Building Computational Agents using Neuronal Networks, Schema Theory and Artificial Intelligence[1]

Francisco Cervantes-Pérez, Osvaldo Cairó, José Incera, and Alfredo Weitzenfeld

Academic Computer Engineering Department
Mexico Autonomous Institute of Technology (ITAM)
Río Hondo 1, San Ángel, CP-01000, México D.F., MEXICO
{cairo, cervante, jincera, alfredo}@itam.mx

Abstract. At the Mexico Autonomous Institute of Technology (ITAM) there is a group of research interested in developing both theoretical and computational tools to facilitate the construction of *intelligent agents*. In this paper, we give a brief description of some of the projects under development at our Department; specifically, the design of a Multi-agent Programming Environment to support the modeling and analysis of neurobiological mechanisms underlying animals behavior, which, in turn, might be used as the basis for the proposal of biologically inspired robotic systems. Additionally, we describe the development of computational agents for solving complex problems in real-time applications.

1 Introduction

Developing computational agents requires not only to carry out their modeling and analysis, but also having a Programming Environment where they can be developed and tested. In the laboratory of Adaptive Neural Behavior, Neurosciences and Simulation (CANNES by its acronym in Spanish), our main objectives are: the development of computational (i.e., Schema Theoretic an Neuronal Networks) models to explain the underlying neural mechanisms responsible for animals' behavior; the design of simulation languages and software architectures to support our modeling efforts; and the application of these models in the design of autonomous robotic systems. On the other hand, in other research labs (e.g., Knowledge Acquisition Lab, and Computer Networks and Telecommunications Lab) we consider of great importance that the technology developed in our research fields (e.g., Computational Neuroscience, Artificial Intelligence, and Telecommunications) be used to develop computational systems to solve complex problems, in areas of application where traditional techniques offer a poor solution or no solution at all.

Thus, in here, we give a brief description of some of our research projects. In the first part, the design of a Neural Simulation Language (NSL) is presented. NSL is

[1] F. Cervantes-Pérez and J. Incera acknowledge partial support from the "Laboratorio Franco Mexicano de Informática (LAFMI)", under the contract for 2004-2005.

intended to support the development of biologically based models of the underlying neural mechanisms of animal's behavior. In addition, we discuss how these models, in turn, have been used as the basis for building behavior-based robotic systems.

In the second part, two other projects related to technological development are described. The aim here is to construct computational agents for solving complex problems in real time applications: a) automated negotiation with humans, and b) traffic prediction in communications packet networks.

Finally it must be pointed out that our work has allowed us to propose a knowledge representation paradigm comprised of the interactions among several subsystems working at different levels of temporal abstraction. This knowledge representation model, and its relationship to planing and learning, are key issues in Distributed Artificial Intelligence, and in Behavior-Based Robotics [1][2][3], in particular, when the aim is to build *agents* that could incorporate into their control system different aspects of their relationship with other *agents*, or with an uncertain environment (i.e., their "*ecology*").

2 NSL Programming Environment

In terms of simulation languages and software architecture design, we are currently completing the integration of previous programming environments (i.e., Neural Simulation Language and Abstract Schema Language) into a new version of a Neural Simulation Language (NSL), in order to support simulation at the behavior and neural networks levels. This work integrates aspects such as compiled languages to describe models, scripting languages for interactive simulation control, visual programming languages, graphical interfaces, visualization techniques, concurrent (multithread) and distributed processing, meta-architectures, numerical analysis tools and simulation methodologies. Two implementations of NSL are currently being completed: NSLC in C++, and NSLJ in Java [4].

In terms of computational models, a multi-level simulation methodology is being developed to provide a framework in answering some of the questions arising in highly complex neural systems which single level models cannot. In particular, four different levels of analysis are studied: autonomous robotic agents, agent behavior, neural networks, and detailed neurons.

- At the highest level, autonomous robotic agents are designed to interact with the world via sensors and actuators. These agents are simulated in virtual robots and implemented in real robots with systems such as *MissionLab* [5].
- At the behavior level, neuroethological data from living animals is gathered to generate single and multi-agent systems to study the relationship between an agent and its environment, -giving emphasis to aspects such as cooperation and competition between agents. Agent behavior is described in terms of hierarchical and distributed perceptual and motor *schemas* [6]. Schemas agents at the behavioral level are simulated via the Abstract Schema Language ASL [7]. Examples of schema models include the praying mantis *Chantlitlaxia* (in search of a proper habitat) [8] and frog and toad prey acquisition and predator avoidance models [9].

