The potential of “Analog Computing” based on Cellular Neural Networks (CNN) for Modeling and Simulation of Dynamic Systems: Motivation, Historical Notes, and some Case Studies for Illustration

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The availability of computationally efficient and accurate methods to analyze, simulate and predict the dynamic behavior of real physical systems is high interest in diverse areas of engineering. Indeed, these systems are in many cases complex nonlinear dynamical systems which are used/exploited to perform various tasks in industry and even in day to day life. The complexity of these engineering systems is a key aspect which calls for high performance analysis tools. It is well-known that the common approaches to analyze these systems are either analytical or numerical or experimental. Due to the high degree of nonlinearity and complexity in many of the systems, the analytical approach is tough and deriving exact analytical solutions is in many cases impossible. The classical numerical simulation approach (implying the numerical solution of the nonlinear differential equations (ODE’s or PDE’s) describing the systems) on Von Neumann based computer architectures could be an alternative solution to tackle the difficulties faced by the analytical approach. However, the numerical approach appears to be very time consuming. It also faces at times low accuracy due to rand-off errors accumulated during computations. In fact, these errors do increase as the degree of stiffness increases in the motions of the technical systems and, sometimes manifest themselves by floating point overflows during computations. Therefore, these facts clearly underline the crucial need and high importance of an efficient alternative simulation paradigm which is robust with regard to the difficulties just mentioned. Otherwise, getting full insight of the dynamical behavior related to the models describing the real behavior of the systems could be impossible. A full insight in all aspects of the systems’ behaviors does require computations in wide ranges of the systems parameters values, even in parameter ranges in which the system models do experience high stiffness.

A novel version of the “analog computing” paradigm, which involves cellular neural networks (CNN), is viewed be a good candidate to tackle the difficulties faced by both numerical simulation and analytical approaches. The CNN-based analog computing paradigm provides an adequate methodology and adequate instruments for efficient analysis, simulation, behavior prediction and even design of complex dynamical systems. Indeed, the efficiency of calculations using CNN processors at observed speedups (through own experiments) of many orders of magnitude while compared to the classical approaches demonstrates that this novel analog computing platform it an excellent candidate to perform ultra-fast simulations even in cases of high stiffness and is therefore an appropriate tool to tackle the difficulties underlined above.

This talk provides, after some historical notes, a short but sufficient description of the basics of CNN. Implementation related issues of CNN processors either in software (for example in Matlab/Simulink) or in hardware (for example on DSP/FPGA) are discussed and illustrated by a short description of some own concrete realizations. To finish, a series of application examples, proof of concepts or case studies is presented and discussed for illustration of the superiority and effectiveness of the novel analog computing paradigm: (a) ultra-fast scheduling in transportation and production through a CNN-based analog computing platform; (b) robust and fast nonlinear image processing; and c) CNN-based ultra-fast solution of nonlinear differential equations with high degree of stiffness.