Computer Graphics Design of Auxetic Metamaterials

European FET OPEN project ADAM2 (https://www.adam2.eu)

PhD (3 years) / PostDoc (1 year) - Start October 2022

Mélina Skouras*****, Stefanie Hahmann*****, ANIMA team, INRIA-LJK, Grenoble
Jonàs Martínez, MFX team, INRIA-LORIA, Nancy
Georges-Pierre Bonneau*****, Maverick team, INRIA-LJK, Grenoble

Contact : *stefanie.hahmann@inria.fr* *georges-pierre.bonneau@inria.fr*

Context

Recent advances in computer graphics, digital fabrication and material science raise thrilling new research challenges in computer science with applications to product design, architecture, medicine, and art. One of them relies on the fact that 3D printing technologies, coming along with increasing computational capabilities, nowadays allow to realize more complex geometries and even control the deformation behavior.

Geometry plays an important role when designing metamaterials. Indeed, metamaterials are materials whose mechanical properties arise from their internal geometric structures rather than the properties of their constituent materials. For example, by adding small notches to a sheet of material, one can easily fabricate 2D metamaterials, that can bend significantly and take on doubly curved shapes when deformed, see Figure 1. Metamaterials thus enable obtaining exotic mechanical properties from common materials by tailoring the small-scale geometry.

Among the mechanical properties, auxeticity is of particular interest, because auxetic materials have a counter-intuitive deformation behavior: instead of becoming thinner when stretched, they become thicker. Auxetic materials are known to exhibit properties important in applications as diverse as biomedical engineering, aerospace industry, or protective sports gear, among others. Most existing auxetic metamaterials are defined as a repeating regular periodic structure [1]. A distinct line of research is otherwise interested in random auxetic materials since they offer certain advantages over regular structures. Recently, some methods have been developed in computer graphics to generate 2D random auxetic metamaterials based solely on a geometric approach, e.g., by pruning a dense network [5], or conducting a parametric growth process [3][4], or combining rotating unit with exotic crystals [6]. However, the design of new and controlled auxetics remains an underdeveloped field of research.

Figure 1: Examples of metamaterials: their mechanical behavior is governed by their geometric structure and not by the material they are fabricated of.

Research Goal

The goal of this Ph.D. is to study the geometric conception of 3D auxetic mechanical metamaterials with a focus on (but not limited to) randomness.

To this end, we will leverage a combination of well-known algorithms from computer graphics, computational geometry and existing regular auxetic structures. We will also investigate to which extent geometric shape parameters can allow for controlling the mechanical behavior to obtain custom mechanical properties. Numerical simulation aspects have to be investigated, in particular when the 3D structures have complex geometries.

Finally, we will integrate these algorithms into intuitive modelling tools that will allow users to easily create free-form 3D objects composed of the designed metamaterials.

Required skills

We are looking for a candidate with a combined math-informatics profile interested in geometric algorithms, data structures, graphical programming and taste for mechanics and simulation. The candidate should have a good knowledge of geometric modeling or computational geometry and good skills in numerical methods, algorithmics and programming (C/C++, Python). Good knowledge of written and spoken English is expected. Curiosity and enthusiasm are essential.

Information for applicants

The PhD will be located at INRIA Grenoble, with regular short visits to INRIA Nancy.
The project ***is part of the European FET OPEN project ADAM2*** (https://www.adam2.eu). The candidate will benefit from an international research environment.

References

[1] Auxetic mechanical metamaterials, H. Kolken, A. Zadpoor, RSC Advances, 7 (9), 5111-5129, 2017

[2] Fabrication and testing of auxetic foams for rehabilitation applications, V.C. Vinay, D.M. Varma, J. Indian Inst Sci 99, 2019

[3] Random Auxetic Porous Materials from Parametric Growth Processes**,** Jonàs Martínez, Computer-Aided Design, Elsevier, 139, 202, 2021

[4] Star-shaped metrics for mechanical metamaterial design, Jonàs Martínez, Mélina Skouras, Christian Schumacher, Samuel Hornus, Sylvain Lefebvre, and Bernhard Thomaszewski. ACM Trans. Graph. 38(4), 2019

[5] 3D periodic cellular materials with tailored symmetry and implicit grading, Semyon Efremov, Jonàs Martínez Sylvain Lefebvre. CAD 140, (2021)

[6] Geometric construction of auxetic metamaterials**.** Georges-Pierre Bonneau, Stefanie Hahmann, Johana Marku. (Eurographics 2021), Computer Graphics Forum 40 (2), pp.291-303, 2021