- At the neural network level, neuroanatomical and neurophysiological data are studied to explain the underlying neural mechanisms for sensory-motor integration corresponding to schema models developed at the behavioral level. Neural networks are simulated via the Neural Simulation Language NSL [10]. Neural network models are exemplified by the prey acquisition and predator avoidance neural models [11] and the retino-tectal-pretectal neural circuitry modulated by learning processes responsible for habituation [12].
- At the detailed neural level, electrochemical neural mechanisms are studied to understand different neural phenomena, such as presynaptic inhibition in the control of synaptic selectivity [13].

3 Laying the basis for Building Biologically Inspired Agents

Living animals have been valuable biological models to the study of sensory-motor coordination, not only for getting an in-depth understanding of the neurobiological basis of behavior but also for inspiring control schemas in mobile robotics [14][3]. For example, frogs and toads are animals that live within complex and uncertain three dimensional environments rich in different modes of sensory signals; although their behavior is mainly guided by visual information. They have a limited behavioral repertoire, and their survival chances depend on their ability for displaying, at every moment, the most appropriate action in order to cope with diverse environmental situations. The amphibia's visually guided behaviors have been classified in seven categories [15]: a) orienting; b) prey-catching; c) avoidance and hiding; d) eye responses (e.g., accommodation and ocular movements); e) vegetative responses of short latency (e.g., breathing and heart beating); f) vegetative responses of long latency (e.g., circadian rhythms); and g) changes on skin color to changes in illumination, or in the background.

Among these behavioral patterns, prey-catching is essential for survival, and it can be studied under lab conditions at different levels of analysis. In ethological studies, using different types of visual dummies, it has been shown that these animals' response to potential prey is determined by different factors, whose processing runs at multiple temporal scales:

- *stimulus characteristics* (e.g., form, size, geometrical configuration with respect to the direction of motion), and the spatial temporal relationship between the animal and its prey [15][16];
- *previous experiences with the stimulus*, e.g., learning and conditioning [17][18]; and
- *motivational factors*, e.g., season of the year, food deprivation and maintenance within the lab prior to the experiments execution [19][20].

In previous work [3], we used Schema Theory as an interlingua to implement a model of the agent-environment interactions of living animals (i.e., with data taken from our experiments with the Praying Mantis [8] and with toads [11] into the control system of a robotic hexapod, Hermes II, that displays visually guided behaviors, such as prey-acquisition, mating, predator-avoidance, obstacle-avoidance, and the "*chantlitaxia*" behavior.

Aditionally, the idea of sensory-motor coordination being modulated by changes in motivational factors was put in practice, by including three motivational variables: *hunger*, *sex-drive*, and *fear*. There, the first two were considered to increase linearly with time, and to reset to zero when the robot makes contact with a prey, or a mate; at that time it is assumed that the robot has eaten or mated. *Hunger* was also assumed to increase more rapidly than *sex-drive*. In the case of *fear*, its level remains equal to zero until a predator appears in the robot's visual field, then, the corresponding variable is set to a predetermined high value, and reset to zero once the predator is no longer visible. Thus, in order for the robot to properly cope with specific environmental situations, in the *Action-Selection* algorithm the state of the variable with the greatest current value is integrated with the level of activity produced by the current situation. If there is an associated stimulus (i.e., a prey for the *hunger* variable), then the robot executes the corresponding behavior; otherwise, this process is repeated with the motivational variable with the next greatest value, and so on. In case there is not a prey, or a predator, or a mate, or an object that signals a *hiding* place, then, the robot keeps on exploring the surroundings. As a sequel of our work, the challenge remains to design control algorithms that include more realistic models of how motivational variables, as well as learning processes, changing over time at multiple temporal scales, affect the efficacy of visual stimuli to yield proper behaviors.iles.

4 Computational Agents in Real-Time Applications

Another important issue in our research group is to use our schema-theoretic and neuronal networks models, in combination with techniques developed within Distributed Artificial Intelligence, to build computational agents for solving complex problems in real-time applications. Thus, in this section an agent for conducting automated negotiations with humans is presented, followed by the description of a neuronal networks based agent for predicting the traffic in a LAN (Local Area Network) interconnected to a communications packet network (e.g., Internet).

