Bio-Inspired Dynamical Tools for Analyzing Cognition

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INTRODUCTION

The knowledge about higher brain centres in insects and how they affect the insect's behaviour has increased significantly in recent years by theoretical and experimental investigations. Nowadays, a large body of evidence suggests that higher brain centres of insects are important for learning, short-term, long-term memory and play an important role for context generalisation (Bazhenof *et al*., 2001). Related to these subjects, one of the most interesting goals to achieve would be to understand the relationship between sequential memory encoding processes and the higher brain centres in insects in order to develop a general "insect-brain" control architecture to be implemented on simple robots. In this contribution, it is showed a review of the most important and recent results related to spatio-temporal coding and it is suggested the possibility to use continuous recurrent neural networks (CRNNs) (that can be used to model non-linear systems, in particular Lotka-Volterra systems) in order to find out a way to model simple cognitive systems from an abstract viewpoint. After showing the typical and interesting behaviors that emerge in appropriate Lotka-Volterra systems (in particular, *winnerless competition processes*) next sections deal with a brief discussion about the intelligent systems inspired in studies coming from the biology.

BACKGROUND

What do we name "computation"? Let us say a system shows the capability to compute if it has memory (or some form of internal plasticity) and it is able to determine the appropriate decision (or behavior, or action) given a criteria and making calculations using what it senses from the outside world. Some biological systems, like several insects, have brains that show a type of computation that may be described functionally by a specific type of non-linear dynamical systems called Lotka-Volterra systems (Rabinovich *et al*., 2000). According to our objectives, one of the first interests focuses on how an artificial recurrent neural network could model a non-linear system, in particular, a Lotka-Volterra system (Afraimovich *et al*., 2004) and what are the typical processes that emerge in Lotka-Volterra systems (Rabinovich *et al*., 2000). If it could be understood, then it would be clearer how the relationships between sequential memory encoding processes and the higher brain centres in insects are.

About higher brain centers (and how they affect an insect's behaviour) it is possible to stop the functioning of particular neurons under investigation during phases of experiments and gradually reestablish the functioning of the neural circuit (Gerber *et al*., 2004). At the present, it is known that higher brain centers in insects are related on autonomous navigation, multi-modal sensory integration, and to an insect's behavioral complexity generally; evidence also suggests an important role for context generalization, short-term and long-term memory (McGuire *et al*., 2001). For a long time, insects have inspired robotic research in a qualitative way but insect nervous systems have been under-exploited as a source for potential robot control architectures. In particular it often seems to be assumed that insects only perform 'reactive' behavior, and more complex control will need to be modeled on 'higher' animals.

SPATIO-TEMPORAL NEURAL CODING GENERATOR

The ability to process sequential information has long been seen as one of the most important functions of "intelligent" systems (Huerta *et al.*, 2004). As it will be shown afterwards, winnerless competition principle appears as a major type of mechanism of sequential memory processing. The underlying concept is that sequential memory can be encoded in a (multidimensional) dynamical system by means of heteroclinic trajectories connecting several saddle points. Each of the saddle points is assumed to be remembered for further action (Afraimovich et al., 2004).

Computation over Neural Networks

Digital computers are considered universal in the sense of capability to implement any symbolic algorithm. If artificial neural networks, that have a great influence on the field of computation, are considered as a paradigm of computation, one may ask how the relation between neural networks and the classical computing paradigm is. For this question it is needed to consider, on the one hand, discrete computation (digital) and on the other hand, nondiscrete computation (analog). In terms of the first, the traditional paradigm is the Turing Machine with the Von Neumann architecture. A decade ago it was shown that artificial neural networks of analog neurons and rational weights are computationally equivalent to Turing machines. In terms of analog computation, it was also showed that three-layer feedforward nets can approximate any smooth function with arbitrary precision (Hornik *et al.*, 1990). This result was extended to show how continuous recurrent neural nets (CRNN) can approximate an arbitrary dynamical system as given by a system of *n* coupled first-order differential equations (Tsung, 1994; Chow and Li, 2000).

Neural Network Computation from a Dynamical-System Viewpoint

Modern dynamical systems theory is concerned with the qualitative understanding of asymptotic behaviors of systems that evolve in time. With complex non-linear systems, defined by coupled differential, difference or functional equations, it is often impossible to obtain closed-form (or asymptotically closed form) solutions. Even if such solutions are obtained, their functional forms are usually too complicated to give an understanding of the overall behavior of the system. In such situations qualitative analysis of the limit sets (fixed points, cycles or chaos) of the system can often offer better insights. Qualitative means that this type of analysis is not concerned with the quantitative changes but rather what the limiting behavior will be (Tsung, 1994).

Spatio-Temporal Neural Coding and Winnerless Competition Networks

It is important to understand how the information is processed by computation from a dynamical viewpoint (in terms of steady states, limit cycles and strange attractors) because it gives us the possibility of manage sequential processes (Freeman, 1990). In this section it is showed a new direction in information dynamics namely the Winnerless Competition (WLC) behavior. The main point of this principle is the transformation of the incoming spatial inputs into identity-temporal output based on the intrinsic switching dynamics of a dynamical system. In the presence of stimuli the sequence of the switching, whose geometrical image in the phase space is a heteroclinic contour, uniquely depends on the incoming information.

Consider the generalized Lotka-Volterra system (N=3):

$$\dot{a}_1 = a_1\left[1 - \left(a_1 + \rho_{12}a_2 + \rho_{13}a_3\right)\right]$$
$$\dot{a}_2 = a_2\left[1 - \left(a_2 + \rho_{21}a_1 + \rho_{23}a_3\right)\right]$$
$$\dot{a}_3 = a_3\left[1 - \left(a_3 + \rho_{31}a_2 + \rho_{32}a_2\right)\right]$$

If the following matrix and parameter conditions are satisfied,

$$\left(\rho_{ij}\right) = \begin{pmatrix} 1 & \alpha_1 & \beta_1 \\ \beta_2 & 1 & \alpha_2 \\ \alpha_3 & \beta_3 & 1 \end{pmatrix}$$

$$0 < \alpha_i < 1 < \beta_i$$

When the coefficients fulfill that $\alpha_1 = \alpha_2 = \alpha_3 < 1$ and $\beta_1 = \beta_2 = \beta_3 > 1$, we have three cases:

1. Stable equilibrium with all three components simultaneously present/working.
2. Three equilibria (1,0,0), (0,1,0) and (0,0,1) all stable, each one attainable depending on initial conditions.

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