2nd International Workshop

Insect bio-inspired microtechnology



Thursday **21st November** & Friday **22nd November 2019**

MINATEC Campus | Grenoble
3 parvis Louis Néel - 38054 Grenoble cedex 9, France

Organized by

Jérôme CASAS, University of Tours & CEA-Leti Carnot chair in bio-inspired technologies
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Steering and Scientific committee

Jérôme CASAS
Professor, University of Tours & CEA-Leti Carnot chair of Excellence in bio-inspired technologies

Susana BONNETIER
Carnot Program Manager at CEA-Leti of Grenoble, France

Thomas ALAVA
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Summary



Introduction

Bio-inspiration is taking off big time, worldwide: from hydrophobic surfaces, structural colors, neuromophic computing to a wild array of bio-inspired robots, just to name a few. Whole research institutes, from China to Harvard, are now harboring entire teams that would place bio-inspiration as the core moto of their science developments. With millions of species, insects are in this respect a cornucopia for bioinspiration. The miniaturization of the nuts and bolts within insects, combined with speed and precision of control, is furthermore a marvel. Beyond their sheer number which implies a multitude of possible models, insects are thus an excellent source of bio-inspired designs because of their size, of the order of the millimeter, which matches in many ways the one of micro- and nano-technological systems. This often promotes system scale approach as a more sound method for the observer.

Following the highly successful workshop in Tours in 2017, we have again collated a series of speeches from international speakers that balances biology, physics and engineering. We believe these works and visions to be of the highest interest to microtechnologists, systems engineers and biologists.

This second international workshop is funded by the CNRS INEE within the RTP (*réseau thématique pluridisciplinaire*) "Bioinspiration", by the CEA-Leti Chair in "Bioinspired microtechnologies", and it is supported by *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) at the University of Tours and supported by the *Région Centre-Val de Loire*.

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. 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. He holds the CEA-Leti Carnot Chair of Excellence in bio-inspired technologies. 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 co-organized the 1st Intl. workshop on insect bio-inspired microtechnologies in November 2017 in Tours (F).

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INSTITUT CARNOT Leti · cnrs · leti ceatech · Intelligence des Patrimoines · IRBI Institut de Recherche sur la Biologie de l'Insecte

Susana BONNETIER

Susana Bonnetier obtained her Bachelor and Master of Science in Mechanical Engineering from MIT with a major in mechanics of materials. Over her 30 career years, she has held various positions in research and industry in the USA and France, covering many areas ranging from R&D, product and process design all the way to product management, sales and marketing. She has a strong understanding of the technological value creation process thanks to her experience as R&D engineer at GE Aircraft Engines and Freescale Semiconductor, Process Engineer and Product, Sales and Market Manager at Saint-Gobain, and Project and common lab manager and International academic collaborations coordinator at CEA-Leti. She is currently the Carnot Program Manager at CEA-Leti (1,800 people) and a member of Leti's scientific directorate, playing a key role in the implementation of the institute's scientific and technological strategy.

CEA-Leti is one of the 30 French Carnot public research institutes, having repeatedly received the distinctive Carnot Label of Excellence from the French government for over 10 years. The Carnot institutes' mission is to create innovation with and for industry, bridging the gap between public research and industrialization. Susana is Vice-President of the Carnot Network and a member of its board of directors and executive committee.

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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 where he pioneered non-covalent functionalization of graphene surfaces for various biological applications and biological sensors. In 2013, he joined the Microsensors laboratory at CEA-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 environmental monitoring at the Microsensors Laboratory within CEA-Leti. He shares a joint effort with Professor Jérôme Casas on understanding and quantifying the key mechanisms that make animal olfaction so powerful and robust.

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Speakers

First session: extracting and moving fluids

Pascal DAMMAN

Pascal Damman received a Ph.D. degree in 1992 about the formation of supramolecular assemblies with helical polymers. After a post-doc in the *Institut Charles Sadron* under the supervision of J.C. Witmann, focused on the epitaxial growth of polymer crystals, he got a tenure position as *chercheur qualifié* of the FNRS in 1995. In 2007, he becomes Professor and head of the InFluX laboratory in the University of Mons. His research interests are related to the emergence of patterns from fluids, solids and granular matter. Within this framework, the fundamental understanding of the mechanics of soft matter and slender objects, i.e., plates, rods, ribbons, shells, appears to be of great value to understand the Biomechanics of living organisms.

