Forty years in Biocybernetics
Luigi Ricciardi memorial lecture

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Abstract: Luigi M Ricciardi (1942-2011) was a leading figure in biocybernetics, biomathematics and related fields. The lecture reviews some stages of the development in these disciplines in the last forty years by following some stations in his life in terms of some of the positions he hold and conferences he played a major role (Naples, Chicago, Salerno, Vienna, Osaka and Kyoto, Las Palmas etc.) These stages well characterize the transition from the age of the classical cybernetics (in the spirit of Wiener and McCulloch) to the modern theory of neurons and neural networks, and some other fields of biocybernetics and biocomplexity.

Keywords: Luigi M Ricciardi, Naples, biocybernetics, biomathematics, biocomplexity, neuron, neural network, stochastic model, small world network, scale-free network

Acknowledgement: Many thanks to Tonia Ricciardi and Nello Buonocore (Napoli-Naples), Paul Cull (Oregon), Laura Sacerdote (Torino-Turin), Hiromi Seno (Hiroshima), Francesco Ventriglia (Napoli-Naples).

1. From Naples to Naples

“...Professor Caianiello’s interests in Cybernetics were indirectly originated by Enrico Fermi who in 1954 strongly supported the setting up of a seminar activity on Computers and on Norbert Wiener's Cybernetics at the University of Rome. In that occasion Professor Caianiello became acquainted with Dr Valentin Braitenberg, a specialist in psychiatry, neurology and neuroanatomy, who eventually joined him at the Institute of Theoretical Physics in Naples and largely co-operated to the setting up of a Division of Cybernetics, sponsored by the Italian National Research Council, with premises in the Institute of Theoretical Physics of Naples University. Dr Braitenberg's role was
determinant in focusing Professor Caianiello's interest on the mathematical description of brain activity. It was the beginning of a very happy period for Neapolitan research in Physics, Mathematics and Cybernetics. (LM Ricciardi: Cybernetics and Systems 25 (iii), 1994)

From 1968 until his retirement in 1994, Valentino Braitenberg was director of the department Structure and Function of Natural Nerve-Nets at the Max Planck Institute for Biological Cybernetics in Tübingen. His research was mainly based on the combination of neuroanatomy with brain theory, with the aim to understand mechanisms of brain functions. Main fields of research were the visual system of the fly, cerebellum and the physiology of movement, and structure and function of the cerebral cortex. Some of his topics on the cerebral cortex were: quantitative-anatomical studies on the cortex of the mouse and on the human cortical white matter, orientation specificity in the visual cortex of primates, connected also with psychophysical studies on humans, as well as a neurological theory of language. (http://www.kyb.tuebingen.mpg.de).

Luigi Ricciardi came to Chicago in 1969 as Assistant Professor of Mathematical Biology. At that time, the Committee on Mathematical Biology was being expanded and was expected to morph into the Department of Theoretical Biology. Luigi was among a group of young new assistant professors who went on to distinguished careers. In this group, there were such names as Art
Winfree, Stuart Kauffman, and Montgomery Slatkin. They joined a group that included such established professors as Jack Cowan, Dick Levins, and Richard Lewontin, as well as recent recruits who were already well-known in other fields, such as Stuart Rice and Morrel Cohen. There was also a distinguished roster of visitors, including Warren McCulloch, Michael Arbib, E. O. Wilson, Rene Thom, and Eduardo Caianiello. At that time, neural nets were a hot topic. McCulloch, who had invented neural nets 25 years earlier, was still active and he had a number of students working in that area. Stu Kauffman had recently shown that related Boolean models could also be used to describe genetic systems. Since Luigi had worked on neural nets with Caianiello and DeLuca, it seemed natural that he should supervise my thesis on neural nets. My thesis showed that techniques from linear algebra could be used to study neural nets if they were considered as polynomials over finite fields rather than as linear threshold devices. I successfully defended my thesis in June 1970 with Luigi as my major professor and Prof. Caianiello as a member of my committee.” (Paul Cull: Mathematical Biology in Chicago)
2. Biomathematics and Biocybernetics

Among others:

R Rosen: Feedforward control and senescence
H Haken: Mathematical methods of synergetics for applications to self-organizing systems
AV Holden: The mathematics of excitation
V. Braitenberg: Outline of a theory of the cerebral cortex
G. Palm: How useful are associative memories?
S Amari: A mathematical theory of self-organizing systems
E Labos: Eective extraction of information included in network descriptions and neural spike records
Radil-Weiss, T: Human visual perception and recognition

A.G. Nobile, L.M. Ricciardi and L. Sacerdote: On a class of difference equations modeling growth processes

A very important conference organized by Luigi in Salerno (1980).
3. Neural Network - Stochastic Models

Membrane potential as a Brownian particle: continuous time continuous state space stochastic process (diffusion process).

\[ dX(t) = \mu[X(t), t]dt + \sigma[X(t), t]dW(t) \]  
\[ T = \inf_{t \geq t_0} \{ t : X(t) > S(t) \} \]  
\[ g[S(t), t|x_0, t_0] = \frac{\partial}{\partial t} P\{ T \leq t \} \]

**First Passage Problem**: When the voltage at a particular place on a neuron reaches a threshold, an action potential (nerve impulse) is produced. Many point processes in biology have similar origins as "first passage times"; that is, they occur when some underlying process first reaches a critical level or threshold.

*Luigi with Henry Tuckwell and Hugh Wilson*
Even for simple models of the underlying process (1-dimensional stochastic differential equations), very few analytical results are available for first passage times. Through simulation and heuristic approximation methods, several different types of behavior have been identified. The main current research activities are further development of approximation methods.

4. Neural Networks

**Determinism versus randomness**: János Szentágothai (1912-1994)

4.1. **Small world and scale-free networks?**

1. The nervous system of the nematoda worm *Caenorhabditis elegans* forms a small-world network.
2. Mammalian cerebral cortex: its network is neither regular nor random.
3. The distance of two arbitrarily chosen cortical neurons is 5. (John Szentágothai)

1. **Anatomical connectivity**: the set of synaptic connections linking its elements
2. **Functional connectivity**: the correlations between spatially remote neurophysiological events.
3. **Effective connectivity**: the influence a neuron (or neuronal population) on another. At the neuronal level this is equivalent to the effect pre-synaptic activity has on post-synaptic responses, otherwise known as synaptic efficacy. Models of effective connectivity are designed to identify a suitable metric of influence among interconnected components (or regions of interest) in the brain.
4.2. Brain Connectivity

Modes of brain connectivity. Sketches at the top illustrate structural connectivity (fiber pathways), functional connectivity (correlations), and effective connectivity (information flow) among four brain regions in macaque cortex. Matrices at the bottom show binary structural connections (left), symmetric mutual information (middle) and non-symmetric transfer entropy (right). Data was obtained from a large-scale simulation of cortical dynamics ... (Olaf Sporns: http://www.scholarpedia.org/article/Brain Connectivity)

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