PhD Thesis Proposal

Title

Implicit modeling for additive manufacturing

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Context

Additive manufacturing completely changes the way objects can be produced. On the one hand, it simplifies the manufacturing process itself, allowing everyone - including the general public - to physically realize a virtual model using a 3D printer. On the other hand, it affords for unprecedented possibilities in terms of shape complexity, both at the macro and micro scales: objects can be filled with multi-material structures that vary in size, orientation and shape to give specific properties to the final parts. Unfortunately, describing shapes at this level of customization, scale and complexity is beyond the reach of current software. The challenge lies in how to specify shapes than can be easily manipulated, optimized for properties, as well as visualized during manipulation and prepared efficiently for the manufacturing process.

A key technical choice is that of shape representation. Boundary representations (e.g. triangle meshes) are very effective to represent surfaces. However, additive manufacturing blurs the frontier between surfaces and volumes. « *Implicits* », a mathematical definition which computes whether a point is solid or empty, provide an efficient scalable representation **[MDL16,MHSL18]**. Such approaches are referred to as procedural and can be used to represent both gradient of material and microstructures the latter being a key advantage of additive manufacturing. Variation in the microstructures or material composition can be driven by specifying different parameter inputs to the evaluation procedure based on spatial position. The *control field* defining those parameters is itself an important part of the design. There is currently a lack of methodologies to author, manipulate and process such property driving fields.

Objectives

The main objective of this project is to explore representations for the modeling, visualization and processing of both geometry and control fields within the authoring pipeline for additive manufacturing.

The proposed research is regrouped in three main axes.

Generalizing skeleton-based representation

Conducted research will mainly focus on skeleton-based implicit representations (and more precisely convolution-like surfaces **[BS91,ZBQC13]**), the reasons are that those representations are compact and expressive. The proper thickness definition provided by skeletons not only helps for direct manipulation of shape and modeling **[JLW10]** but also provides a way to automatically enforce fabrication constraint such as minimal wall and spike thickness. Furthermore, skeleton representations have many applications **[TDS*16]**: computation of shape collisions will be useful for interactive modeling and shape segmentation can be generalized to describe area within a volume. The first objective of the PhD will be to develop a new skeleton-based implicit representation allowing simple and precise control of the generated shapes and analyze its mathematical properties which will be the foundation for the two other axis.

Controlling gradient of materials and microstructures

We will define interpolations of materials and microstructures' parameter following the methodology of blending of implicits **[GBC*13,ZGC15]**. Hence, this axis will be divided in two parts : interpolation and control structures – relying on skeleton - to achieve shape dependent property description. Fabrication constraints (such as maximum angles that can print without auxiliary support) or properties of the microstructure generator (such as smooth parameter fields with bounded variations (Lipschitz)) should be taken into in the developed methodology.

Visualization and geometry processing for 3d printing

We will first investigate ray-tracing algorithms, indeed rendering algorithms can be used in the slicing process in order to perform it more efficiently **[Lef13]**. For slicing, the main goal is to provide guarantees over the topology of the resulting shape. We will explore the use of topological structures such as Reeb graph and Morse theory (CW-complex representing topology **[Har05]**) or critical points of the scalar field **[SH97]**. Additionally, since implicit surfaces are a smooth continuous representation, it would be a crucial advantage over tessellation to extract slices that are also smooth (some machines can accurately reproduce curves, e.g. 5-axis robots) while allowing easier processing.

To summary, this project seek to explore novel implicit representations in order to provide a unified approach for the modeling and slicing of both macro geometry, microstructures and gradient of material.

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