Swarm Intelligence Modeling of Root Growth

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Apexes: autonomous coordinators of Roots' growth

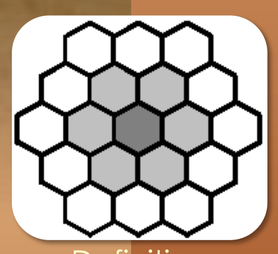
Apexes perceive their local context, and from that they control growth and branching of their root segment;

The collective action of this swarm of apexes over time generates the root structure.

➢ No existing *decentralized* models in Biology are currently able to explain Root formation in terms of local apex activity.

Cellular Automata modeling of Soil & Root dynamics

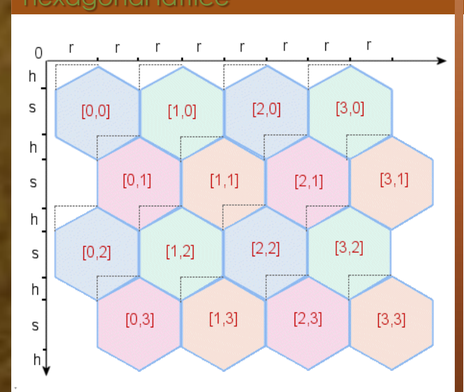
- Cellular Automata modeling of soil variables and dynamics
  - Soil state variables representing *Water*, *Nitrogen* & *Phosphorus*
- Overlayed structure representing the Root interacts with the soil variables
  - structure that changes due to growth & branching
- Modeling of internal Root dynamics
  - transportation of nutrients and water



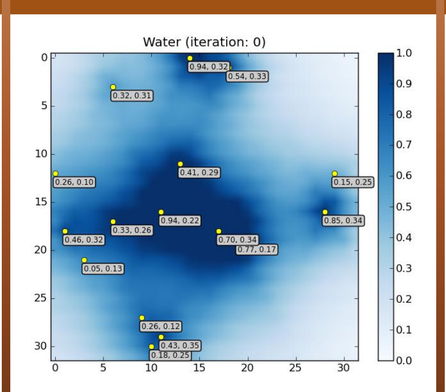
Definition of a Soil patch's **Neighbourhood** (same as Apexes' perception radius)

