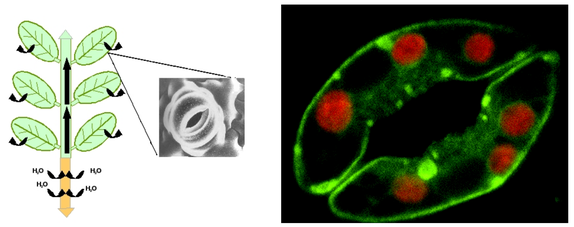
Modelling Integrated Signalling Networks in Stomatal Guard Cells

Mariano Beguerisse Díaz,[1,2] Radhika Desikan,[2] Jaroslav Stark[1,3]

[1]*Centre for Integrative Systems Biology,* [2]*Division of Biology,* [3]*Department of Mathematics*
Imperial College London, South Kensington Campus, London, SW7 2AZ, U.K.

Introduction

- *Stomata* are microscopic pores on the surface of plant leaves.
- Each pore is formed by a pair of cells (known as *guard cells*) which control the aperture of the pore by swelling or becoming flaccid.
- Stomatal movements mediate the exchange of gases and water between plants and their environment.



Images by Desikan (left), and Costa (right).

- Stomata can open or close in response to different internal or external stimuli such as:
  - Drought stress
  - Pathogen attack
  - Humidity
  - Heat stress
  - Hormone Challenge
  - Carbon dioxide.
- Under adverse conditions the otherwise regulated movements of the stomata can be disrupted, leading to water loss exceeding water intake which results in plant death.

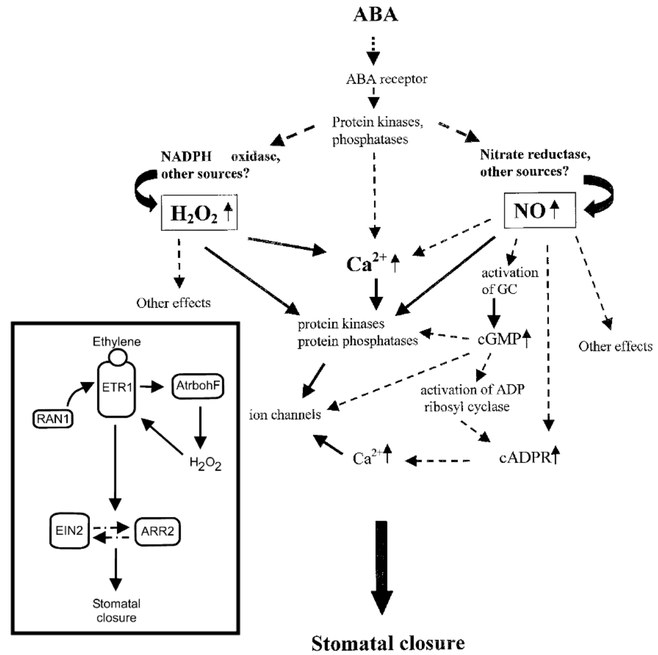
Why is it important to understand stomata?

Images by Mundoo (left), and studom (right).

- Global climate change and lack of availability of water in several parts of the world increase the need of understanding of how plants regulate stomatal closure, and its potential significance on crop yield and productivity.
- An estimated 65% of the Earth's fresh water passes through these pores.
- Stomata are also a useful cell-signalling research tool, where the outcome of experiments can be easily observed. The study of guard-cell signalling is a very active area of research with over 40 identified components.
- Understanding how this system works will not only be useful in plant-research, but in other areas of cell biology as well.

The problem

- Plant hormones ethylene and abscisic acid (ABA), cause individually the stomata to close. However, a combination of both causes the stomata to remain open.
- Common signalling intermediates such as hydrogen peroxide (H_2O_2), Calcium (Ca^{2+}), and proteins have been identified in the ABA and ethylene pathways.
- The presence of a combined stimulus forms an *OR* operation in the signalling pathway which is quite unusual in Biology.
- These observations are hard to reconcile biologically are not easily performed *in vivo*.



Bright *et al.* Inset: Desikan *et al.*

- It is important to have better understanding of what are the roles of reactive oxygen species (ROS) such as H_2O_2, and Ca^{2+} in plant stress-responses.
- We want to understand the interactions of these signalling networks, where does the crosstalk occur and under which circumstances can plants overcome these difficulties.
- To obtain a clear picture of the complete signalling network purely by experimental means is very difficult.
- Most components of the signalling pathway cannot be measured easily, a new theoretical framework is needed to overcome this difficulty.

Research methodologies

In a Systems Biology framework, theoretical predictions of models are used to design experiments, whose results are used to improve models in an iterative cycle.

Models will be constructed using ordinary differential equations (ODEs) which allows the use of a vast array of theoretical and computational techniques like:

- Bifurcation analysis.
- Numerical optimisation and data fitting.
- Stochastic ODEs.
- Statistical mechanics.

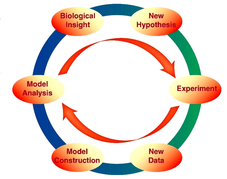
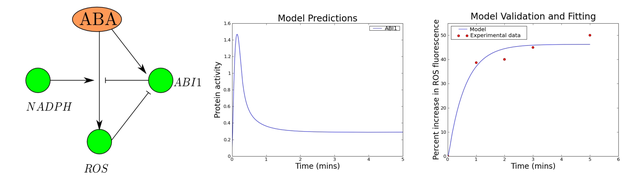


Image: CISBIC.

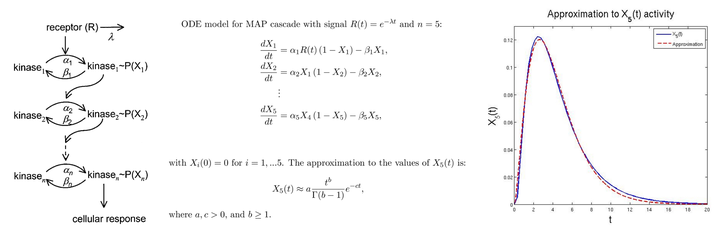
Expected outcomes

- A collection of simple models that describe mathematically signal integration and component behaviour in stomata.



Images: Beguerisse Díaz. ROS data: Pei *et al.*

- A design framework for future experiments, strategy for verification of models integrating multiple stimuli and an increased understanding of plant behaviour.
- A catalogue of mathematical functions that can summarise network module behaviour, thus reducing the number of parameters and complexity of the model.



Model: Heinrich *et al.* Model reduction: Beguerisse Díaz.

- Increased knowledge of plant physiology and its effects on plant function.