# Interactive Modeling of 3D Shapes filled with Anisotropic Microstructure using Reaction Diffusion

*Example of filling 3D shape with complex microstructure [Garnier21].*

3D shapes filled with complex porous structure have been made popular with the recent advance of 3D printing in enabling such representation to be manufactured [Tricard20, Wu21]. These shapes typically enable good stiffness property while limiting the amount of required material compared to a fully volume filled with plain material. Interestingly, several natural elements that follows a growing process such as bones or coral exhibits such complex and convoluted shape [Fratzl07, Zanni12].

One of the most widespread model to represent a wide variety of biological grows behavior is the Reaction Diffusion (RD) equation proposed in a seminal work of A. Turing [Turing52]. Expressed as a Partial Differential Equation, RD simulates the time evolution of two, or more, fields called “species” (initially derived for chemical species) that continuously diffused in one another, while interacting non linearly (the Reaction term). RD has been largely studied to generate primarily texture [Turk91, Sanderson06], displacement maps [Witkin91], as well as surfaces grows [Gingras19], but the result remains challenging to control due to the non linear nature of the PDE.

One of the most studied RD is the Gray-Scott model [Gray84] that set a specific function of the Reaction term parameterized by two values: the feed (f) and kill (k) rates and can model dotty or wormy-like patterns[1] that evolves in space from an arbitrary initial condition.

$$\frac{\partial u}{\partial t} = \Delta u - uv^2 + f(1-u)$$

$$\frac{\partial v}{\partial t} = D\,\Delta v + uv^2 - (k+f)v$$

This relation can be extended to generate a material that evolves only in a pre-defined spatial domain, as well as exhibit anisotropic behavior. We showed in a recent work [Garnier21] that using such extended formulation coupled with multiple RD simulation enables to generate robustly complex shapes exhibiting microstructures such as stripes and lattice patterns with good regularity. The advantage of the use of RD other parametric approach relies on its very robust shape generation that can be perturbed by user input (like dynamically removing some parts) during its evolving process, while preserving its global coherence.

So far, we studied the use of this controlled extended RD evolution in the context of mechanical shapes generation with prescribed tensor field automatically computed from Topological Optimization. In this project, we aim at extending its use toward interactive modeling of 3D shape for Graphics applications in order to leverage RD as a simple and robust way to generate shape infilled with complex patterns. The resulting shape may look like a biology-inspired representation or can be used for an efficient abstract art-based shape design.

**Methodology**:

We aim at proposing an interactive interface allowing to easily control the degrees of freedom of the extended Gray-Scott RD model using painting and sketching metaphor, first in 2D and possibly in 3D.

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[1] https://pmneila.github.io/jsexp/grayscott/

The objective will be to provide in a most expressive way the following inputs:

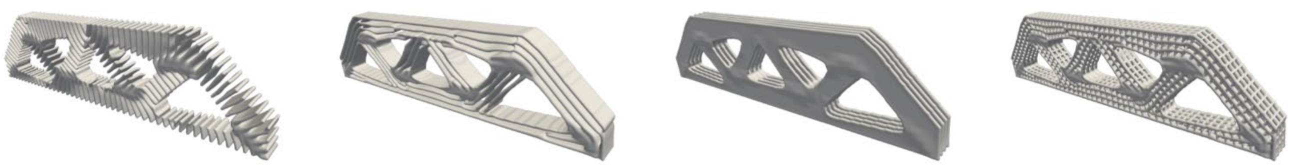
- The domain of evolution of the RD: A binary field.
- The local orientation and magnitude of anisotropy: A tensor field.
- Additional scalar fields possibly indicating local feed/kill values, variation of blending/isovalues of the RD specie, blending between multiple RD.

The RD process is then obtained in numerically simulating the evolution of the fields/species in a discrete 2D/3D grid. The final shape is obtained as an isosurface of one of the field/specie.

The following steps will be implemented during this work:

1. The domain of evolution of the RD is defined from a user painting, or using a pre-defined shape.
2. An anisotropic tensor field is defined using an expressive approach. For instance, in sketching a few stokes over the domain defining the main diffusive orientation. This coarse set of information will need to be converted into a continuous field over the domain using diffusion or interpolation schemes.
3. Additional local information is added such as the magnitude of anisotropy, using either sketching or color painting.

4+. Additional fields to control the other parameters of the RD, as well as blending with multiple RD processes.



*Blending multiple RD processes can be used to bring additional structure – here the three orthogonal RD processes are blended used to generate the shape on the right.*

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