Why decentralized computation in plants?

Jevin West[1], Keith Mott[1], David Peak[2]

1 Biology Department, Utah State University, Logan, UT 84322-5305, USA
2 Physics Department, Utah State University, Logan, UT 84322-4415, USA

The *what* part of information processing in leaves has been addressed by the plant physiology community. Plants on a daily basis must solve a constrained optimization problem: how should stomatal aperture should vary for the plant to take up the most amount of CO_2 for a given amount of H_2O loss as environmental conditions change throughout the day? The *how part* of information processing remains an open question. Traditionally, stomata were assumed to operate independently, with each stoma processing signals from the environment and the rest of plant in isolation. However, recent studies have shown that the plant may be solving this constrained optimization task using emergent distributed computation. The purpose of this study is to address the *why* part of the story. Why do plants resort to decentralized computation when there clearly are disadvantages to this type of information processing (e.g., redundancy, pathological deadlocks and increased processing time and resource costs)? To address this question, a theoretical analysis has been done addressing the topics of robustness, metabolic investment costs and evolutionary happenstance.

Sophisticated Information Processing in Plants...

Jevin West, David Peak, Keith Mott, Utah State University, Logan, UT, USA

Centralized vs Decentralized

• Decentralized information processing tends to be more robust to spatial and temporal noise (see Messinger poster) and to cell death
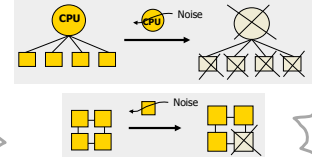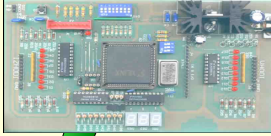
• Centralized processing requires greater resource allocation (Milgrom), has a higher metabolic investment and is more prone to information bottlenecking (Cruchfield, Mitchell)

Hardware Leaf

• The goal is to closely mimic stomatal physiology in hardware

• In so doing, the intent is to determine whether the leaf really is computing and to perform artificial experiments that may provide insight into real leaf physiology
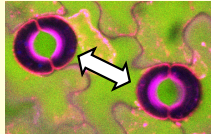
• Image: FPG array trained to predict fluorescence images

Software Leaf

• A spatially explicit version of a single stoma physiological model is a cellular nonlinear network (CNN)

• The stomatal CNN agrees with steady uniform experiments and correctly reproduces the wrong-way response

• CNNs performing global tasks can exhibit dynamical patchiness—does one that performs a global optimization also exhibit dynamical patchiness?

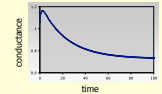• Image showing a CNN with patches at one time step

Realware Leaf

• By perturbing a single stoma with light and humidity and using the pressure probe, we are determining the "rules" among neighboring stomata

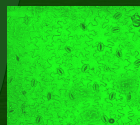• The "rules" can then be used to parameterize the software leaf

ARE STOMATAL NETWORKS CELLULAR COMPUTERS THAT SOLVE THEIR DILEMMA VIA AN EMERGENT DISTRIBUTED COMPUTATION?
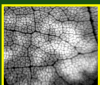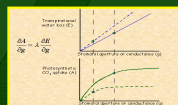
Plant's Dilemma

• During photosynthesis a plant incorporates CO_2 from and loses H_2O to the atmosphere

• This dilemma can be framed as a constrained optimization problem

• Stomata are the hardware the plant uses to resolve this dilemma and they interact through short range hydraulic and chemical signals via a locally connected network

• Stomatal connected networks show spatially coordinated dynamical behavior (i.e., stomatal patches)

Plant's Solution?

(a)

(b)
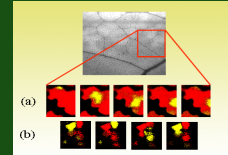
• Qualitatively, stomatal dynamics are reminiscent of the behavior of cellular computers that perform a global task like density classifiers

• Quantitatively, there is evidence of persistent correlations in space and time that are virtually indistinguishable from those seen in cellular computers