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Plantae Agrestis: Distributed, Self-Organizing Cybernetic Plants in a Botanical Conservatory

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Abstract

Conventional digital logic embodied in silicon-based materials has long neglected the capabilities of natural systems. This work seeks to embody a new hybrid form, analogizing chemical signaling to electrical signaling and vice versa. Through an installation at a botanical garden, technological functions in this setting are relegated to plant controls. Several plants are interfaced individually through their own internal signals with robotic extensions and self-organize in a botanical conservatory. The authors observe emergent behavior to consider implications to bioelectronics models, materials, and processes.

Evolutionary processes change the traits of an organism based on fitness for the environment. In recent history, humans domesticated plants selected for desirable traits [1]. A few became house plants; others were fit for agricultural practice. From natural habitats to microclimates, the plants' environments have been significantly altered.

Consumerist models of modern industrialization have led to our technological and design practices being human-centric [2]. However, for a sustainable progression, the acceleration of evolution needs to include ecology and nature as well [3]. French philosopher Gilbert Simondon describes technological objects as part of human nature evolving through "concretization" [4]. Such machine philosophy and cybernetic theories [5] see technological and biological beings as very similar.

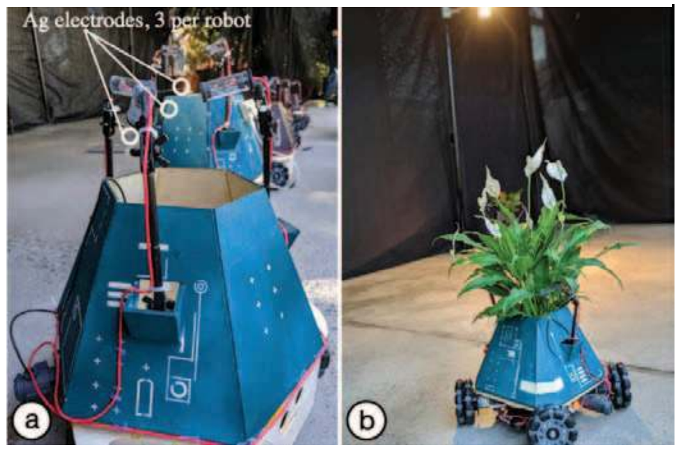
Plantae Agrestis was a 2019 installation at the New England Botanic Garden at Tower Hill in Boylston, Massachusetts, where technological functions were relegated to plant control. Several plants were interfaced individually through their own internal signals with robotic extensions and were left to self-organize in a botanical conservatory. Rather than being stationary, this led to a constantly changing layout affected by the plants themselves. Visitors to the botanical garden observe a compounding of ecology with machines, with an emphasized dynamic between objects and environment in a continuous dialogue to adapt. Considering Norbert Weiner's hybrids where "machine parts become replacements, integrated or supplemented" to an organism's body image [6], the installation focused on the tension between natural and artificial, exploring posthuman sensibilities that we may desire in our world.

Beyond "in-silico"

Organic matter's sensing and computation abilities have long been observed with eukaryotes and lower plants. However, industrial material processing learned to emulate these processes prior to the development of cellular bioelectronics [7].

Through this project, we explored the analogy of signaling systems where plants, like silicon circuits, actively conducted these signals for transmission between tissues and organs. Such electrical signals inside plants may occur in response to changes in light, gravity, temperature, and other environmental conditions. In each unit of *Plantae Agrestis,* naturally occurring signaling potentials (light/dark, dark/light transitions) within plants become on/off triggers to wheel drives at the base (Fig. 1). The interface boundaries are highlighted (Fig. 1a) where an Ag/AgCl electrode is connected to the leaf of more vascular plants such as *Spathiphyllum* and *Anthurium andraeanum*. Such conjunction of chemical signaling with electrical is meant to reflect on new biotic materials and processes.

Fig. 1. ***Plantae Agrestis*. (a) Fixed position and transparent holders with designed Ag electrodes. (b) *Spathiphyllum* with electrodes connected to nodes in three directions. (© Harpreet Sareen)**



Related Work

The adjacency of plants and technology has been used as an artistic medium before. While emotional attachment of people to plants has attracted artists to using them in community building [8], others have explored material relations and dichotomies [9–11]. The electrochemical signals themselves have been used in information processing, divulgence, conversation, and politics in projects such as *OneTree* [12], *Plantron* [13], *Florence* [14], *CMD* [15], and *Alt-C* [16]. Other works such as *Floraborgs* [17] and *Soybots* [18] demonstrate roaming artificial sensor-equipped robots where plants are close but separate entities. Inspired by theories of convergence and hybridization, we have composed a singular system [19] by interfacing plant calcium signaling directly with robotic extensions.