4.1 A Negotiation Strategy for Electronic Trading using *Intelligent Agents*

Automated negotiation is an important type of interaction in systems composed of autonomous agents [21]. Given their ubiquity, such negotiations may exist in many different shapes and forms. However, we consider a particular type of automated negotiation: *competitive negotiation*. This negotiation takes place over a single price between an agent and a user with different firm deadlines. This is exemplified by the e-commerce scenario in which both a buyer and a seller agent negotiate over the price of a specific product. The buyer clearly prefers a low price, while the seller prefers the opposite. In order to obtain the best price, usually, agents need to ensure that negotiation ends before a certain deadline. However, the timeout may not be the only way in which time influences negotiation behavior. This may be the case when one of the participants, for instance the buyer, is losing utility along time as a result of not getting the service. On the other hand, the seller may perhaps gain more utility by providing the service as late as possible. In short, it is clear that an agent can have different attitudes toward time [22].

In this subsection, we describe a computational agent capable of conducting a negotiation process in a B2C electronic transactional model. In our project, the problem of building interactive systems for the World Wide Web is addressed. First, we define the system to be developed, which leads us to focus on a negotiation protocol and its operation. In order to support a web design, both an intelligent reactive agent and the architecture associated to its environment are defined. It is important to remark that animations are included in order to communicate that the agent might represent an actual person. The idea of providing a *virtual person* should reduce the impact created on people by the new technology. We claim that our computational system improves the critical business processes by using *intelligent agents* to make them robust.

At the moment, in the Latin American market there isn't an appropriate tool to perform automated negotiations over Internet. The approach given to the electronic commerce is either static (without using the inherent advantages of e-commerce) or uses methods like auctions, primarily the English auction, which work fine in other countries; but are not suited for the Latin-American way of thinking. The use of auctions didn't have the desired popularity mainly because:

- A vast majority of the people doesn't know the underlying process of an electronic auction.
- Latin American consumers focus more on the price, so the perception of auction prices going up instead of going down has a negative impact.
- Electronic auctions have the problem of the auction closing time –clearance-, sometimes the bidders have to wait for a long time until a winner is announced.
- The need of having a critical mass of buyers in order for the auction to work properly. This is because the reserve price may not be met and, thus, the item remains unsold or the seller receives a low payment for it.

Based on these reasons, it can be concluded that the English Auction model is not well suited for the idiosyncrasy of buyers and sellers in Latin-American. Here, a negotiation strategy based on a haggling approach is proposed, which is somehow more related to the Dutch Auction model. This model provides the following advantages:

- The buyer uses the same strategy model when he/she buys things in the real life.
- The buyer has a buying experience closer to the real life and the feeling of achieving a lower price, because it always goes down.
- The negotiation agreement can be reached in a few minutes.
- It eliminates the need for a critical mass of buyers.

4.1 A Neural Network-Based Agent for Traffic Prediction in Packet Networks

Traffic prediction in packet networks, like Internet, is a key issue because it would improved the quality of service associated to a wide range of real time multimedia applications, such as video streaming, IP telephony, and videoconferencing; as well as to successfully implement congestion control algorithms, bandwidth allocation, and traffic shaping and other engineering processes.

The traffic prediction problem has been attacked by using several techniques: least mean square filter or similar techniques [23], regression and statistical models (AR, ARIMA, FARIMA, etc.) [24], fuzzy logic with regression [25], etc. There have been also some attempts to solve this problem by using artificial neural networks [26]; however, in those papers, people has concentrated only in short-term dependencies, neglecting the long-term ones.

Our aim in this type of study has been to develop a neural networks based multi-agent architecture (i.e., artificial neural networks located at different routers in a Local Area computer Network), working in a continuous training paradigm, for on-line traffic prediction. In addition, the neural networks are combined with statistical models of their performance, and a mathematical equation associated to the characteristics of the LAN's output router that determines the instant when bandwidth resources are insufficient and packets need to be dropped.

The "Multi Router Traffic Grapher" (MRTG) software was used to record real traffic traces, in time blocks of five minutes, from ITAM's Local Area Network (LAN). Additional information was stored with the traffic traces, and it is related to the date, day and time of the day of the recordings. It was found that traffic behavior is highly non linear, with clear temporal non regularities.