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Collection of nectar by bumblebees: How physics of fluid demonstrates the prominent role of tongue's morphology

During evolution, various and sometimes surprising methods have been developed by animals to ingest liquids. Gravity, viscous, capillary, and inertial forces balance to determine the rate and volume of captured fluid. For most insects and other tiny animals, beyond the action of muscles, capillary and viscous forces are dominant. While the viscosity of water is relatively low, plant secretions like nectar can show very high viscosity challenging the food intake strategy of the floral visitors. To solve this problem, some bee species become highly specialized, their tongue being adapted to specific flowers. *Bombus terrestris* in contrast is able to feed on a wide variety of flowers and can thus be considered as a kind of universal nectar catcher. Since plant nectars show highly variable sugar content, *Bombus terrestris* have developed a capture mechanism that works for almost any fluid viscosity. Their tongues are decorated with very elongated papillae forming a hairy coating surrounding a rod-like main stalk. When settled on a flower, *Bombus* rapidly dip their tongue into the inflorescence to catch the highly sought-after nectar. To determine the physical mechanism at the origin of this outstanding ability, the capture dynamics was followed from videos recorded during viscous fluid ingestion. To explain these observations, we designed a physical model of viscous dipping with structured rods. Predictions of the model compared to observations for bees showed that the nectar is not captured with the help of bare viscous drag, as proposed in the Landau–Levich–Derjaguin model, but thanks to the hairy structure that traps the viscous fluid, capillary forces drastically limiting the drainage. Our approach can be transposed to others nectar foragers such as bats and hummingbirds.

Jake SOCHA

Dr. Jake Socha is an associate professor in the Department of Biomedical Engineering and Mechanics at Virginia Tech. He earned a Bachelor of Science degree in physics and biology from Duke University in 1994 and a Ph.D. in biology (with a focus on biomechanics) from the University of Chicago in 2002. After graduate school, he was the Ugo Fano Postdoctoral Fellow at Argonne National Laboratory, studying insect flow systems using synchrotron x-ray imaging at the Advanced Photon Source. His research program at Virginia Tech combines both interests, investigating the biomechanics and functional morphology of flows in and around organisms, specifically flying snakes, frogs, and insects. He received the NSF CAREER Award in 2014. Prior to entering science, he was a member of the Teach for America national teacher corps working in southern Louisiana.

Contact: jjsocha@vt.edu

Biomechanical mechanisms of fluidic pumping in insects

Insects use multiple mechanisms to transport fluids within the body. In this talk, I will discuss our studies of insect respiratory, circulatory, and feeding systems, which integrate a range of methods including synchrotron imaging, material testing, and classical physiological techniques. Insects take advantage of active pressurization as well as passive material properties to deform structures such as tracheae, and use functional compartmentalization to control internal flows. We are using such results from work on beetles, roaches, and grasshoppers as inspiration for new microfluidic devices and modeling, some of which will also be discussed in Yasser Aboelkassem's talk to follow.



Yasser ABOELKASSEM

Yasser Aboelkassem received his B.Sc. in Aerospace Engineering from Cairo University, Egypt and an M.Sc. in Computational Mechanics from Concordia University, Canada. He received another MSc in Applied Mathematics from Virginia Tech. He obtained a Ph.D. in Engineering Science and Mechanics from Virginia Tech. He is currently a research scientist in the Department of Bioengineering at the University of California, San Diego. He promoted this position after he spent two years as a postdoctoral fellow in the Institute for Computational Medicine at Johns Hopkins University. He also spent two years as a research associate in the Department of Biomedical Engineering at Yale University. His research focuses on insect bioinspired microfluidics pumping technology, micro-electrokinetics, microcirculation, fluid transport in the human cardiovascular system, and stochastic multiscale modeling of cardiac muscle biophysics and micromechanics.

