OpenAG: A Globally Distributed Network of Food Computing

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In the 10,000 years of agriculture's history, advancements have enabled three society-altering revolutions. First came the domestication of plants and the resulting first human settlements in 8,000 BC, followed by the horse-and-plow and the rise of technology-based societies in 600 AD, and finally the vertical integration of farming brought on by the mechanization, chemical fertilization, and biotechnology of today.[1] Agricultural revolutions have been a major driving force behind humanity's societal progress.

The current industrialized food system feeds 7.3 billion people,[2] of whom more than half live in cities,[3] and very few of those are involved in the production of their own food. The backbone of this system is comprised of large, centralized, chemically intensive single-crop farms. With natural-resource scarcity, flattening yields, loss of biodiversity, changing climates, environmental degradation, and booming urban populations, our current food system is rapidly approaching its natural limit.

What will define the fourth agricultural revolution, and how will it impact and shape global societies? This is the central research question of the Open Agriculture (OpenAG) Initiative at the MIT Media Lab. As we at the OpenAG Initiative and our collaborators develop a greater understanding of the unintended ecological and nutritional consequences of industrialized agriculture, we envision an alternative distributed farming system based on new methods of communication, sensing, data collection, and automation that will enable network-effect advantages in the next generation of food production.

The Internet was built to compute and share information using interconnected open systems and networks. In the same way, this next agricultural revolution will be based on interconnected open food production platforms (food computers) to increase production either by scaling up or scaling out and sharing data to form a new kind of network, the Internet of Plants (IoP). This new Internet is a digital-plant-recipe-centric network. One can imagine digital plant recipes as the equivalent of "IP packets" in computer networks. The recipes are the logical structured containers of exchanged information within the IoP. We believe that food computing, open data platforms, and networked production communities will each play a pivotal role in the next agricultural revolution.

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FOOD COMPUTING

Donald Baker, a Distinguished Fellow in the American Society of Agronomy and the American Association for the Advancement of Science, suggests the following:

> *The third revolution may run its course or it may receive a boost from biotechnology. But with or without the application of a new technology, a fourth method of yield measurement may be used in the near future. It is the ratio of yield to a critical factor other than land. As the critical factor in the past has gone from human effort, to the amount of seed sown, to the amount of land used, it may soon change, for example, to the nitrogen, the phosphorus, or the energy expended. Perhaps the best one would be an economic one, since it also requires a superior bookkeeping system. Thus, the next yield expression might become yield per dollar spent.*[1]

It is the premise of the OpenAG Initiative that the "superior bookkeeping system" to which Baker refers could

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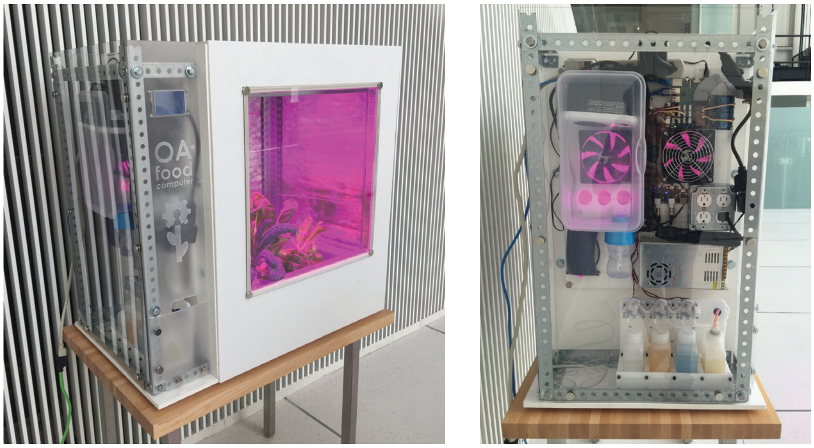
be realized through leveraging the networked and computational power of "food computing" in the fourth agricultural revolution.

The food computer, or FC, is a proposed term for an agricultural technology platform that creates a controlled environment using robotic control systems and actuated climate, energy, and plant sensing mechanisms. Not unlike climate-controlled datacenters optimized for rows of servers, FCs are designed to optimize agricultural production by monitoring and actuating a desired climate inside of a growing chamber. Climate variables—such as carbon dioxide, air temperature, photosynthetically active radiation levels, leaf surface humidity, dissolved oxygen, potential hydrogen, electrical conductivity, and root-zone temperature—are among the many potential points of actuation within the controlled environment.

These points of actuation, coupled with the plant machine interface (PMI), are the drivers of plant-based morphologic and physiologic expressions. For example, FCs can program biotic and abiotic stresses, such as an induced drought, to create desired plant-based expressions of color, texture, taste, and nutrient density. Operational energy, water, and mineral consumption are monitored (and adjusted) through electrical meters, flow sensors, and controllable mineral dosers throughout the growth period. When a plant is harvested from the FC, a digital plant recipe is created based on the corresponding data.

Digital plant recipes are composed of layered data that includes operational consumption data, plant morphology and physiology data, and a series of climate set points. Such points read like machine code and include a time stamp, an environmental control code, and a value associated with that environmental control. For example, a single climate set point reading of "00:00:00 SAHU 60" would set the air humidity to 60 percent at time 00:00:00 hours or 12:00 am. All of these layers of data are compiled to form a repeatable digital plant recipe with known inputs and outputs. With iterative experimentation, we could hypothetically map the entire phenome of a selected plant and correlate certain phenotypic traits with specific environmental stimuli.



(a) (b)

Figure 1. A personal food computer. This FC is designed for an at-home user, hobbyist, or student. Image of an open sourced OpenAG prototype at the MIT Media Lab.

