soft adhesive pads and claws, which are passively coupled to their compliant foot mechanisms for robust friction during jumping. Experimenting their foot slip behavior on a variety of surfaces while jumping, we get inspiration from their foot design and attachment methods and build a robotic foot with similar principle. The robot can jump more than 3.5 meters using such robust foot on a variety of surfaces. Finally, I will mention briefly about our insect-inspired flying robot studies, where we design a flapping-wing based flying robot using the similar aerodynamic forces like hummingbirds and flying insects. Design and control methods and current challenges of such robots are reported.

Scientific programme

Wednesday 29th November, 2017

7:00 pm | Wine & Cheese cocktail

Thursday 30th November, 2017

8:30 am | Welcome coffee

8:45 am

Official opening

Benoist PIERRE, Director of the CESR and *Intelligence des Patrimoines* programme (University of Tours - CNRS)

9:00 am

Scientific opening

Jérôme CASAS, Professor (University of Tours - CNRS – Institut Universitaire de France)
Barbara DE SALVO, Scientific Director of CEA – Leti Grenoble, France

First session: material sciences and adhesion

9:15 am – 9:40 am

Stanislav GORB (University of Kiel - Zoological Institute / Germany)
Biologically inspired structure-based adhesives: Where are we now?

9:40 am – 10:05 am

Tristan GILET (University of Liège / Belgium)
The capillary adhesion of dock beetle tarsi: a source of inspiration for microrobotic pick-and-place

10:05 am – 10:30 am

Maryam TADAYON (Max Planck Institute of Colloids and Interfaces / Germany)
Materials level characterization of the spider Cupiennius salei metatarsal lyriform organ in relation to its dual-functionality as a proprioceptor and as an exteroceptors

10:30 am – 10:55 am

Walter FEDERLE (University of Cambridge - Department of Zoology / United Kingdom)
Walking on the ceiling: biomechanics of surface adhesion in insects

10:55 am – 11:20 am | **Coffee break**

Second session: neuromorphic computing

11:20 am – 11:45 am

Christian GAMRAT (CEA - List / France)
From silkworms to bugs: information processing toward new paradigms

11:45 am – 12:10 pm

Sabina SPIGA (CNR Institute for Microelectronics and Microsystems / Italy)
Memristive devices for brain-inspired computing: From materials and devices to applications

12:10 pm – 12:35 pm

Marc DURANTON (CEA - List / France)
How bio-inspiration lead to the new hype on Artificial Intelligence

12:35 pm – 1:00 pm

Eric MÜLLER (Universität Heidelberg - Kirchhoff-Institute for Physics / Germany)
Simulating without a computer - Physical models of neural circuits

1:00 am - 2:30 pm | **Lunch**

Third session: sensors

2:30 pm – 2:55 pm

Daniel ROBERT (University of Bristol / United Kingdom)
The bee, the flower and the Coulomb force: towards an electric ecology of pollination

2:55 pm – 3:20 pm

James WINDMILL (University of Strathclyde - Electronic and Electrical Engineering/ United Kingdom)
Biologically Inspired Acoustic Sensors – From Insect Ear to 3D Device

3:20 pm – 3:45 pm

Claire RIND (Newcastle University - Institute of Neuroscience / United Kingdom)
Raising the alarm: a bioinspired circuit for looming detection

3:45 pm – 4:10 pm

Gijs KRIJNEN (University of Twente / Netherlands)
In Search of Fabrication Tools for Insect-Inspired Transducers

4:10 pm – 4:35 pm | **Coffee break**

Fourth session: bio-inspiration: new techniques and approaches

4:35 pm – 5:00 pm

Thomas AVALA & Yves FOUILLET (CEA - Leti / France)
Opportunities offered by the biomimetic approach for the development of microsensors and microfluidic circuits and vice versa

5:00 pm – 5:25 pm

Jérôme CASAS (University of Tours/CNRS – IRBI / France)
The contribution of physical ecology to insect-inspired micro-technology

5:25 pm – 5:50 pm

Thomas VAN DE KAMP (Karlsruhe Institute of Technology / Germany)
Fast X-ray imaging and semi-automated analysis of insects

Bio-inspiration: back to the origins

5:50 am – 6:35 pm

Pascal BRIOIST (University of Tours/CNRS – CESR / France)
Leonardo da Vinci and bio-inspiration



Friday 1st December, 2017

8:30 am | **Welcome coffee**

Fifth session: locomotion

8:50 am – 9:15 am

Barbara WEBB (University of Edinburgh - Informatics Forum / United Kingdom)
How insects exploit physics for efficient locomotion and navigation

9:15 am – 9:40 am

Richard BOMPHREY (Royal Veterinary College, University of London - Structure and Motion Laboratory / United Kingdom)
Aerial sense-and-avoid technology based on a nocturnal mosquito model

9:40 am – 10:05 am

Ramiro GODOY-DIANA (ESPCI Paris - Physique et Mécanique des Milieux Hétérogènes / France)
Insect-inspired flapping wings

10:05 am – 10:30 am

Stéphane VIOLLET (Institut des Sciences du Mouvement / France)
From fly to robot and vice versa

10:30 am – 10:55 am | **Coffee break**

Sixth session: towards the future

10:55 am – 11:20 am

Paul VERSCHURE (Pompeu Fabra University - Synthetic Perceptive, Emotive and Cognitive Systems / Spain)
Towards a system level model of the insect nervous system

11:20 am – 11:45 am

Metin SITTI (Max Planck Institute for Intelligent Systems / Germany)
Insect-inspired attachment materials and small-scale mobile robots

11:45 pm – 12:30 pm

European project discussion