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MecaCell: an Open-source Efficient Cellular Physics Engine

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Abstract

We present an open source physics engine specialised for multi-cellular artificial organisms simulations. It is computationally efficient in comparison to gas-based and finite element models and more realistic than standard mass-spring-damper systems.

Introduction

Morphogenetic engineering can often make good use of some biologically plausible improvements. Mechanics, in particular, are quite important to a certain group of bio-inspired artificial life experiments. The usual tradeoff in cell simulation being between accuracy and computational efficiency, we have developed a model specialised in cellular physics which aims to stay efficient while precise enough for most artificial life applications. It is based on an improved mass-spring-damper (MSD) system, the use of which is widespread in the literature, mainly because of its computational efficiency. The main limitation in MSD systems is the difficulty they have when taking into account uneven adhesive forces and global tensegrity of a simulated biological system while allowing the simulation of freely moving cellular clusters in a 3D environment (Joachimczak et al. (2013)). We improved on this model by adding adhesion and collision springs, and we took inspiration from Euler-Bernouilli beam theory to account for flexure, torsion and shear, which are only possible with standard MSD system (which natively only handle compression) by using complex topologies.

Physics model

In our current cellular model, a cell is represented by a 3D position, an orientation and an implicit surface. Each cell also has a mass, a radius, a stiffness and an adhesive strength (influencing connection length, resistance to traction, flexure, torsion and shear). Cells are linked two by two by a simplified elastic beam modeled by one compression spring that embeds two tendons per cells. One is used to simulate the flexure relative to the compression spring and the other the torsion. These forces allow for the development of linear structures with interesting tensegrity characteristics.

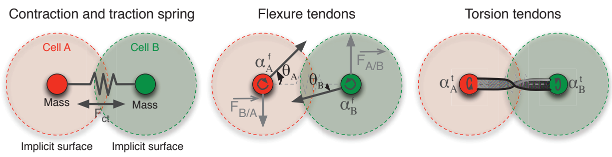

Figure 1: 3 different kinds of connections are used. Traction springs apply equal forces (of opposed directions) to cells A and B, torsion joint apply a torque and flexure joints applies both a torque and an orthogonal force to the opposed cell.

The contact surface between two cells is also used to determine the angular stiffness coefficients. These springs and articulations are created dynamically when the distance between two cells is under a given threshold (given by the cell properties) and are deleted when torn apart too strongly. An explicit integration scheme is used to update the world state.

Conclusion

A simplified 2D version of this engine has been successfully used with a developmental model that open-endedly grows virtual organisms in a constraintfull environment (Disset et al. (2014)) and the current version is being investigated as the basis for more complex 3D morphogenetic engineering experiments. Benchmarks have shown that our implementation of the model can run at 30 frames per seconds with about 20000 cells on a state of the art machine. We plan to test the engine against real in-vitro biological experiments. An implementation as well as videos are freely available at https://github.com/jdisset/MecaCell.

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