NanoSaclay
Laboratoire d'Excellence
en Nanosciences et Nanotechnologies

JULY 15-25

Visit of Prof. Sandip Tiwari to Labex NanoSaclay

Class: An electroscience introduction of information and its processing

We live in an uncertain world and our actions use incomplete knowledge. As humans, this is claimed to be either system 1---a gut reaction---or system 2---a modeled thought-through reaction---to events. With computing machines, it is a usually a deterministic calculation based on a mathematical model even when using probabilities. This human reasoning approach versus a machine's inference-drawing approach has been, and remains, an important theme of research in our times. It has implications for how one may conduct complex computations with energy efficiency, rather than have ever-increasing supercomputing on a global warming mission of its own.

This sequence of introductory lectures is an exploration of this physical--natural world landscape of information processing with the objective of stimulating discussion and thoughts towards approaches for efficient robust low energy and fast deciding hardware. I will begin with a discussion of our physical understanding of information and entropy, their connection to energy, the principle of maximum entropy and its connections to drawing inferences as in machine learning approaches. I will follow this with a discussion of approximation, incompleteness, sparse data and mathematical approaches of compressed sensing that do pretty well with information extraction and data fusion. Probabilities and Bayesian methods tackle uncertainties most naturally in our mathematical constructs, so we will start with a simple discussion of these. We will follow this with a look at examples in literature from the natural world and our current understanding of the principles, such as infomax---an adaptive maximization of mutual information---apparently employed there for information processing. Some of these principles have been employed in neural networks and its most recent successes in deep learning. There is much to learn from these, and we will connect this to simpler Bayesian networks and their implementations to conclude with a discussion of mapping of these approaches in hardware where the probabilities will be natural to the system and not an *ad hoc* transplant to a deterministic system. Such approaches are one path to achieving efficient low energy information processing towards an outcome based on the principles, such as of maximum entropy or infomax, discussed during the course of the lectures.

Eight 45-minutes lectures

Lectures start at 11am. Coffee and cakes will be served at 10:45am.

Lectures take place at IEF, room 44. I would like the lecture July 18 to take place at Collège de France (but we will decide this together).

July 15 11am IEF	Information, energy, entropy, principle of maximum entropy and inferencing
July 17 11am IEF	Approximations, incompleteness, sparsity and compressed sensing
July 18 11am Collège de France *(to be confirmed)*	Probabilities and Bayesian approaches
July 21 11am IEF	Nature’s approaches
July 22 11am IEF	Statistical mechanics of learning
July 23 11am IEF	Neural networks and deep Learning
July 24 11am IEF	Probabilistic hardware?
July 25 11am IEF	Gestalt, review and future questions

SEMINAR: JULY 16, 11am, At NANOINNOV

"Nano" and Connecting Scales in Electronics

Electronics serves an interesting dichotomy of the power and poverty of nanoscale. Information technology is arguably the most powerful and pervasive human creation of these past decades. Yet, thermodynamically, the electronic data processing engine that this information serving and knowledge creation serves is terribly inefficient. . The information content of the most complex of integrated circuit we can envision currently in a mobile platform, say *10 Giga gates*, with a fan-in and fan-out of *4*, and 1000 terminals, has a maximum information content of *1.5 terabits*. If this chip accesses about *256 gigabits* of data from a chip-form memory, the maximum convertible negentropy is 5.8×10^{-9} *J/K* for the chip and 3.5×10^{-12} *J/K* for the data, i.e., a total capability of *6.9 nW-s* of information engine capacity. If it performed all this work in a second, it would consume *6.9 nW*, if it performed all this work in a *ns*, i.e., about one clock cycle, it would consume *6.9 W*. Real microsystems consume nearly *10 decades* of order of magnitude higher power. I will explore how one may take a stab towards these limits by exploiting the native probabilism of nanoscale, its devices and of architectures that can connect this scale to the real world scale by debating the underlying deterministic and non-deterministic approaches and conventional and unconventional device forms.

BIOGRAPHY

Sandip Tiwari is **an electrical engineer with the soul of a scientist** born into third world experiences. He was educated at IIT Kanpur, RPI, Cornell, further educated at IBM Research during that institution's remarkable period, and has taught at Michigan, Columbia, Harvard, Indian Institute of Science, Stanford and Cornell, where he is the Charles N. Mellowes Professor in Engineering.

His research has spanned a broad range of topics in semiconductor digital, high frequency, and optical devices and their circuits, technology and architecture. Among the current interests are finding approaches in information processing that integrate variability and probabilities throughout the nanoscale hardware-to-software stack for robustness and efficiency, in autonomous approaches that can learn and evolve, the use and understanding of phase transitions such as from correlated electrons in memories, in rapid low power configurability, and novel electronic specific applications of atomic and nanoscale materials and structures. In probing the interesting questions that arise when connecting large scales of massively integrated electronic systems to small scales, his students and his group have developed ideas and explored adaptive and configurable electronics, and Bayesian and learning-based implementations using small devices and their circuits via three-dimensional and functional integration. Among the widely cited experimental contributions are **the invention of nanocrystal memories, adaptive and configurable low power approaches, development of architectures and technologies of three-dimensional integration, and the early investigations of III-V and SiGe transistors and their technologies**. His theoretical efforts have provided the fundamental understanding of several device phenomena including the **electron injection processes in coupled confined systems**, **frequency limitations of quantum-wire lasers due to gain compression, surface recombination and injection and**

collection effects at high currents in heterostructure bipolar transistors, and energy implications of inexact computing approaches.

He is a **Fellow of IEEE and APS**, and has received the **Young Scientist Award from Institute of Physics**, **IBM Outstanding Contribution Awards**, **Distinguished Alumnus Award from IIT-Kanpur**, and the **Cledo Brunetti Award from IEEE** for contributions to heterostructure devices, nanoscale electronic and optical devices, technology development, and the nanocrystal memory and quantum-effect devices across the different semiconductor materials. He is a **frequent keynote** and invited speaker summarizing learning and articulating new themes, technical directions and their needs.

He has contributed to national and international technical vitality by serving the Defense Sciences Research Council, the national advisory committees of educational institutions and national laboratories, the technical activities board of large and small companies, as the **founding Editor-in-Chief of IEEE Transactions on Nanotechnology** and **associate editorship** of IEEE Transactions on Electron Devices, Applied Physics Reviews and by organizing and chairing conferences, workshops and teaching schools. As **Director of the NSF-funded National Nanotechnology Users Network and National Nanotechnology Infrastructure Network**, the multi-university effort expanded over 12 years to 14 universities as an effective and critical element for the vibrancy of national nanotechnology research and development. During his tenure, the impact of this effort expanded to nearly a quarter of the national experimental physical engineering and science PhD graduates and a significant fraction of small experimental nanotechnologies-based companies depending on this infrastructure. He also directed the Cornell Nanoscale Facility and its development and move to a major new interdisciplinary research building at Cornell. **He is author of a widely used graduate text-book** “Compound Semiconductor Device Physics” that is now available as an open textbook, and is currently working on a text series for undergraduate to graduate electroscience education.

He believes passionately in science and engineering as a global effort and as a social force for human development and poverty alleviation. As a native of India, his efforts have included international winter graduate schools bringing together US students and faculty with hundreds of Indian students, rural libraries and early education. The invariant in his efforts tend to be the difficulty of the challenge and possible solvability through his experience and insights.