Biological implementation of algorithms and unconventional computing

J.N. Argota Quiróz, R. Basurto Flores, T.G. Bermúdez Cisneros, I.Y. Fernández Rosales, A.G. Naranjo, J.C. Gómez Sánchez, M.E. González Jiménez, R.E. Gordillo Padilla, A.J. Leal Baena, P.A. Leon Hernández, P.G. Padilla, R. Peña Miller, I.N. Ríos Gaspar, J.C. Rodríguez Chico, A. Rodríguez Martínez, J.P. Romero, A. Sánchez Arzate, J.S. Aranda Barradas, D. Araujo Díaz, A. Becerra Bracho, C. Benítez, C.I. Franco Arteag, F. Hernández Quiroz, G. Juárez Martínez, J. López Rabadán, M.C. Oliver Salvador, P. Padilla Longoria, R. Palma Orozco, F. Ramírez Corona, E. Salgado Majarrez, E. Samra Hassan, C. Silva Sánchez, U. Vélez Saldaña and P.B. Zarate Segura

Abstract: The Mexican iGEM team (http://parts2.mit.edu/wiki/index.php/IPN_UNAM_2006) is a recently established group whose main interest is the implementation of algorithms in biological systems. Our goal is to take advantage of the intrinsic features of these systems in order to explore new approaches to certain computations (unconventional computing). We focus on three different frameworks: cellular automata, reaction-diffusion based computations and approaches from game theory. In the near future we plan to develop real-world applications that not only contribute to the understanding of specific problems in biology, computer science and related disciplines, but that also have a positive social impact. We are optimistic about the great benefits that genetically engineered machines might offer, particularly in a country like Mexico. On the other hand we are also conscious of the risks they involve and would like to stimulate a serious discussion about ethical and legal implications as well as the impact they might have on the community.

1 Aims of the project

The project focuses on the implementation of algorithms in biological systems. For that we have chosen three specific aspects:

(1) Computation based on cellular automata
(2) Reaction-diffusion implementations
(3) Game theory problems and applications

Our group has previous experience in cellular automata, in particular through the work of G. Martínez who has extensively studied the diffusion life rule 110 [1] (see Fig. 1). Much progress has been made in exploring the possibilities of these systems in unconventional computations. More specifically, how gliders, blinkers and other structures arising in cellular automata can be used in order to implement logical gates and, eventually, more complex algorithms. One of our first goals is to be able to realise these automata in biological systems. From a more abstract point of view, we are also interested in the connection of these systems with formal languages and graph theory.

In recent years the implementation of unconventional computational techniques, specifically those based on reaction-diffusion systems have attracted interest for both theoretical and applied reasons (see [2] for example). Several computations have been successfully carried out in real chemical systems and it seems natural to try to extrapolate them to a biological setting.

From a theoretical point of view, it is of great importance to understand the role of the architecture of genetic networks that lead to pattern formation. In particular, simple network architectures might account for the emergence of complex patterns. Currently we are working on the implementation of an activator-inhibitor model in the simple setting of a network consisting of two genes (Fig. 2) that has a counterpart in a real system [3]. We investigated whether such systems could produce so-called Turing patterns.

Finally, we also considered the possibility of designing genetic circuits coding different strategies in several classical games, such as the dove–hawk or the prisoner's dilemma. Once done, it would be possible in principle to create several types of populations of bacteria that each carried out a different strategy. This would allow us to test and further explore collective behaviour from a game-theoretical point of view. In particular it would be interesting to see if some concepts such as evolutionary stable equilibria or Nash equilibria can be obtained. This approach could lead to potentially useful applications, since modifying the strategy of the bacteria can result in a viable therapy for some diseases.

2 Description of the work

As pointed out before, iGEM Mexico is a recent group and we are still at the initial stages of our project. Right now we have met all the requirements in terms of experimental equipment as well as expertise and are beginning to develop and build our prototypes. We are hoping to present them at the next iGEM competition. We are also actively seeking financial support from our institutions as well as from other sources both public and private. Fig. 3 shows some members of the iGEM Mexico team who

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The authors are with the National Polytechnic Institute (Instituto Politécnico Nacional), Zacatenco, Mexico; the National Autonomous University of Mexico (Universidad Nacional Autónoma de México), Mexico City, Mexico; the National Autonomous University of Hidalgo State (Universidad Autœnoma del Estado de Hidalgo), Pachuca Hidalgo, Mexico; and the Centre of Advanced Studies and Research (Centro de Investigación y de Estudios Avanzados), San Pedro Zacatenco, Mexico

E-mail: pablo@mym.iimas.unam.mx

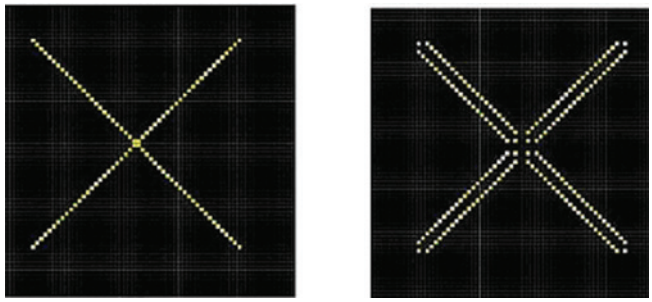

Fig. 1 *An example of a configuration obtained with the diffusion rule*

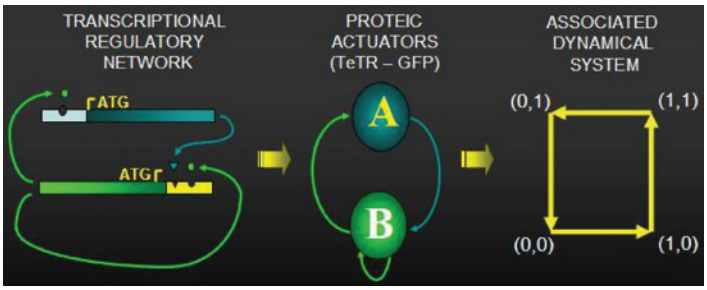

Fig. 2 *Schematic representation of a simple transcriptional regulatory network leading to an activator-inhibitor system and its dynamical systems counterpart*

Fig. 3 *Several members of the iGEM Mexico team in the 2006 Jamboree at MIT*

From left to right are Paulina A. León Hernández, Jaime López Rabadán, Tania Bermúdez Cisneros, Randy Rettberg, Carlos Silva Sánchez, Fabiola Ramírez Corona and Rosaura Palma Orozco

participated in the iGEM2006 Jamboree 2006 at MIT and received from Dr Rettberg the 'Best Work in Progress' award.

3 About the group

The iGEM Mexico team started around March 2006 when Randy Rettberg and Genaro Martínez began to explore the possibility of forming a Mexican group. In July the iGEM ambassador for Latin America, Meagan Lizarazo, visited Mexico City. By then several students and researchers from the IPN (the National Polytechnic Institute) and UNAM (the National Autonomous University of Mexico), including biologists, computer scientists, physicists and mathematicians had put forward a specific program based on unconventional computing.

4 Conclusions

We have been able to successfully integrate a group of students and researchers in order to start iGEM Mexico. We have also proposed concrete projects based on the implementation of algorithms in biological systems which focus on:

- Cellular automata, in particular the rules of diffusion needed to carry out unconventional computations
- Connections with formal languages and graph theory
- Pattern formation generated by simple genetic regulatory networks and its possible connection with Turing patterns.

Eventually, we would also like to investigate:

- Genetic algorithms in real biological systems
- Information processing with genetically engineered machines
- Distributed data bases
- Virtual reality applications.

5 Acknowledgments

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6 References

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