**CHEMICAL ARTIFICIAL INTELLIGENCE, NATURAL COMPUTING AND FUZZY LOGIC TO FACE THE CHALLENGES OF COMPLEXITY AND CHAOS.**

**Papers in Journals**

| (15) | Pier Luigi Gentili, Hiroshi Gotoda, Milos Dolnik, Irving R. Epstein  
*Analysis and prediction of aperiodic hydrodynamic oscillatory time series by feed-forward neural networks, fuzzy logic, and a local nonlinear predictor.*  
Chaos, 2015, 25, 13104 (1-14) |

| (14) | Pier Luigi Gentili  
*“The human sensory system as a collection of specialized fuzzifiers: A conceptual framework to inspire new artificial intelligent systems computing with words.”*  
J. of Intel. & Fuzzy Sys., 2014, 27, 2137-2151 |

| (13) | Pier Luigi Gentili  
*“The Fuzziness of a Chromogenic Spirooxazine.”*  

| (12) | Pier Luigi Gentili  
*“Le sfide della complessità e il contributo dell'intelligenza artificiale chimica”*  
100news-Scienza, raccolta del 15 gennaio 2014, 3-4. |
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<td>10</td>
<td>P. L. Gentili</td>
<td>Small steps towards the development of chemical artificial intelligent systems</td>
<td>RSC Advances 3, 2013, 25523-25549</td>
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<td>Chemical intelligence: Different types of logic can be implemented with molecules. In absence of decoherent effects, quantum logic can be carried out. Otherwise crisp logics can be processed (see flowchart). In case of</td>
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collections of molecules, there are conditions favourable for building fuzzy logic systems which are playing an increasingly important role in the development of artificial intelligence. Future Information Technology Systems will hinge on logic gates implemented at the molecular level. To expand the intelligence quotient of next artificial machines, it is necessary to find out how to process Fuzzy logic at the molecular level. Fuzzy logic allows certain and uncertain information, objective and subjective knowledge to be dealt with.

If the logic gates, sculpted from bulk semiconductors, are based exclusively on electrical signals, those based on single molecules can be extended to chemical, optical and other physical inputs and outputs. Purpose of the chemist is to find out always-new powerful molecular systems that can carry out the logic operations required for computer circuitry. If the compound behaves as a versatile molecular switch, it can be adopted to process Boolean binary logic. On the other hand, if a chemical species responds to external inputs with a continuously variable output signal and the relation between inputs and output can be rationalized in terms of IF-THEN statements, it can be employed to process Fuzzy logic.

The Sun is an energy source of utmost importance for the Earth. Solar energy has been crucial for the emergence of Life and is still fundamental for its support. In this paper, the role fulfilled by the Sun’s energy toward the terrestrial evolutionary processes and the current action performed toward the living beings are presented. Life on Earth employs the solar radiation as both energy source and information spring for its spatial and temporal orientation.

**Chapters in Books**

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(6) P. L. Gentili  
*Molecular Processors: From Qubits to Fuzzy Logic.*  

(5) P. L. Gentili  
*Fuzzy Logic Implemented at the Molecular Level*  

(4) P. L. Gentili  
*Fuzzy Logic in Molecular Computing.*  

(3) P. L. Gentili  
*Boolean and Fuzzy Logic Gates Based on the Interaction of Flindersine with Bovine Serum Albumin and Tryptophan.*  

(2) P. L. Gentili  
*Boolean and Fuzzy Logic Implemented at the Molecular Level*  

(1) P. L. Gentili  
*Fotorecettori Biologici. Il sole e la vita sul pianeta terra.*  
The Development of Chemical Artificial Intelligence Processing Fuzzy Logic

The Human Nervous System is an outstanding example of natural complex system. Its hierarchical architecture and its basic nonlinear working principles store the secrets of Complexity. Of course, a scrutiny of the Human Nervous System is going to have a profound impact on the challenges to Complexity. In this contribution, we present the first results in our analysis of the human nervous system at the “computational”, “algorithmic” and “implementation” levels. Such analysis will probably bring to the development of a new generation of computing machines imitating the human intelligence that computes with words and solves quite easily computational problems like the recognition of variable patterns.

