Master internship :

Biologically-inspired control of complex systems for pattern generation.

Location : Équipe-projet MANAO, INRIA, Université de Bordeaux, France

Supervision : Pascal Barla (**pascal.barla@labri.fr**) - Bastien Morel (**bastien.morel@u-bordeaux.fr**)

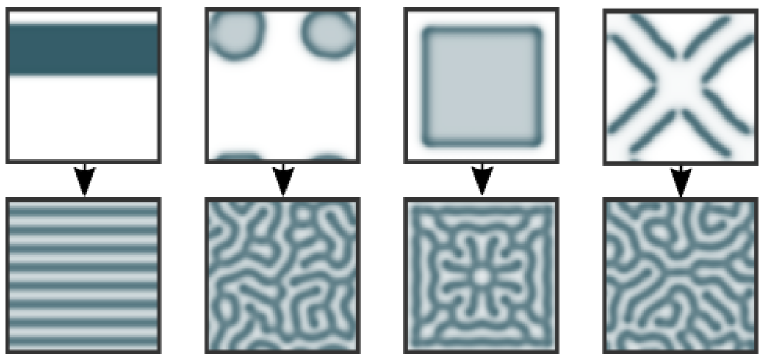

Figure 1: Initial conditions (top line) and pattern produced (bottom line) by a Gray-Scott reaction-diffusion system.

In the living world, a large number of processes enable patterns to emerge at different scales (e.g. butterfly wing structuring, skin pigmentation distribution, vegetation distribution in a landscape). The processes at work are of different natures, but have in common a robustness to the perturbations inherent to living organisms (e.g. temperature variations). Reaction-diffusion systems [1] (and, to a lesser extent, cellular automata) enable the formation of patterns similar to those observed in nature. However, they tend to be sensitive to initial conditions and perturbations [2], limiting their control by reducing the predictability of the patterns produced. This sensitivity to initial conditions is illustrated above.

In addition, the generation of certain patterns (e.g. leopard rosettes) involves a succession of different processes. One way of modeling these patterns is to run a sequential sequence of different reaction-diffusion systems. The pattern produced by one system is applied as the initial condition to the next.

Objectives :

The goal of this internship is to develop methods for controlling complex artificial systems, with the aim of increasing their robustness to disturbances and initial conditions.

A first approach is based on biologically-inspired control methods: growth of the domain over which the system is simulated [3], anisotropic parameterization [4] or the setting up of a propagation front [5], locally activating the system's interactions. We want to study the impact of these methods on a sequential rollout of different systems. The aim is to increase the complexity of the patterns produced, while retaining the robustness introduced by these methods.

The second approach is based on artistic control. In this case, patterns will be generated in the form of *"alive textures"*, with which a user must interact. For example, he or she will be able to freeze the system locally, apply perturbations to the parameters or the grid, or re-generate sub-parts with different initial conditions, all with real-time feedback of these modifications. The sequence of these actions may lead to the destruction of the pattern, so the goal is to design a process whose continuous perturbation still leaves room for emergence. The robustness of the pattern depends on the nature, location and temporality of these disturbances.

Required skills :

- Python and associated software libraries (NumPy, JAX).
- 3D programing (OpenGL / WebGL, GLSL).

Depending on the candidate, the internship may focus on biologically inspired and/or artistic control.

References

[1] A. Witkin and M. Kass, “Reaction-diffusion textures,” *ACM SIGGRAPH Computer Graphics*, 1991.

[2] P. K. Maini, T. E. Woolley, R. E. Baker, E. A. Gaffney, and S. S. Lee, “Turing’s model for biological pattern formation and the robustness problem,” *Interface Focus*, 2012.

[3] M. De Gomensoro Malheiros, H. Fensterseifer, and M. Walter, “The leopard never changes its spots: Realistic pigmentation pattern formation by coupling tissue growth with reaction-diffusion,” *ACM Transactions on Graphics*, 2020.

[4] T. W. Hiscock and S. G. Megason, “Orientation of Turing-like Patterns by Morphogen Gradients and Tissue Anisotropies,” *Cell systems*, 2015.

[5] Y. Liu, P. K. Maini, and R. E. Baker, “Control of diffusion-driven pattern formation behind a wave of competency,” *Physica D: Nonlinear Phenomena*, 2022.