Generating Diversity: Art, robots, and the future of farming

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Abstract

The dominant systems of agriculture that provide food for much of the world suffer from a lack of crop diversity, which leaves them vulnerable to the spread of disease and pests. This paper proposes that this is, in part due to the machinery used in industrial agriculture. It introduces a project, *Evolving Species One*, that is grounded in artistic practice and robotics research that draws inspiration from gallery-based robotic artwork to try to design and evolve robots that can cultivate diversity in the plants that are growing within a complex farm ecosystem.

Introduction

Farmed food sustains the majority of human life on this planet. The contemporary global system of agricultural production and trade is both a result and a driver of a complex network of ecological, political, economic, and social factors. It is also highly fragile. Its fragility has many sources [1–3], one of which is a consequence of humanity's dependence on relatively few foods for a large portion of day-to-day nourishment and the reliance on a small number of distinct varieties of those foods in agriculture [4]. It is estimated that 12 plant species account for about 80% of plant-based food that humans eat[1] [3].

The Irish potato famine of 1845-1849 serves as a ghastly reminder of what can happen when a society relies on monocultures for the majority of its nutrition. The confluence of heavy reliance on a single staple crop and the rapid spread of a pathogen

[1] Measured by caloric intake.

through that crop caused almost inconceivable human tragedy. In light of this, there are a number of scientific efforts to mitigate the problems caused by a lack of crop diversity. Researchers have accelerated efforts to store copies of a wide range of crops in disaster-resistant seed banks to serve as genetic repositories [5–8]. Others are actively creating new varieties of key crops — through genetic engineering and conventional breeding techniques [1, 9, 10]. These are attempts to create crops that are resistant to the pests and pestilence that are most likely to threaten them in the near future [1, 10] or that can grow in the shifted ecosystems that climate change will create [1, 9].

These efforts represent important contributions to the conservation of crop diversity and food security in the current agricultural system, but they are insufficient on their own. Seed banks are useful repositories, but they contain static snapshots of a plants' genetic composition at a particular point in time rather than living, evolving specimens [6]. Those seeds are also stripped of their ecological contexts: climates, soils, symbionts, predators, diseases, and the cultural knowledge that is often required to successfully cultivate them [5, 6]. The engineering and plant breeding that takes place at research labs is important for helping agricultural systems cope with emerging challenges, but by necessity — due to the intensity and scale of the effort required to create new breeds — they are wedded to a form of agriculture that focuses on "crops that could be grown across millions of acres, regardless of where someone might plant them" [3].

This paper suggests an alternate and complimentary approach to generating and maintaining crop diversity, that arises from a series of explorations of generativity and complexity in robotic art and agroecology[2]. It begins with a discussion of several works of art that explore themes of emergence, hybridity, and the generation of diversity through the use of robots and artificial intelligence systems.

The behaviours and systems found in those works give rise to one of the premises of the ongoing artistic project explored in this paper: the ongoing exploration of robots in agroecological systems called *Evolving Species One*. *Evolving Species One* envisions a future agriculture in which many varieties of food are grown together in a complex web that emulates a grassland or forest[3] that also hosts biological and robotic "animals" that live in and among the plants. The robotic animals monitor the growth of the plants and the health of the ecosystem, they harvest edible parts of plants, and distribute waste and seed as would biological animals. *Evolving Species One* represents an attempt to evolve[4] the first robotic species that will inhabit such an ecosystem.

Seeds, Diversity, and Fragility

Crops are traditionally propagated in one of two ways [14]: sexually, via the collection and dispersal of seeds, and asexually by techniques like grafting and the replanting of

[2] A system of producing food that relies on principles of ecology and ecosystem management to cultivate a complex landscape that produces food with minimal use of external inputs [4]

[3] Depending on the ecosystem that typically exists in the region. This type of agriculture is known as agroecology and encompasses of a number of novel [11] and well-established [12] practices as well as many traditional agricultural systems [6].

[4] Using techniques from evolutionary computing and robotics [13].

harvested roots and bulbs. Sexual reproduction in plants is a key driver of hybridisation and diversification as it allows the plant to incorporate genetic material from neighbouring plants and varieties and leads to seeds that are genetically distinct from the parent plant [14]. Cereals are reproduced this way and researchers have used this to trace the genetic origins of wheat [15] and to understand how forces of natural and human selection have combined to form the basic types of wheat found in grocery stores today. However, these same cereals also have a trick to maintain a variety that is well-adapted: they self-fertilize. Most wheat flowers are fertilized by their own pollen, producing a genetically identical offspring.

Potatoes, on the other hand, are almost always planted from seed potatoes from a past harvest. The term "seed potato" is somewhat misleading in that they are in no way seeds, but rather a genetically identical part of the parent plant. This confers some benefits such as the knowledge that the potatoes grown from the "seed" potato will be the same as the potatoes grown the year before[5] as well as the other potatoes planted from the same stock. They will all taste similar, require the same nutrient amendments, and be ready for harvest at the same time.