Given the high complexity of the LAN traffic traces, the database was analyzed to search for behavioral patterns that permit to segment the overall problem. That is, the question being addressed was whether or not, different types of days (e.g., week-days, week-end, holydays, etc.), or different time periods within a day (e.g., working hours, lunch time, or closing hours) present behaviorally similar network traffic. In searching for behavioral patterns, based on qualitative and quantitative characteristics, Kohonen's clustering algorithm was used for analyzing the network traffics temporal behavior. Different data combinations were tried, but from the results obtained in our simulations, it was concluded that even though there are several days, or times during a single day, where certain regularity can be observed, there are always some parts in time when that regularity is lost. Thus, the data base of traffic traces can not be segmented, and a single neural network should be developed in order to explore if this approach might generate a good LAN' traffic prediction.

In building the neural network, a three-layered architecture was selected and the *backpropagation* learning algorithm was used to train it. Our computer simulations served to build an agent that uses traffic traces data from the previous 30 minutes, and a two-weeks historic database, in order to produce a good prediction (i.e., with a R^2 of 0.916, and a correlation coefficient of 0.958) when been retrained every day. Currently, we are working on adding data obtained from a performance analysis of the trained neuronal network, to compensate for the error associated to its traffic prediction. Also, in futures stages this prediction will be used in combination with the LAN's output router characteristics to determine the instant when the allocated bandwidth would become insufficient to handle current traffic conditions and, therefore, it becomes necessary to start dropping some packets.

5 Final Remarks

At ITAM, a multi-disciplinary research group has been formed whose main concern is to carry out R&D projects based on the integration of technologies originated in the fields of Computational Neuroscience and Artificial Intelligence.

In this paper, it was described how our approach includes, on the first hand, the use of Schema Theory and mathematical models of biological neuronal networks as an interlingua to implement a model of the agent-environment interactions of living animals (e.g., Praying Mantis, and Amphibians) into the control system of a robotic system that displays visually guided behaviors, equivalent to prey-acquisition, mating, predator-avoidance, obstacle-avoidance, and the "*chantlitaxia*" behavior.

Finally, it was also described, on the other hand, our interest in the construction of "hybrid" *intelligent* agents (i.e., based on the integration of Expert Systems, Artificial Neural Networks, Statistical and Mathematical models, etc.) which can be used in solving complex problems in areas where traditional approaches produce poor results, or don't offer any solution at all.

References

1. Sutton, R.S. and Barto, A.G. *"Reinforcement Learning: an Introduction"*. MIT Press, Cambridge, MA (1998).
2. Beer, R., Chiel, H. and Sterling, L. "A biological perspective on autonomous agent design". *Robotics and Autonomous Systems*, (1990) Vol. 6, pp. 169-186.
3. Arkin, R., Khaled Ali, Weitzenfeld, A., and Cervantes-Pérez, F. "Behavioral models of the praying mantis as a basis for robotic behavior". *Robotics and Autonomous Systems*, (2000) Vol. 32, pp. 39-60.
4. Weitzenfeld, A., Arbib, M.A., and Alexander, A. *The Neural Simulation Language: A System for Brain Modeling*, MIT Press, Cambridge, MA (2002).
5. MacKenzie, D., Arkin, R.C., and Cameron, J. "Multiagent Mission Specification and Execution", *Autonomous Robots* (1997) Vol. 4, No. 1, pp. 29-57.
6. Arbib, M.A. "Schema Theory". In: Shapiro, S. (ed.). *The Encyclopedia of Artificial Intelligence, 2nd Edition*. Wiley-Interscience, New York (1992), pp. 1427-1443.
7. Weitzenfeld, A., "An Overview of ASL: Schemas and Neural Networks in Concurrent Object-Oriented Programming". In: Proceedings of OOPSLA '92, Workshop on Next Generation Computing, Vancouver, Canada. (1993).
8. Franco, A., y Cervantes, F. "Análisis Teórico-Experimental de la Coordinación Visuomotora de la Mantis Religiosa". *CIENCIA* (1990) Vol. 41, pp.249-264.
9. Cobas and Arbib, 1992
10. Weitzenfeld, A. and Arbib, M.A. NSL Neural Simulation Language. In: Skrzipek, J. (ed.) *Neural Networks Simulation Environments*. Kluwer Press (1994).
11. Cervantes-Pérez, F., Guevara, D. and Herrera, A. "Modulation of prey-catching behavior in toads: data and modeling". In: Ewert, J.P. and Arbib, M.A. (eds.). *Visual structures and integrated functions*. Research Notes in Neural Computing, Vol. 3. Springer Verlag, Berlin Heidelberg New York (1991), pp. 397-415.
12. Cervantes-Pérez, F. "Visuomotor Coordination in Frogs and Todas". In: Arbib, M.A. (ed.): *Handbook of Brain Theory and Neural Networks* 2nd Edition. MIT Press, Cambridge, MA (2003), pp. 1219-1224.