The human plant interface (HPI), a combination of the user experience and user interface, is a software layer that lets a human operator monitor sensors and actuator systems; browse and predict inventory; and load, override, or create derivative digital plant recipes. The HPI abstracts the operator from the mechatronics and reduces the biological or engineering expertise required to operate the system.

There are currently three scales of FCs being developed throughout the world. The personal FC is a product-scale (2–10 sq. ft.) FC designed for an at-home user, hobbyist, or student (see Figure 1). The boutique production FC is a shipping-container scale (200–500 sq. ft.) FC designed for owner/operators or franchisees to sell small amounts of high-value produce into local markets, restaurants, or cafeterias (see Figure 2). The factory FC is a light industrial scale (+10,000 sq. ft.) FC designed to operate in urban or peri-urban environments and distribute fresh produce into a regional supply chain or produce a large quantity of a very high-value crop (see Figure 3).

Currently, the commercially available systems are being developed as unique, closed, and proprietary systems that are non-compatible with FCs of the same scale or across scales. Knowledge is being developed locally on closed platforms, and questions remain unanswered regarding the functionality, scalability, economic viability, safety, and environmental sustainability of these systems.

OPEN PLATFORMS AND DATA

We, at the MIT Media Lab OpenAG Initiative and our collaborators, imagine a very different future. This future is one where open and compatible technology platforms underlie a distributed network of FCs of various scales using digital plant recipes and the controlled environment climate as the scaling factor. Conventional agricultural data has been difficult to export and use to replicate plant growth and output, because the growing conditions are dependent on the idiosyncratic variables created by

SPOTLIGHT

Figure 2. The boutique production FC is designed for owner/operators or franchisees to sell small amounts of high-value produce into local markets, restaurants, or cafeterias. Image of an open sourced OpenAG prototype at the MIT Media Lab.

Figure 3. The factory FC is designed to operate in urban or peri-urban environments and distribute fresh produce into a regional supply chain or produce a large quantity of a very high-value crop. (Source: Caliber Biotherapeutics; used with permission.)

the time of year, regional climate, and local resource availability.

FCs operate autonomously of local climate. Therefore, creating an agricultural product in one FC can easily be shared as a digital plant recipe and recreated, almost identically, in another compatible FC anywhere in the world, greatly expanding the concept of agricultural exports. We have begun piloting this concept through collaborations among boutique FCs at MIT, Guadalajara, Detroit, and India.

This cross-platform compatibility would create the framework for rapid scalability of valuable discoveries. For example, innovations made at the personal scale could be quickly tested and verified across a network of compatible FCs and then deployed at the boutique or light industrial scales. FCs, then, could be imagined as networked cores of agricultural experimentation and production, capable of responding to local or global environmental, cultural, or market demands.

As the global network of FCs begins to create, iterate, and deploy digital plant recipes, we imagine these recipes would be open source licensed and hosted on a public forum, such as Wikipedia, and downloadable as an executable file. Similar to the Human Genome Project, we envision the Open Phenome Project to be a crowdsourced cataloging of plants and their phenotypic traits correlated with the causal environmental variable. Over time, recipes would be optimized to decrease water, energy, and mineral use, while increasing nutrient density, taste, and other desirable characteristics. This database of functional plant phenomics would be the basis for scientific discovery, interdisciplinary collaboration, and new methods of efficient and distributed food production.

BUILDING THE IOP AND ENABLING COMMUNITIES

As the IoP develops, we look to the development of the Internet for useful guiding principles for adaptation—specifically, flexibility, diversity, and openness. These guiding principles enable user-driven development, which has characterized the Internet's history.[4] The IoP design is based on the premise of abstracting the information we share and its logical distribution algorithms from how we implement and interconnect physical things. In other words, the logical definition of the information is conceived in a different plane from the physical implementation. Therefore, the physical implementation is left open and enables the desired versatility, flexibility, and easy management of the IoP.

This openness would also allow for FCs customized in size and design, according to their application. For example, a research lab design (MIT OpenAG boutique FC) might be different from a restaurant implementation. Imagine retailers in different locations designing a custom "case," similar to a custom iPhone case, for their FCs to coordinate with local décor, marketing, and regional aesthetics, while still not altering the core functionality of the FC. FCs might also have customized HPIs according to farming expertise: new, amateur, expert, or research farmer. In collaboration with Jose Pacheco, our partner in the MIT Advanced Manufacturing and Design Program, we are refining the design, distributed manufacturing, statistical process control principles, and policies to enable robust user-driven innovation in the FC hardware.

The combination of open sourced digital plant recipes, open technology platforms, and the IoP will lead to the democratization of food production enabled by massive communities of users. Social communities will be formed by users according to interests, preferences, levels of expertise, and so on. These communities will be comprised of the usual features: chats, forums, wikis, social networks, and blogs. Recipes will be quickly shared, validated, and customized. The recipes and FC hardware and software customization will become the center of the socialization process. The sharing of recipes (data) will allow a knowledge base to develop new plant data and technological setups, creating more accessible food production methods and meeting the everlasting demand for optimized food growth.

Open communities of food innovators, drawn together by collaborative and readily accessible technology platforms, will form the foundation of the next agricultural revolution. These communities will yield a diversity of thought and solutions and will nurture new connections between people and their food. The more ubiquitous the tools and knowledge of production systems become, the more informed, innovative, and empowered the average person can be in contributing to the global future of food. The accessibility of data, hardware, software, and, most importantly, food and nutrition for the projected nine billion people of 2050 hinges on fostering a creative forum of thinkers and doers on collaborative platforms today.

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