Modeling Plant Morphodynamics in Predefined COMSOL Multiphysics® Interface

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Abstract

Introduction: Change of form of an organism (morphodynamics) takes place during growth as result of different growth rates of its parts. The growth can be considered as intercalation of "new" material particles between "old" ones. Such inhomogeneous intercalation (growth) results in deformation of different parts depending on mechanical properties of biological material. This deformation is observable as morphodynamics. The question is: how an organism controls such growth distribution. In some cases it is possible to obtain partial information on this distribution. So in a first step one is interested in the growth distribution itself that could result in an observed morphodynamics with given material properties of biological system. In our work we study morphodynamics of plant embryo at very early stage of its development, when it transforms from globular form to "heart-similar" form.
Use of COMSOL Multiphysics®: For such a study one has not to develop a mechanistic (biophysically adequate) model of growth - it could be sufficient to imitate it. To do it we used evident similarity between volume increase by intercalation and volume increase by heating - in the both cases distances between "old" material particles increase. To specify growth model using Physics Interface for Structural Mechanics / Thermal Stress we interpreted $\alpha \bullet \vartheta$ as growth tensor εg in $s=s0+C:(\varepsilon-\varepsilon 0-\alpha \bullet \vartheta)$. So, when $\varepsilon g = \varepsilon$, observing deformation is without stress - that is deformation by growth. To set up value for growth tensor we used controlled heat source to get predefined temperature distribution, and consider material as media without thermal conductivity. The last allowed us to specify growth distribution as we want. We have a plan to perform the calculations with some rounds of remeshing of deformed geometry to imitate growth in more adequate manner.
Results: We were successful in reproducing observable transition from globular to heart stage for Arabidopsis plant embryo by ascribing specific growth for different parts of the embryo (fig.1). We plan to test some other sets of growth distribution and mechanical parameters, and compare the results with some experimental data obtained with confocal microscopy.
Conclusion: The work demonstrates a simple and useful way to model growth phenomena by using predefined COMSOL Multiphysics® interface, and to study mechanical aspects of plant morphodynamics. It could be applied to other problems studying in plant development biology as well as to study other organisms beginning from one-celled ones to animals.
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Figures used in the abstract

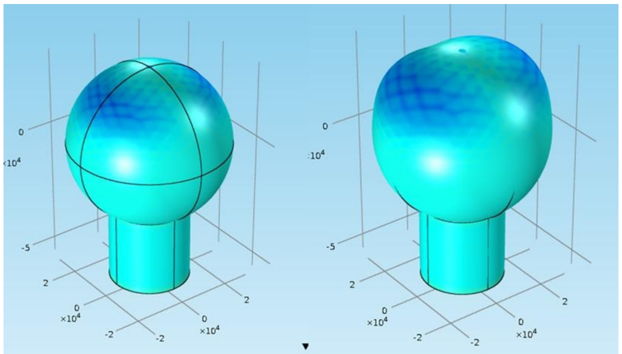

Figure 1: Initial (left), and final (right) forms of morphodynamics calculation.