Installation

The installation was composed of six robots in the central area of the botanical conservatory, normally a sun parlor for the plants. Each plant-robot unit had three Ag/AgCl (chloride achieved with 15min bleach dip of 0.99 pure 28 Ga silver) electrodes inserted into plant nodes (Fig. 3, secondary stem beginning) that measured their Local Electrical Potential (LEP, sub-threshold response), induced by various environmental factors that were electrically indistinguishable. We used light as stimuli (Fig. 2) in this work, due to a faster electrical signaling response in plants than when using other factors (such as varying soil conditions, gravity, etc.). The signals were generated with a dark-to-light transition with the following event flow: Dark to Light Transition > Stomata opens > Depolarization of cells > Signals read in the electrodes.

The space (Fig. 3a) was covered with a shade-cloth to control the amount of natural light, and Lowell Pro 300W hot lights (Fig. 3b) are positioned toward the plant-robots for controlled signal stimulation. All lights were controlled via a six-channel programmable dimmer manipulated by our custom scene software. Our software turned any single light on (180s turn-on time) and off at random, while cycling through lights in the space. The software also took thresholds of ~60mins of occurrence (signals did not occur faster than this in each plant, as

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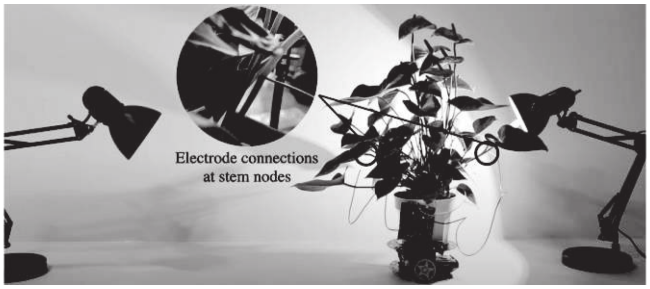

Fig. 2. Monthlong installation at Tower Hill Botanical Gardens. (a) Space measurements. (b) Six hot lights in the space at a distance of 4ft from the ground. (c) Robot moving to a spot with light after activation. (d) Robots swarming together. (© Harpreet Sareen)

found experimentally) of plant signals in consideration before turning the corresponding lights on/off.

Each robot with its three electrodes measured individual voltages at the nodes, also triangulating for any false positives. The time between a light illuminating and a signal being read is ~120–180s. These signals (peak: 60 mV, time: 1ms) were amplified by AD620 instrumentation amplifiers, following which the 3WD/4WD robot locomotion was activated in the direction of the operational electrode.

Plant-Robot Behaviors and Reflection

Plant cells become bioelectrochemically active under the influence of several external factors. The conduction of these excitation signals in tissues and organs leads to synchronization of internal functions with the environmental responses. During cycling and toggling hot lamps in the space, light-to-signal transduction mechanisms inside plants were not instantaneous and sometimes did not engage a response from the plant tissues. At other times, these signals were activated in the opposite direction of the usual light direction cycle. Such absence of instant and predictable patterns seldom led to behaviors that could be seen as swarming (Fig. 2d), while most of the time, the plant-robots are spread throughout the space, organized by their chemical responses. The plant-robot movements were observed to have a higher frequency during the late evenings than in the bright mornings (due to the October sun).

Many ethologists have posited behavior as interface between mechanistic and ecological studies, while analogizing it with computation. Our intention in merging the electronic with plant behaviors is to point to the process of hybridization, one that draws on plant capabilities achieved on a billion-year evolutionary timeline. These photosynthetic organisms are self-powered, self-regenerating, and self-fabricating, all the capacities that we are only beginning to understand the significance of in our synthetic developments.

While garden installations have existed primarily as traditional sculpture, we seek to make these conservatories dynamic plant-controlled spaces. Machines in the cybernetic loops of human functions have profoundly reconfigured human composition [20] externally and internally, rendering us with novel capabilities. Recognizing the computational universality of physical systems will lead larger communities to posit questions at the boundaries of information and natural science that have been long neglected by conventional digital logic. Combining ecology with machines and building hybrid bioelectronic models may lead us to novel organic materials, interfaces, and interactions as sustainable systems of the future.

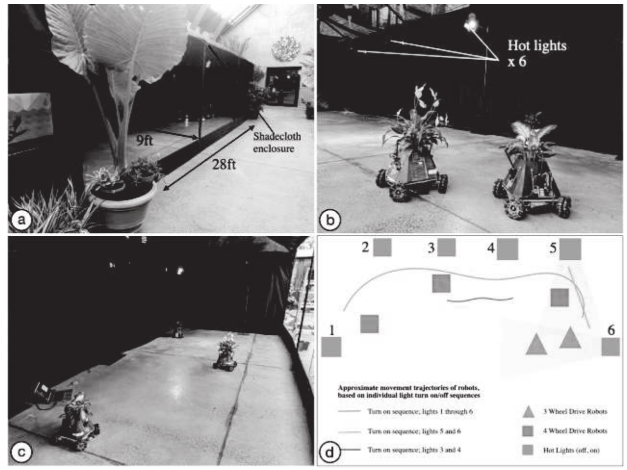

Fig. 3. Fundamental plant-robot unit with two electrodes, developed and tested in lab-controlled conditions. (© Harpreet Sareen)

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