13. Rodríguez, T.G. “Control de flujo de señales en redes neuronales”. Tesis en Ingeniería en Computación, Instituto Tecnológico Autónomo de México (ITAM) (1999).
14. Arkin, R. “Neuroscience in motion: the application of Schema Theory to Mobile Robotics”. In: Ewert, J.P. and Arbib, M.A. (eds.). *Visuomotor Coordination: Amphibians, Comparisons, Models, and Robot*. Plenum Press, New York (1989), pp. 649-672.
15. Grüsser, O.J. and Grüsser-Cornehls, U. “Neurophysiology of the anuran visual system”. In: Llinás, R., and Precht, W. (eds.). *Frog neurobiology*. Springer Verlag, Berlin, Heidelberg, New York (1976), pp. 297-385.
16. Ewert, J.P. “Tectal mechanisms that underlie prey-catching and avoidance behaviors in toads”. In: Vanegas, H. (ed.). *Comparative neurology of the optic tectum*. Plenum Press, New York (1984), pp.247-416.
17. Ewert, J.P. and Kehl, W. “Configural prey-selection by individual experience in toad *Bufo-Bufo*. *J. Physiol.*. (1978) Vol. 126, pp. 105-114.
18. Finkestädt, T. “Stimulus specific habituation in toads: 2DG studies and lesion experiments. In: Ewert, J.P. and Arbib, M.A. (eds.). *Visuomotor Coordination: Amphibians, Comparisons, Models, and Robots.* Plenum Press, New York (1989), pp. 767-797.
19. Cervantes-Pérez, F., Herrera, A. and García, M. “Modulatory effects on prey-recognition in amphibia: a theoretical-experimental study”. In: Rudomín, P., Arbib, M.A., Cervantes-Pérez, F., and Romo, R. (eds). *Neuroscience: From Neural Networks to Artificial Intelligence*. Research Notes in Neural Computing, Vol.4: Springer-Verlag, Berlin Heidelberg New York (1993), 426-449.
20. Ewert, J.P. *Neuroethology: an introduction to the neurophysiological fundamentals of behavior*. Springer Verlag, Berlin, Heidelberg, New York (1980).
21. P. Faratin; C. Sierra & N. Jennings. Negotiation decision functions for autonomous agents. *International Journal of Robotics and Autonomous Systems*, (1998), Vol. 24, Num. 3-4, pp. 159–182.
22. S. Fatima; M. Wooldridge & N. Jennings. Optimal Negotiation Strategies for Agents with Incomplete Information. In J. Meyer and M. Tambe (eds.). *Intelligent Agents VIII*. Lecture Notes in Artificial Intelligence, Springer Verlag, Berlin Heidelberg New York (2002).
23. Leland, W.E., Taqq, M.S., Willinger, W., and Wilson, D.V. “On the self-similar nature of Ethernet traffic”. In: Proceedings of ACM SIGCOMM (1993), pp. 183-193.
24. Shu, Y., Jin, Z., Zhang, L., Wang, L., and Yang, O.W. “Traffic prediction using FARIMA models”. In: Proceedings of IEEE International Conference on Communication (1999), pp. 891-895.
25. Chen, B-S., Peng, S-C., and Wang, K-C .“Traffic modeling, prediction,, and congestion control for high speed networks: A fuzzy AR approach”. *IEEE Transactions on Fuzzy Systems* (2000) Vol. 8, Num. 5, pp. 491-507.
26. Youssef, S.A., Habib, I.W., and Saadawi, T.N. “A neurocomputing controller for bandwidth allocation in ATM networks”. *IEEE Journal on Selected Areas in Communications* (1997) Vol. 15, Num. 2, pp. 191-199.