In Silico Modeling of Stomatal Patterning

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Introduction

Stomata are specialized pores localized in the epidermis of leaves, stems and other plant organs.

Figure 1: Stomata on epidermis of rose leaf

Their role is to control the exchange of gases between the plant organ and the environment as well as to regulate water evaporation from the organ.
The stomatal pore is surrounded by two kidney-shaped guard cells. These form as the result of a **symmetric** cell division and **differentiation** event following one or more **asymmetric** cell divisions.

Objective

The goal of the project is to understand what triggers the asymmetric cell division and differentiation steps that lead to the formation of guard cells and the regular distribution of stomata on the plant epidermis.

Hypothesis

Experimental results in *Arabidopsis thaliana* suggest that the phytohormone **auxin** is involved in the regulation of the stomatal developmental path [1]. In order to investigate the impact of auxin, we first consider a possible feedback mechanism between auxin concentration, cell differentiation and tissue geometry.

Modeling approach

- The initial model is based on the assumption that the cell area determines the differentiation direction for the cell which, in turn, will determine the type of cell division.
- To determine how cell area influences auxin concentration, we are investigating models in which tissue topology determines auxin fluxes and vice-versa.

Feedback mechanisms

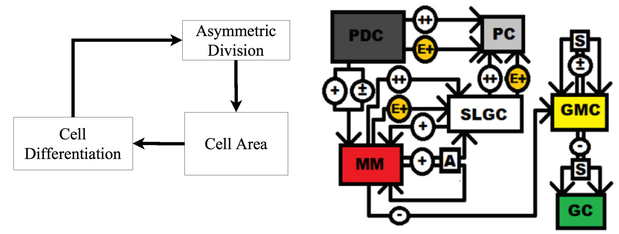

Figure 2: Feedback mechanisms (left); Stomatal development decision tree based on cell area: $-, +, ++$ indicate cell area thresholds, E+ indicates the presence of EPF2 and A/S stand for asymmetric/symmetric division (right)

VirtualLeaf simulation of stomata mutants

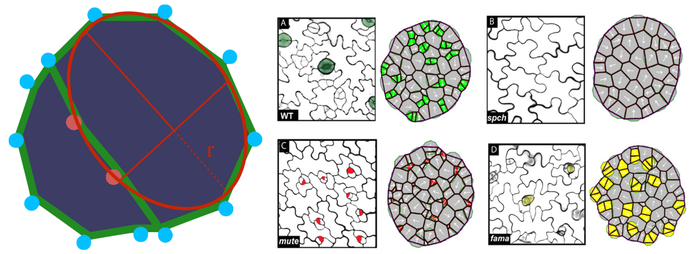

Figure 3: Asymmetric cell division (left); Stomata mutants (right)

Auxin transport

We make use of a modified up-the-gradient model [2] which takes into account various asymmetries in the tissue geometry (cell area V_i and membrane length L_{ij}). Thus, the governing equations are given by

$$\begin{aligned}
\frac{dA_i(t)}{dt} &= \frac{T_{active}}{V_i}\sum_j\left(\frac{P_{ji}A_j(t)}{k_a+A_j(t)}-\frac{P_{ij}A_i(t)}{k_a+A_i(t)}\right)+\\
&\quad\frac{T_{diffusive}}{V_i}\sum_j L_{ij}\left(A_j(t)-A_i(t)\right)+\sigma(V_i)-\epsilon A_i(t),\\
\frac{dP_i(t)}{dt} &= -k_1\sum_j L_{ij}\frac{P_{ij}(t)f(A_j(t))}{k_m+P_i(t)}+k_2\sum_j P_{ij}(t),\\
\frac{dP_{ij}(t)}{dt} &= k_1 L_{ij}\frac{P_i(t)f(A_j(t))}{k_m+P_i(t)}-k_2P_{ij}(t).
\end{aligned}$$

Topology study

Having developed a new model for auxin transport, we are currently investigating the effects of tissue topology on the auxin concentration.

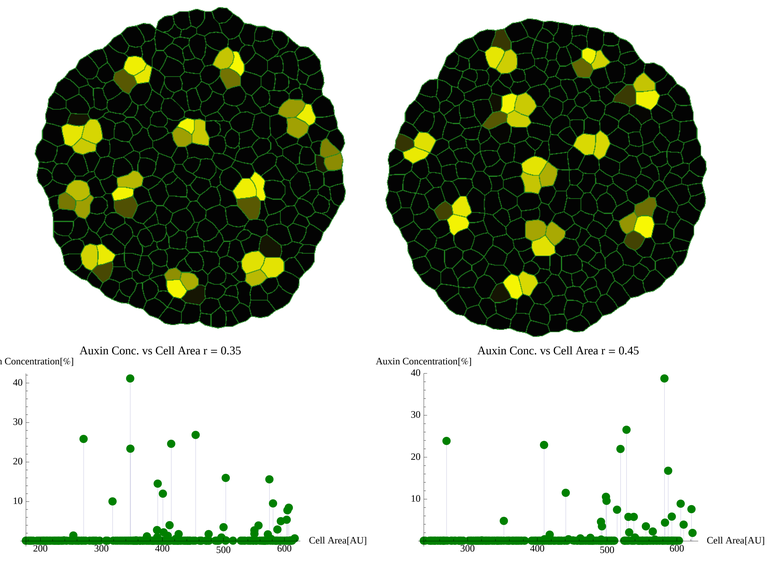

Figure 4: Auxin redistribution for asymmetric division r=0.35 (left) and r=0.45 (right) together with plots of auxin concentration vs cell area

Future work

We are investigating the stomatal patterns that arise using this specific transport model and are developing new models in line with experimental results.

Acknowledgements

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References

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