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Insect-inspired flow transport model and electrokinetics pumping in microfluidics

Inspired by the rhythmic wall contraction in insect tracheal tubes, we propose three different pumping flow models in a microchannel with attached wall membranes. These membranes are subjected to non-propagative and/or propagative dynamic contractions. In the first pumping model, we show that at least two membranes that operate with time-lag and in "non-propagative" dynamics are required to produce unidirectional flow. In the second model, the results demonstrate that an inelastic channel with a single membrane contraction that operates in a "propagative" mode can work as a micropump. Finally, we study the electrokinetics flow transport of aqueous electrolyte solution coupled with propagative style membrane contraction. An external electric field is employed to study to control the effects of electroosmosis mechanisms on the pumping process in a microchannel by electroosmosis. The results have shown that these derived insect-inspired models can be useful to better understand flow transport in many biological systems, including but not limited to insect respiration, urine flow, and fluid dynamics of duodenum and intestine. Moreover, the present pumping paradigms are relatively easy to fabricate and are expected to be useful in many microfluidics devices and contribute to the next generation of bio-inspired microtechnology.

Second session: colorful ideas

Bodo WILTS

Bodo Wilts is a Group leader at the Adolphe Merkle Institute in Fribourg, Switzerland. Prior to this, he was a postdoctoral research associate in the Cavendish Laboratory at the University of Cambridge. He received his Ph.D. in 2013 from the *Rijksuniversiteit Groningen* in the Netherlands with highest distinctions. His research focuses on the optical function, development, and design of biological photonic structures, bio-inspired functional materials and polymer-templated plasmonic optical metamaterials.

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Functional optical materials in insects

The existence of multifunctional materials in nature, often assembled from a few building blocks that are hierarchically organized in material motifs, are not only enviable adaptation to their life style, but also have long inspired novel technological applications. This talk will present two special adaptations found in insects and elsewhere in the biological world: deeply colored photonic nanostructures and anti-slip coatings. Biophotonic structures present an exceptional feat of evolutionary engineering of optically functional nanostructures at the nanoscale, where nature has brought forward most diverse optical structures, from gratings to gyroid with varying degrees of order. Here, I will present the examples of order and disorder in peacock spiders, damselflies and beetles, before showing our recent endeavors to manufacture bio-inspired non-stick surfaces for insects.



Salim BOUTAMI

Salim Boutami received his Engineering and Ph.D. degrees in electrical engineering from the *Ecole Centrale de Lyon*, France, in 2004 and 2007 respectively. Since 2007, he has been a researcher at the Optronics Division of CEA-Leti in Grenoble, France. In 2017-2018, he was a visiting scholar at Stanford University, in Professor Shanhui Fan's group. He has been involved in computational electromagnetism, and nanophotonic design for Silicon photonics. He has authored and co-authored 36 papers, filed 82 patents, and written one book.

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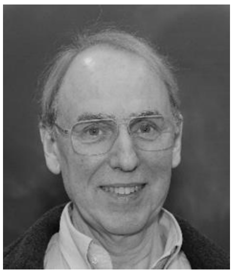
From bio-inspired to optimized non-intuitive nanophotonics

At the early years of nanophotonics, researchers have been largely inspired by nature. One remembers photonic crystal developments, especially band-gap type structures, which parallel the morphology and optical behavior of butterfly wings, for example. By structuring the matter in a fashion similar to some biological species, one could get interesting properties for light propagation, as a reflection behavior, or light trapping.

More recently, it has been shown however that complex-form devices could provide much better performances than bio-inspired photonic structures. Although these complex devices have non-intuitive disordered shapes, light propagation within these structures shows unexpected and very interesting behavior. To obtain such exotic structures, mathematical optimization techniques are used, among which lies the adjoint variable method (AVM). AVM is a powerful method to obtain very efficient devices for any targeted optical function. However, its mathematical formalism is rigorously efficient only for devices with continuous permittivity distribution. Most fabricable devices are though made of a binary set of materials (for example Silicon photonic devices are made of Silicon and Silica).

In collaboration with Prof. S. Fan's group at Stanford University, we have developed a new optimization method that gets rid of this continuous permittivity constraint, and allows an efficient optimization of photonic devices in a full binary fashion, with a control of minimal feature size. This method, which represents a generalization of AVM for discrete permittivity changes, is perfectly suited to Silicon Photonics devices optimization. We will present the mathematical background of the method, and some examples of photonic devices optimizations.

