Doctoral thesis position – 2024

Title: Study of constrained patterns for the synthesis of procedural materials

Host team: IGG (Computer Graphics and Geometry Group), ICube laboratory

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Keywords: Computer graphics, procedural materials, spatial arrangements

Desired skills:

- Knowledge and experience in computer graphics
- Basic machine learning skills
- Curiosity and ability to communicate, share progress and write reports
- Autonomy and good organizational skills

Abstract

The generation of spatial arrangements of patterns is a major component in the creation of virtual materials in image synthesis. This thesis focuses on procedural representations, enabling the generation of pattern arrangements at different levels of scale over large spatial areas with very low storage costs. In nature, as well as in engineering structures, spatial arrangements respond to multiple constraints: physical, statistical or artistic. However, most existing procedural models, such as the Point Process Texture Basis Function (PPTBF) model we developed, do not take such constraints into account. The aim of this thesis is to enrich the PPTBF model, which is based on 2D point distributions convolved by local shapes, with new parameterized and differentiable distributions and shape functions capable of adapting to spatial constraints. The work will begin with a review of state-of-the-art procedural models and spatial point distributions. It will then develop a point generation method based on an example distribution and a procedural map enabling constraints to be parameterized and applied. Our novel method will be extended to the multiple point classes, while studying also the contribution of hyperplane distributions and an extension to 3D. Its main application will be the synthesis of natural scenes.

1. Context and problem statement

The creation of spatial arrangements (or spatial distributions) of patterns (or discrete shapes) is present in many applications of computer graphics, in particular to synthesize structured materials to be applied to three-dimensional virtual environments such as landscapes, and populate these environments (rocks, vegetation, hydrographic networks, infrastructures, habitat). Procedural representations are characterized by random accessibility in an unbounded domain, making it possible to generate arrangements of patterns at different scales over large spatial areas in 2D or 3D with very low storage costs [EMP+02]. It's now commonplace for designers in the graphics industry to design procedural material graphs using tools such as Adobe Substance 3D Designer [Sub] to create complex materials. Procedural material graphs are made up of nodes corresponding to the implementation of algorithms for generating patterns (e.g., a brick wall) or noise (e.g., cloud patterns), or to image processing operations applied to the generated patterns (e.g., a Gaussian filter). The IGG team has developed the Point Process Texture Basis Function (PPTBF) model, based on 2D point distributions convolved by local parametric shapes, covering a wide range of stochastic structures [GAD+20]. To cope with the time-consuming nature and high level of expertise required to build such models and set their parameters, methods have been developed for automatically estimating parameters from examples provided in the form of images, notably by gradient descent using differentiable functions [HGH+22, BAD23, LSM23]. These estimation methods are applied without modifying the structure of the procedural models, and are limited by the representational power of each model.

In nature, as in engineered structures, spatial arrangements respond to multiple constraints, formulated in different ways and at different scales, whether physical, statistical, semantic or artistic. These may be mechanical, space-occupation, relative placement or manufacturing constraints. Most existing procedural models do not take such constraints into account. The PPTBF model [GAD+20] does not, for example, allow the distribution of points to conform to a particular example of a set of points that does not correspond to a distribution implemented in the model, or to a density function. Models therefore need to be adapted with new parameters to extend their representational power.

1. Thesis goal

The goal of this thesis is to enrich the PPTBF model [GAD+20] using new parameterized and differentiable distributions as well as shape functions capable of adapting to spatial constraints.

The work will begin with a review of state-of-the-art procedural models and spatial distributions. It will then develop a distribution estimation and point generation method based on an example point set and a procedural map for parameterizing and applying constraints. Particular attention will be paid to constraints represented in the form of label maps and density maps. This work could be based on recent work on the stratification of point sets by optimal transport [DBC+23] and on *Curl Noise Jittering* [FM23], to represent a wide variety of distributions, while being controllable by continuous parameters suitable for efficient estimation from gradient descent examples. The method developed can be extended to the multi-class case, i.e., several overlapping distributions [SGS+22].

The contribution of hyperplane distributions based on the STIT formalism (STable with respect to ITerations of tessellations) [Cow10], will then be studied, as well as extension to 3D.

The methods developed will be applied to the synthesis of natural scenes, especially landscapes. The codes associated with the team's work will be provided, as well as databases of examples of textures and materials. Developments will be mainly performed in C++ and Python, with the help of graphics libraries and machine learning. A PC equipped with a graphics card suitable for the work will be provided.

3. References

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