Soil Structure

- A 2D cut of soil is discretized by a hexagonal lattice

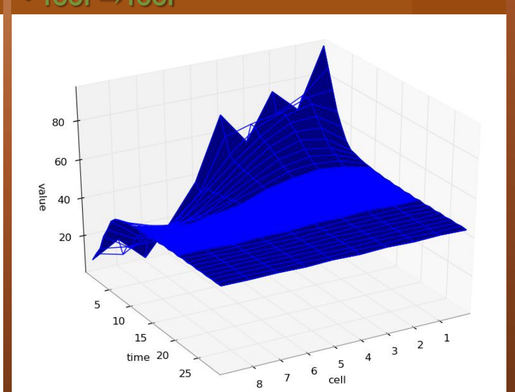


Generation of random Soil conditions



Diffusion

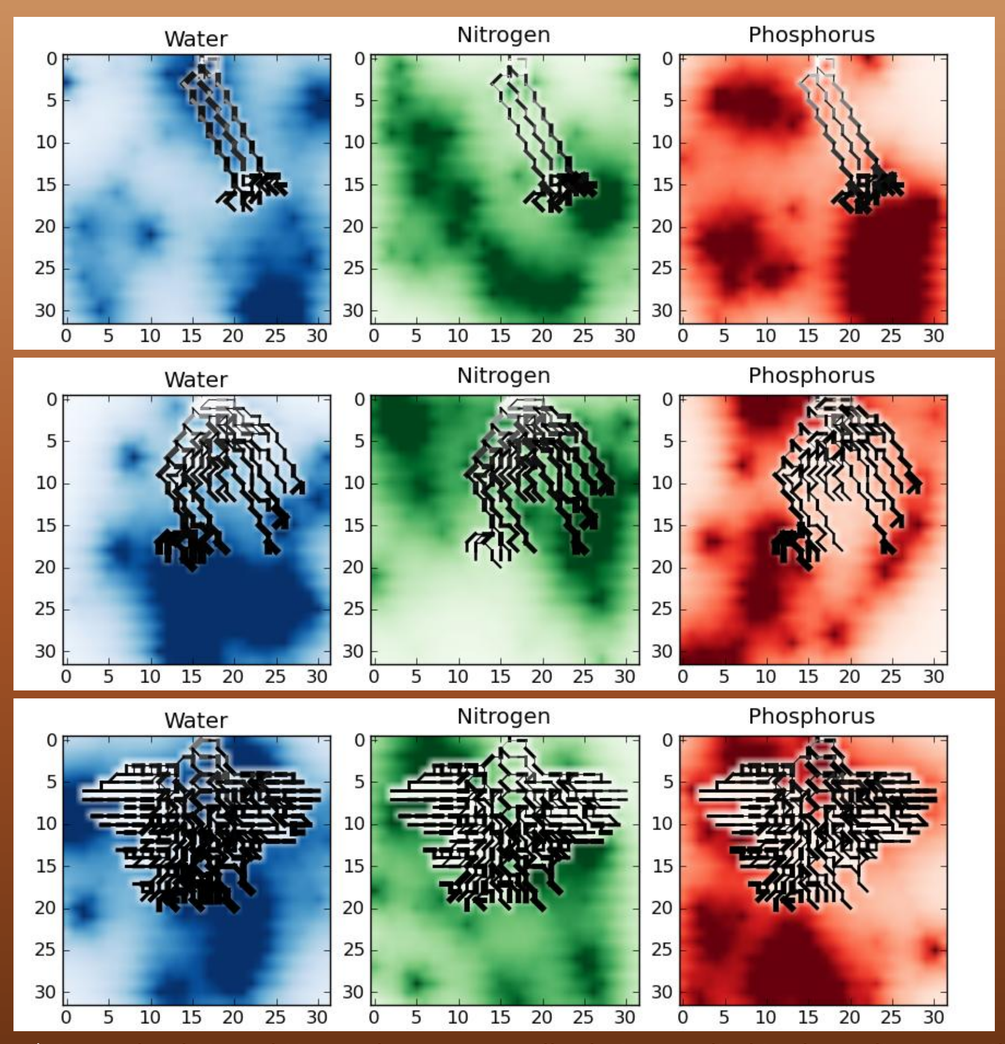
- soil → soil & root
- root → root



Evolutionary Design of Apex Controllers

Optimal mapping of local perception to appropriate actions sought.

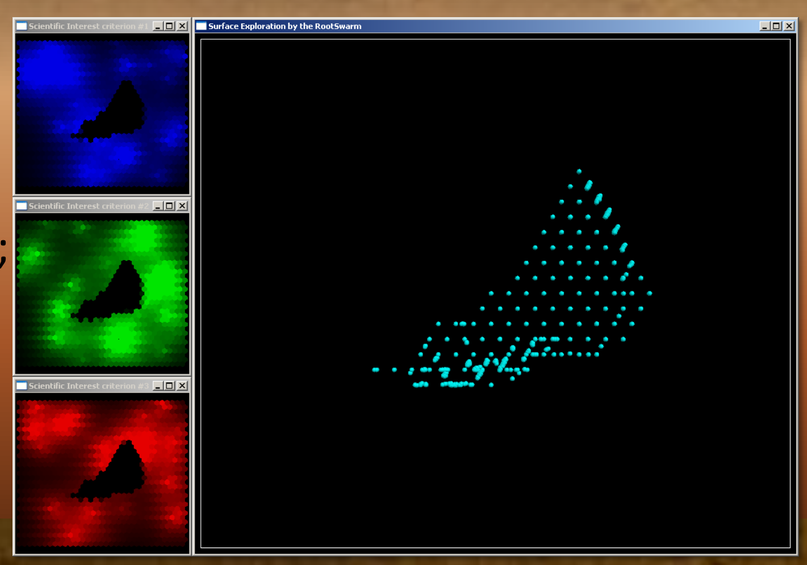
- *Water*, *Nitrogen* & *Phosphorus* amounts perceived inside the root segment and in the surrounding soil patches at each time step
  - Direct communication between apexes through the root structure; stigmergic communication through the soil
- Given perception, apexes must choose between the following actions: *StayStill*, *Elongate*, *Elongate & Branch*;
- Controllers: Rule-based system (evolved using Pittsburgh Learning Classifier System) and Feed-Forward Neural Networks (optimized using Particle Swarm Optimization);
- **Objective function**: maximize the amounts of water and nutrients extracted collectively by the root system.



↑An evolved Neural Network apex controller being applied in three distinct soils

Planetary Surface Exploration through Root-based Deployment of Robot Swarms

- A swarm of robots departs from a central location (planetary rover);
- The system seeks to deploy the swarm as fast as possible into locations that are the best possible for the fulfillment of the mission's scientific goals;
- Apexes become groups of robots moving together, towards the same destination;
- A region's quality is evaluated, according to multiple criteria, as the robots reach it;
- A decision to Branch is applied by reassigning the robots in the group to two subgroups, and leaving some units behind for exploring the present surface location, and serve as communications relay units between those units/groups "above "and "below" itself.



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