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The particle-based model of foraminiferal morphogenesis

Foraminifera are a large group of single cellular organisms. About 275,000 species are recognized, both living and fossil. They produce shells made of calcium carbonate, agglutinated sediment grains and/or organic compounds. Shells are typically built from several chambers organized in very elaborated way. The question what govern their morphology to produce such great wealth of forms was unanswered for decades. Early suggestions come from D'Arcy Thomson (1919) who recongnised that simple physical forces associated with fluid dynamics are responsible for cell morphogenesis. First theoretical morphospace was defined over 40 year ago by Berger. His model included only simple geometrical operation (rotation, translation) and produced simple spiral form. Subsequent models used a similar approach and were able reproduce only narrow group of forms.

We showed that diversed shell patterns forms can be produced by using a simple optimization process. It is assumed that foraminifera locally optimizes the way of intracellular transport between the chambers. When every new chamber is formed, a new aperture is located at the shortest distance from the previous aperture. This simple formula produced several diversed forms. However, the model works well only for spheroidal chambers, it does not work for other shapes of chambers.

The next stage in research on the formation of foraminiferal shells is to build a low-level emergent model that can be able explained why "local optimization rule" was so accurate. We are searching for a model of processes that occur just before a new chamber is formed. Foraminifera create a "bubble" of cytoplasm attached to the shell which is mineralized preserving its shape. The "bubble" is not only deformed by external factors but mainly by internal organization of the cytoskeleton. We want to reflect this processes in the computer model and present its impact on final shapes of chambers. The cytoplasmic "bubble" is sourrounded by thin membrane made of lipid bilayer.

Lipid bilayer is an example of complex fluid phenomena so we employed the DPD (Dissipative Particle Dynamics) method. In this simulation technique a set of interacting particles is considered and their time evolution is governed by Newton's equation of motion. In our model lipid bilayer is modelled by two types of DPD particles: "A" which reflects hydrophilic heads and "B" for hydrophobic tails. Additional two types of particles denote extracellular fluid (water) and intracellular fluid (cytoplasm). Particles "A" and "B" are arranged into chained amphiphilic molecules by establishing constant "spring" connections. In order to avoid bending in chains of particles we apply force that streighten each triplet of connected "A" and "B" particles. Depending on types of particles that interact in pair we choose different potentials of interaction. In our simulation we study the behaviour of planar membranes affected by external forces.

Acknowldgements This research is supported by the Polish Ministry of Science and Higher Education, project no. 0573/B/P01/2008/34.

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