Third session: more flows



Johan L. VAN LEEUWEN

Johan van Leeuwen finished his B.Sc. (Biology, 1978), M.Sc. (Zoology, 1980) and Ph.D. (Biomechanics, 1983) at Wageningen University, the Netherlands. He was a postdoc (1983–1985; topic: fish swimming) at Leiden University, and continued at the same university as Assistant Professor (1985–1999) and Associate Professor (1997–1999). In 1996, he was visiting professor at the Friedrich-Schiller University in Jena, Germany. From 1999 until now, he is full professor and chair of the Experimental Zoology group at Wageningen University. In 2004, he was a visiting professor in the Department of Zoology, University of Cambridge, UK. He was convener of the Biomechanics Group of the Society for Experimental Biology (1999–2003), vice-president of the Royal Dutch Zoological Society (KNDV 2001–2006), member of the Academic board of Wageningen University (2005–2012), member of the executive board of the International Society for Vertebrate Morphology (2001–2005), chairman of the board of the Wageningen Institute of Animal Sciences, member of the World Council of Biomechanics (2004–2018), and served at several editorial boards. From 2016 until now, he is Scientific Director of the Wageningen Institute of Animal Sciences. During his career, he worked on a broad range of topics, including prey-capture biomechanics in fish, biomechanics of locomotion (walking, swimming, and flight), biomechanics of tentacles and tongues, muscle architecture and mechanics, bone and muscle development, bioadhesion in tree frogs, biomimetics of steerable needles, and recently bioinspired soft robotics.

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Biomechanics of the ovipositor of a parasitic wasp – an inspiration for steerable needles

Female parasitic wasps insert their ovipositor into solid substrates to deposit their eggs in hosts. The ovipositor is a slender beam-like structure that consists of three longitudinally connected valves (one dorsal and two ventral ones) that can slide along each other. Two tongue-and-groove connections keep the valves aligned with one another. Using high-speed 3D and 2D motion analysis, we quantified the probing kinematics of the fruit-fly parasitoid *Diachasmimorpha longicaudata* (Braconidae) [1]. Strikingly, the wasps can steer and curve their ovipositors in any direction relative to their body axis. In stiff substrates, the valves always make reciprocal motions, whereas in soft substrates, the ovipositors can be inserted without such motions. Reciprocal motions presumably limit the overall net pushing force and thus help to avoid damage. Steering can be achieved by varying the asymmetry of the distal part of the ovipositor by protracting one or more valves with respect to the other(s). Tip asymmetry is enhanced by curving of protracting ventral elements if the opposing force is low enough. Curvature changes of the ovipositor tip are supported by stiffness gradients along the dorsal and ventral valves in combination with sliding and pretension [2]. Our results increase the understanding of the functional morphology of the ovipositor in hymenopterans and is a source of inspiration for the design man-made steerable probes. Examples of wasp-inspired steerable needles will be discussed.

[1] Cerkvenik U, et al. (2017). Mechanisms of ovipositor insertion and steering of a parasitic wasp. *PNAS* E7822–E7831.
[2] Cerkvenik U, et al. (2019). Stiffness gradients facilitate ovipositor bending and spatial probing control in a parasitic wasp. *J.Exp.Biol.* 222, jeb195628.

Thomas ENGELS

Thomas received his B.Sc. in mechanical engineering from RWTH Aachen University in 2008, and his M.Sc. from *Université de Provence* in 2011. His doctorate is jointly given by TU Berlin and Aix-Marseille University in 2015 as a joint French-German doctorate (*cotutelle*). He continued his postdoctoral work at TU Berlin until December 2017, before changing to ENS Paris. In May 2019, he changed to TU Berlin again. After visiting JAMSTEC (Yokohama, Japan) from October to November 2019, he will join the Animal Physiology Lab at Rostock University in November 2019. His research focuses on numerical simulations of flying insects, with and without environmental turbulence, on large-scale supercomputers.