Current computers process information based on transistors and electrical signals. The futuristic chemical computers will store, process, and convey information by using molecules, their assemblies, and physical-chemical signals. It is possible to compute by exploiting single molecules or large collections of them. Different kinds of logic can be processed. Since molecules obey the laws of quantum-mechanics, quantum logic can be implemented, as long as decoherent effects are avoided. If the collapse of superimposed or entangled wave-functions is inevitable, molecules can still be used to process either Boolean or discrete multi-valued or fuzzy logic. The conditions favourable to chemically process the infinite-valued fuzzy logic are presented in this text and few examples of its chemical implementation are reported. Fuzzy logic is particularly important for the development of artificial intelligence because it models pretty well human decision making. This property is due to the structural analogies existing between fuzzy logic systems and human nervous system.

There exists a worldwide race to make microprocessors of computers as much powerful as possible by shrinking electronic components and cramming logic gates onto smaller and smaller wafers of silicon. Over the past few years, some companies and several academic laboratories have started seriously entertaining the idea of constructing computers in which computations are performed by individual molecules. If the logic gates, sculpted from bulk semiconductors, are based exclusively on electrical signals, those based on single molecules can be extended to chemical, optical and other physical inputs and outputs. Purpose of the chemist is to find out always-new powerful molecular systems that can carry out the logic operations required for computer circuitry. If the compound behaves as a versatile molecular switch, it can be adopted to process Boolean binary logic. On the other hand, if a chemical species responds to external inputs with a continuously variable output signal and the relation between inputs and output can be rationalized in terms of IF-THEN statements, it can be employed to process Fuzzy logic. Organic compounds exhibiting “Proximity Effect” in their photophysics give an opportunity to implement Fuzzy logic Engines at the molecular level. For these chemical species a quantum state, consisting of a superposition of two electronic levels, can be produced through excitation by UV-Visible radiation. The nature of the quantum state and its ability to emit light can be varied in a continuous manner by regulating environmental conditions such as temperature and hydrogen bonding donation ability of the solvent. This opens up a new avenue to implement Fuzzy logic at the molecular level.

Communications at Congresses and Seminars

1st International Caparica Conference on Chromogenic

“The Fuzziness of a Chromogenic Spirooxazine”
| (10) | XLI Italian Congress of Physical Chemistry. 23-27 June 2013, Alessandria (Italy). | P. L. Gentili | “The development of Chemical Artificial Intelligence to face the challenges of complexity.” 
Proceedings, pag. 155 |
| (9) | XLI Italian Congress of Physical Chemistry. 23-27 June 2013, Alessandria (Italy). | P. L. Gentili | “Fuzzy logic to tame the chaos” 
Proceedings, pag. 154. |
Invited speaker |
| (6) | Seminar taken at the Institute of Complex Systems (CNR), Sesto Fiorentino (FI), the 18th October 2012. | P. L. Gentili | “Small steps towards a Chemical Artificial Intelligence” 
Invited speaker |
|  | XXIII IUPAC Symposium on Photochemistry. | P. L. Gentili |  |
| (3) | Ferrara 11 -16 July 2010 | “Molecular Processors for Fuzzy logic”.
Proceedings page 222. |
| (2) | “Giacomo Ciamician, genio della chimica e profeta dell’energia solare”, Bologna 16 - 18 September 2007 | P. L. Gentili
“Il sole: sorgente di energia ed informazione.” |
| (1) | Congresso Nazionale di Fotochimica, Salice Terme (PV) 14 -16 December 2006. | P. L. Gentili
“Logica Booleana e Fuzzy elaborata a livello molecolare su sistemi fotosensibili.”
Proceedings page 12. |

**Collaborations**

- Prof. Irving Epstein, Prof. Milos Dolnik, Dr V. Horvath, Nonlinear Dynamics Group, Chemistry Department, Brandeis University, (MA, USA)
- Prof. Vladimir Vanag, Immanuel Kant Baltic Federal University, Russia.
- Prof. Hiroshi Gotoda, Department of Mechanical Engineering, Ritsumeikan University, Japan.

**Visiting Students**

Kenta Hayashi, from Ritsumeikan University (Japan) worked on the prediction of chaotic time series from 1/10/14 up to 20/12/2014.