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Foreword

From neuronal assemblies to cyborgs

We have reached a moment in the history of science when the community of politicians, sociologists and scientists are paying worldwide attention to new technologies, from reproductive cloning to the internet. These new technologies have the potential of changing the course of evolution of many species, including ours. At the same time that significant progress is being made in non-invasive imaging, more invasive technologies have been opening windows of observation and action on the human brain at work, and are already improving the efficiency of medicine. It is likely that these new avenues will attract the attention of a large public in the near future.

It is of particular interest to evaluate whether the level of knowledge and technology based on animal and clinical research is sufficient, not only to monitor the dynamic perceptual and decision processes in the brain but also to interact in real time with higher cognitive functions. Communication between artificial devices (sensors, mechanical arms,...) and the living brain can be used to compensate deficiencies of our peripheral sensory and motor systems or to help patients who are disabled or suffer from locked-in syndrome. A first approach is to strive towards a better understanding of the various codes used by the brain to represent sensory information and to elaborate motor commands for active interaction with the environment. This may be pushed further in an evaluation of the activity of large neuronal assemblies using imaging techniques and appropriate computational tools. From the knowledge thus obtained, we may hope to move towards interfacing the brain and developing technologies designed for the intelligent control of neural prostheses.

The purpose of the 2003 TAUC Conference in Neurobiology, organized in Gif-sur-Yvette, has been to further these ambitions by bringing together scientists from different disciplines, including cellular neuroscience (single neurons, large-scale ensemble electrophysiological recordings), brain imaging (two photon imaging at the single cell level, voltage sensitive dye imaging, fMRI, MEG,...), computational neuroscience (theories of neuronal coding, analysis of the dynamics of large neuronal assemblies) and engineering (interface between neurons and artificial devices). The various themes covered have been : (1) the distributed coding strategies used by the brain to analyze and store information from the environment and to plan consequent action; (2) real-time multi-scale imaging of neuronal activity in the living brain; (3) the computational aspects of brain function and current theories of neuronal coding; (4) real-time interfaces between brain cells and computers or artificial devices.

(1) *Unraveling the neural code*: An important issue is to review advances in our current understanding of sensory and motor coding. The study of temporal coding through the different stages of integration in the thalamo-cortical pathways has been one of the success stories in matching convergence and divergence of anatomical links with the specificity of functional integration, from the "Hubel and Wiesel orientation detector" of the occipital cortex to the "face cells" of the infero-temporal cortex. Study of the motor cortex has also provided new insights into distributed coding and the reconstruction of state vectors that can be derived from simultaneous recordings of sparse neuronal assemblies, providing accurate prediction of the intended action on the external world.
(2) *Imaging neuronal and network state dynamics*: New techniques have been recently developed that make it possible to trace the dynamics of calcium in single cells (two photon microscopy), as well as metabolic responses on a larger scale of integration (intrinsic imaging, voltage sensitive dyes, fMRI,...). A fundamental issue is to understand how the different signals (calcium, hemoglobin oxygenation, subthreshold membrane potential, haemodynamic response) used to probe brain activity are related to patterned spiking activity during cognitive operations. A second issue is to extract from these studies new concepts in neural-based computation by the brain, in order to relate different levels of integration from the dendrite to the cell assembly.

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(3) *Computational properties of neuronal populations*: The aim of this session was to review new theories that have emerged in the light of the recent experimental findings on imaging and distributed coding, including attractor states, stochastic dynamics and "liquid" computation. The specific questions that are currently investigated are: how can we understand the genesis of cortical states and their dynamics? Can we make sense of the immense complexity and diversity of neurons in cerebral cortex? Are current theories about distributed coding powerful enough to decipher neural representations and translate them in computational operations understandable by humans or machines?
(4) *Real-time brain-machine interactions*: One application of cybernetics is to create artificial devices directly run by the central or peripheral nervous system in order to offer substitutes for impairment of motor, sensory and possibly even intellectual functions in patients. Technological breakthroughs are needed to achieve such densely multi-connected machine-brain interfaces with connectivity patterns that are biocompatible and stable over time. Examples of interfacing a silicon chip to a small number of biological neurons have already been obtained. Synaptic-like interactions between an intracellularly recorded biological neuron and realistic conductance-based model neurons can be run in real time, following the natural dynamics of the biological cell or network.

The "Hybrid network" approach is proposed as an analytical method complementary to classical electrophysiology or pure theoretical simulation. It provides in-depth and real-time control of membrane and synaptic conductances as well as of the network structure in order to assess their respective roles in the activity of cells and circuits. The reciprocal task of 'interfacing the brain' with the environment, implies that some type of physical interface makes direct connections with one brain cell or a population and transmits 'information' in a biologically compatible way. Neural activity patterns distributed across a preset assembly, for instance in motor cortical areas, can be used to command an external robotic arm. Reciprocally, a stimulation matrix can be implanted in the occipital lobe in blind subjects and may one day be able to translate the image sampled by a wearable camera device, after proper coding.

This international meeting has offered a unique opportunity for 350 neuroscientists, clinicians, engineers and theoreticians to discuss together the future of advanced hybrid technologies and their impact, both at the applied level of human medicine and at the level of the basic understanding of brain functions. Some of the major contributions to this meeting constitute this special issue of Journal of Physiology (Paris) on decoding and interfacing the Brain.

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