Contact: **thomas.engels@ens.fr**

Computational Aerodynamics of Insects in Turbulent Flows

Insects are amazing flying machines that have adopted strategies different from human-designed aircraft. In addition, they populate a turbulent, obstacle-rich environment. In this presentation, we use direct numerical simulations to study the impact of turbulence on virtual insects. We consider both tethered and free flight, the latter without active flight control, in fully developed turbulence. It is shown that the aerodynamics of flapping flight, most importantly the leading edge vortex, remain intact in an averaged sense. We hence conclude that turbulence faces in insects with problems for control, but not force production or power consumption. The free-flight experiments allow quantifying the response to turbulence during the reaction time delay, which is a passive phase before active control can be employed. In addition to fully developed turbulence, we also consider a turbulent cylinder wake as source of perturbations. Using this setup and comparing with *in vivo* flight experiments, we show that the animals do not try to compensate for high-frequency perturbations. As an outlook, we present our new adaptive numerical method, based on biorthogonal wavelets, which allows further advancing the state of the art of numerical simulations of flapping fliers.

Fourth session: a peek into the future

Xavier GIDROL

Xavier Gidrol received his Ph.D. in Molecular and Cell Biology from Aix-Marseille University. He performed post-doctoral research at Harvard School of Public Health and at the Institute of Molecular and Cell Biology, Singapore. He specialized in transcriptional regulation of gene expression. He got a tenure position at INRA France, and then served as Associate Director of R&D at Xenometrix Inc., a spin-off start-up from Harvard University, where he got interested in global approaches and genomics. He then joined in 2000 the newly created Functional Genomics Laboratory at France's Atomic Energy Commission (CEA) in Paris and managed it until 2008. This laboratory focused on large-scale functional genomics approaches to analyze proliferation/differentiation balance in oncology. In 2009, he was appointed director of a new laboratory, *Biomics* at CEA in Grenoble, to use microsystems for cell biology, where he focuses on 3D organoids, organs-on-chip and RNAi-based functional genomics in oncology. Since 2015, he manages both the Biomics Laboratory and the *Unité de Biologie à Grande Echelle* (CEA/INSERM/Université Grenoble Alpes) at CEA Grenoble. Xavier Gidrol authored or co-authored more than 120 publications.

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Organs & organoids on chip: a brief history of the future of biochips

Organs & organoids-on-chip have the potential, as human organ substitutes, to fill the gap that exists today between 2D human cell culture and animal experimentation. We use microfluidics, MEMS (MicroElectroMechanical Systems) and genetic engineering to produce and characterize human 3D organs substitutes. Those will impact our understanding of living organisms, by better mimicking the cellular development of healthy or pathological tissue. Interestingly, they unravel for instance that some cancer cells may behave like ants. On a longer term, these organs substitutes will also make it possible to carry out personalized pharmacological tests, under conditions closer to physiological reality, while reducing the number of experiments on laboratory animals.

Marc DESMULLIEZ

Marc Desmulliez received an Engineering Degree (UK BEng equivalent) from the *Ecole Superieure d'Electricite* of Paris (SUPELEC, France) in 1987, a College Diploma in Microwave and Modern Optics from University College London (UCL) in 1988, a Master of Advanced Studies from the University Cambridge (1991, 2011) and a Ph.D. in Optoelectronics from Heriot-Watt University (Edinburgh, UK) in 1995. After spending two years as a Power Engineering in a steel factory in France, he became a Lecturer in 1995, Reader in 1999 and Professor in 2006 at the Research Institute of signals, Sensors and Systems at Heriot-Watt University. He currently leads the Nature-Inspired Manufacturing Research Centre (NIMC) there. His research interests include nature-assisted novel manufacturing processes, computer-aided biomimetics, microwave sensing and microsystems. He is a Fellow of the Royal Society of Edinburgh (FRSE), of the UK Institute of Physics (FInstP), and of the Institute of Engineering and Technology (FIET). He received in 2019 the National Instruments Global Engineering Impact Award in the humanitarian category for the demonstrators of novel endoscopic capsules for detections of pathologies in the gastro-intestinal tract.

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Computer-aided nature-inspired design, where are we?

The field of biomimetics or nature-inspired engineering is experiencing a lot of public interest with exciting research from laboratories reaching the general public through press articles and television broadcasts. One could compare the field of biomimetics today as that of photonics witnessed at its infancy: a wide spectrum of different activities from established fields of science and technology, a new field of engineering overarching traditional boundaries, but a lack of applications convincing enough to create industrial take up. Industry, with some notable exceptions, have yet to embrace biomimetics. Causes of this hesitant behavior include lack of systematic methodology, need of the involvement of biologists, botanists and/or zoologists in the design process, lack of computer tools to harvest relevant information that answer industrial need. I will provide an overview of the current state of the art regarding the latter. I will explain why the notion of "trade-offs" is more rewarding than the term "function" in obtaining useful information form the natural world. I will also present recent work from my group obtained in using this concept based on natural language processing techniques (NLP).



Fifth session: tiny brains on chips

Elisa VIANELLO

Dr. Elisa Vianello is a scientist of CEA-Leti (Laboratory of Electronics, Technology and Instrumentation of CEA, Grenoble). She joined CEA-Leti in 2011 after spending one year as research staff at *Fondazione Bruno Kessler*, Trento, Italy, working on the development of advanced Silicon Radiation Detectors. Vianello received her Ph.D. in Electrical Engineering from the *Università degli Studi di Udine* (Italy) and the Grenoble Institute of Technology (INPG, France) in 2010. Since 2018, she is Leti senior expert on non-volatile memories and neuromorphic computing hardware. Her current research interests concern the development of new technologies for bio-inspired neuromorphic computing, with special focus on new resistive memory devices. She is author or co-author of more than 100 technical papers and 4 book chapters. She served in several Technical Subcommittees of internarial conferences, such as IEEE-International Reliability Physics Symposium (IRPS, 2013-2014), IEEE-International Electron Device Meeting (2016-2017), and the IEEE European Solid-State Device Research Conference (ESSDERC, 2016-present). She is coordinator of an H2020-ICT project (Memory technologies with multi-scale time constants for neuromorphic architectures, *MeM-Scales*). She is guest editor of the 'Emerging Materials in Neuromorphic Computing' (EMNC2020) AIP APL Material special issue.

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Resistive memories for neuromorphic hardware

Resistive random-access memory (RRAM) is a memory technology that promises high-capacity, non-volatile data storage, low voltages, fast programming and reading time (few 10's of ns, even <1ns), single bit alterability, execution in place, good cycling performance (higher than Flash), density. Moreover, RRAM can be easily integrated in the Back-End-Of-Line of advanced CMOS logic. This will revolutionize traditional memory hierarchy and facilitate the implementation of in-memory computing architectures and Deep Learning accelerators. RRAMs are also promising candidates for implementing energy-efficient neuron and synapse circuits. The memory is truly co-localized with the computational units, thus facilitating the realization of massively parallel local plasticity mechanisms such as spike-timing-dependent-plasticity that is believed to be a foundation of learning in the brain. Second, RRAMs can play a role in the design of asynchronous routing. RRAM-based ternary-content addressable memory (TCAM) are a compact solution for implementing reconfigurable multi-core neuromorphic architectures. We will also explore the use of RRAM for future circuits and systems inspired by the emerging paradigm of biomimicry.

Elisabetta CHICCA

Elisabetta Chicca obtained a *Laurea* degree (M.Sc.) in Physics from the University of Rome 1 *La Sapienza*, Italy in 1999 with a thesis on CMOS spike-based learning. In 2006, she received a Ph.D. in Natural Science from the Swiss Federal Institute of Technology Zurich (ETHZ, Physics department) and in Neuroscience from the Neuroscience Center Zurich. Elisabetta Chicca has carried out her research as a Postdoctoral fellow (2006-2010) and as a Group Leader (2010-2011) at the Institute of Neuroinformatics (University of Zurich and ETH Zurich) working on development of neuromorphic signal processing and sensory systems. Since 2011, she is leading the Neuromorphic Behaving Systems research group at Bielefeld University (Faculty of Technology and Cognitive Interaction Technology Center of Excellence, CITEC). Her current interests are in the development of CMOS models of cortical circuits for brain-inspired computation, learning in spiking CMOS neural networks and memristive systems, bio-inspired sensing (vision, olfaction, active electrolocation, audition) and motor control.

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The Time Difference Encoder (TDE)

Biological and artificial agents strongly rely on sensing to effectively interact with other agents and the environment. Independently of the sensory modality, the time difference between two events can carry important information. Well-studied examples are motion flow and sound source localization computed on the basis of time of flight and interaural time difference respectively. We propose a spiking Time Difference Encoder (sTDE) compatible with any event-based sensor. The sTDE encodes the time difference between two incoming events in the number of spikes and the inter-spike-intervals within a short burst. The application of this novel computation module on a variety of real-word sensory tasks will be presented in this talk.

Sixth session: remote recording and control

Hirotaka SATO

2019 – present	Provost's Chair, Nanyang Technological University (NTU), Singapore
2018 – present	Associate Professor, NTU, Singapore
2011 – 2017	Assistant Professor, NTU, Singapore
2008-2011	Postdoc, University of California at Berkeley
2007	Postdoc, University of Michigan

Award & Honor

- Best Paper, Surface Finishing Society Japan 2017
- Teacher of the Year, NTU, 2016
- The 10 Emerging Technologies (TR10), MIT Technology Review
- The 50 Best Inventions, TIME magazine

Group Website: https://hirosatontu.wordpress.com/

Contact: hirosato@ntu.edu.sg

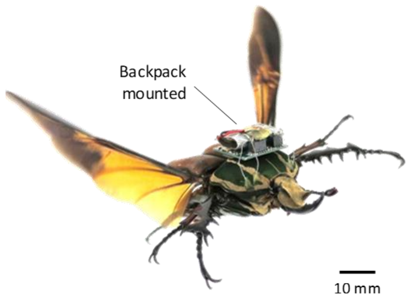

Figure 1: Insect-computer hybrid machine using a giant flower beetle.

Cyborg insect: living legged and winged robot

What? It is the fusion of living insect (platform) and man-made machine & computer (controller). A radio-built-in miniaturized computer is mounted on a living insect and the computer outputs electrical signal (stimulus) to neuromuscular sites (brain, ganglion, neurons, muscles) of the insect in order to induce one's desired motor actions and behaviors. Cyborg insect is attempted to help and assist rescue and search mission at disaster-stricken area in future as insect hybrid drone.

How? We mounted a radio built-in microcontroller (Texas Instruments) and two jumper female connectors (lead to the I/O pins of the microcontroller) onto a custom designed PCB (printed circuit board). The assembly of PCB or 'backpack' (the total mass is ~1.3 g) was glued on the thorax of a beetle. Thin metal wire electrodes were inserted into the female connectors and the other ends of the wires were implanted into the optic lobes (massive neural cluster of compound eyes), flight muscles (basalar and wing folding muscles) and leg muscles. The microcontroller was wirelessly commanded by experimentalist to output defined waveform of electrical stimulus pulse trains at defined frequencies on demand.

Locomotion Control: Initiating flight (take-off) was achieved by applying multi-pulse trains to the optic lobes, whereas flight cessation (landing) was achieved by applying a single long-duration pulse. Applying multi-pulse trains to the brain induced insect descent. A left turn was induced by multi-pulse trains to the right basalar muscle or the left wing folding muscle, and vice versa [1]. Walking gait was modulated by stimulating leg muscles under pre-determined sequences [2]. At the presentation onsite, we will show movies of demonstrations of those flight and walking controls.

[1] Sato, H. et al. Deciphering the Role of a Coleopteran Steering Muscle via Free Flight Stimulation. Current Biology, 25, 798-803 (2015).

[2] Cao, F., Zhang, C., Choo, H. Y. & Sato, H. Insect - computer hybrid legged robot with user-adjustable speed, step length and walking gait. Journal of Royal Society Interface, 13 (2016).

Anthony LEONARDO

Anthony Leonardo received his B.Sc. in Cognitive Science from Carnegie Mellon University, where he worked on problems in artificial intelligence. He received his Ph.D. in 2002 from Caltech in Computation and Neural Systems. He then completed postdoctoral work at Bell Labs and Harvard University. From 2008-2017 he was a group leader at the Janelia Research Campus of the Howard Hughes Medical Institute, where his lab explored the principles underlying neural information processing. This work focused on how internal models drive behavior, and how they are implemented in neural circuits, in dragonfly and salamander prey capture. Since 2017, he has been the Director of Janelia's Experimental Technology laboratory (jET). The mandate of jET is to create instrumentation that pushes forward the frontiers of science at Janelia and beyond, in optics, electromechanics, control systems and other branches of engineering. Selected honors include the Lindsley Prize in Behavioral Neuroscience, the Capranica Prize in Neuroethology, a Helen Hay Whitney Fellowship, a Grass Fellowship, the Burroughs-Wellcome Career Award in the Biological Sciences, and the IEEE BioCas paper of the year award.

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Remote neuroethology: Neural recordings and flight kinematics during aerial pursuits between dragonflies and their prey

Visually guided prey capture is a short-range form of navigation that is ubiquitous in the animal kingdom. It is a computationally complex behavior because, when moving prey are the target, the predator must generally use a guidance strategy based on some form of prediction. This internal prediction must be combined with reactive sensory cues as well as some understanding of the predator's body dynamics. In this talk, I will discuss how such sensorimotor control is implemented, both behaviorally and with neurons, in dragonflies. I will describe custom systems for both in-flight wireless neural telemetry and high precision motion capture of head, body, and wing states. Using these systems, I will show that accurate, predictive navigation continues in the absence sensory cues, demonstrating that these animals fly based largely on internal states rather than sensory reactions. Based on this, I will discuss the challenges in inferring the structure of the underling neural control system.



Scientific program

Wednesday 20th November 2019

19:00 | **Wine & Cheese cocktail**

Thursday 21st November 2019

8:15 | **Welcome coffee**

8:40 | **Official opening**

Lea DI CIOCCIO, CEA-Leti Grenoble, France

8:50 | **Scientific opening**

Jérôme CASAS (University of Tours & CEA-Leti Carnot chair of Excellence in bio-inspired technologies / France)

Susana BONNETIER (Carnot Program Manager at CEA-Leti Grenoble / France)

Thomas ALAVA (CEA-Leti Grenoble / France)

First session: extracting and moving fluids

9:00 – 9:30

Pascal DAMMAN (University of Mons / Belgium)
Collection of nectar by bumblebees: How physics of fluid demonstrates the prominent role of tongue's morphology

9:30 – 10:00

Jake SOCHA (Virginia Tech / USA)
Biomechanical mechanisms of fluidic pumping in insects

10:00 – 10:30

Yasser ABOELKASSEM (University of California-San Diego / USA)
Insect-inspired flow transport model and electrokinetics pumping in microfluidics

10:30 – 10:45 | **Coffee break**

10:45 – 11:15 | **Poster short presentations**



Second session: colorful ideas

11:15 – 11:45

Bodo WILTS (University of Fribourg / Switzerland)
Functional optical materials in insects

11:45 – 12:15

Salim BOUTAMI (CEA-Leti, Grenoble / France)
From bio-inspired to optimized non-intuitive nanophotonics

12:15 – 14:00 | **Lunch & posters**

Third session: more flows

14:00 – 14:30

Johan VAN LEUWEN (Wageningen University / the Netherlands)
Biomechanics of the ovipositor of a parasitic wasp – an inspiration for steerable needles

14:30 – 15:00

Thomas ENGELS (TU Berlin / Germany)
Computational aerodynamics of insects in turbulent flows

15:00 – 15:30 | **Coffee break**

Fourth session: a peek into the future

15:30 – 16:00

Xavier GIDROL (CEA, Grenoble / France)
Organs & organoids on chip: a brief history of the future of biochips

16:00 – 16:30

Marc DESMULLIEZ (Heriot-Watt University, Edinburgh / United Kingdom)
Computer-aided nature-inspired design, where are we?



Friday 22nd November 2019

8:30 | **Welcome coffee**

Fifth session: tiny brains on chips

9:00 – 9:30

Elisa VIANELLO (CEA-Leti, Grenoble / France)
Resistive memories for neuromorphic hardware

9:30 – 10:00

Elisabetta CHICCA (Bielefeld University / Germany)
The Time Difference Encoder (TDE)

10:00 – 10:30 | **Coffee break**

Sixth session: remote recording and control

10:30 – 11:00

Hirotaka SATO (Nanyang Technological University / Singapore)
Remote control of cyborg insects

11:00 – 11:45

Special Guest: Anthony LEONARDO (Janelia Research Campus, Howard Hughes Medical Institute, Virginia / USA)
Remote neuroethology: recordings of neural signals in aerial pursuits between insects and their prey

11:45 – 14:00 | **Lunch**

12:30 | **A general public conference at MIDIS MINATEC**

Marc Desmulliez (Heriot-Watt University, Edinburgh / United Kingdom)
Innovation Inspirée de la Nature: exemples et opportunités

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