The same feature that makes it easy to sell a field full of a particular variety of potato (or wheat) to the supermarket makes those potatoes vulnerable. In Ireland in the mid-19th century, the potato was a key staple food for much of the island's population [16]. Nearly all of the potatoes grown in Ireland were of a single variety, the Irish Lumper, a species which was susceptible to late blight[6] [3, 17]. Weather conditions in Ireland between 1845 and 1849 were ideal for the growth of late blight [3] and the lack of diversity of potatoes contributed to the blight's rapid spread[7] [17]. By the early 1950s, Ireland had lost 20% of its population to famine and migration [19].

Ecologist Rob Dunn [3] explains in a broader fashion why outbreaks like this occur: Many foods are grown far from the ares in which they evolved. This often allows them to escape some of the pathogens and predators they would have encountered in their native territories — those which evolved to prey on them. As they are bred to be more productive, tastier, and easier to harvest, they lose some of the defences that they have developed to combat particular enemies. In escaping their adversaries, they have also left behind close relatives that might retain resistance to a range of adversaries and symbionts that help the plant deal with diseases and infestations. When the foe eventually catches up to the displaced and now-defenceless plant, it spreads like wildfire and decimates entire regions in the span of years or even months. This pattern has repeated with coffee in Sri Lanka [20], cocoa in Brazil [21], and potatoes in Ireland [19], to name a few. Some ecologists are convinced that it is only a matter of time before another staple crop succumbs to disease or pest [3, 11].

Plant scientists take a number of approaches to address this problem. Plant genetic material is banked in storage facilities spread around the world so that a library of genes exists for use in combating future problems. Plant breeders can cross banked varieties with common varieties to produce seeds that combat specific threats. Broadening the horizon, plant geneticists can insert genes across variety and species lines to create

[5] In a genetic sense. This discounts somewhat the effect of the growing environment on the resulting potato.

[6] *Phytophthora infestans*.

[7] There was also a political-economic element to the famine. Agriculture is never just biological. [18]

insecticide-producing plants, and target pathogens and predators even more precisely.

These efforts are met with varying degrees of technical efficacy and public acceptance, but what unites them all is the assumption that, in the end, most farmers in a large area will grow a single, genetically pure variety of a crop for which they purchase material (seeds, bulbs, or "seed" tubers) from a single source. They fail to consider the possibility of renewing the practice of generating diversity — and through it resilience — in the field [6][8].

Robots, Art and Diversity

(a) An installation detail from *Subtle Emergences*. Shows one of the hanging robots and the projection of its shadow.

(b) *Sentient Veil*, a 2017 installation by Philip Beesley, following the work on *Hylozoic Ground* in 2010. © PBAI/LAS 2017

Figure 1: Robotic installations have a long history of experimenting with themes of hybridity and generative environments.

Why has much of the existing agricultural research focused on banking genetic diversity and generating new varieties in labs as opposed to in the field? This paper proposes that one of the main reasons this possibility has been discounted is that agricultural practitioners have the wrong machines for such work. Agricultural equipment — like most heavy machinery — is engineered for mechanical efficiency. The motions required to plow, sow, fertilize, and harvest a field of a single type of wheat grown in rows[9] are mechanically efficient. The complex tasks of finding and separating many varieties of wheat growing among other grains in a mixed grassy ecosystem are not. As a result, agricultural machines enforce monotony and regularity and farmers and researchers have adapted seeds and practices to suit.

But artists have long experimented with machines that generate novelty, creativity, and the unexpected. Even if these works are not explicitly about agriculture, the underlying systems they explore can be relevant in the study of how robots might be deployed to generate and maintain agricultural diversity. Works like Gordon Pask's *The*

[8] There are in fact many local efforts to maintain a diversity of crops on farmers' fields, a practice known as *ex-situ* conservation of diversity [22]. These efforts, however, are largely excluded from agricultural practices in which robotics and automation are employed.

[9] And even this is immensely complicated.

Colloquy of Mobiles (1968), Edward Ihnatowicz's *The Senster* (1970), Harold Cohen's *AARON* (1973), Daniel Jolliffe's *Untitled Ball* (1993), Camille Utterback's *Untitled 5* (2004), Ruairi Glynn's *Performative Ecologies* (2008), Philip Beesley's *Hylozoic Ground* (2010), and my earlier work, *Subtle Emergences* (2015), use combinations of computational intelligence and robotics to create complex systems that explore the relationships between communities of machines and the humans in their environments.

The work of Pask and Ihnatowicz is rooted in the cybernetic principles of feedback [31] and the ever-changing nature of the work arises from the complexity of the interactions and feedback loops built into the system. Pask's hanging elements respond to and produce audiovisual stimuli creating auto-feedback loops as well as being open to external stimulation. *The Senster* operates in much the same way, its movements following sound in the space, though its form recalls a far more animal-like type of robot. *Untitled Ball* is less explicit about how it senses but the viewer is aware that it *is* sensing. While it is still a feedback-driven art machine, it differs from its predecessors in that it locomotes. Where Pask and Ihnatowicz's works move in relation to a fixed mount point, Jolliffe's sculpture is free to traverse the room with gallery attendees, which creates a new level of danger and intrigue for the viewer. The generated novelty in these works does not manifest in the form of new objects; it arises from new configurations of actors in the space, new relationships that are constantly formed, broken and reformed. The novelty is systemic.

A set of different approaches are taken in Cohen's *AARON* and Utterback's *Untitled 5*. Their works are primarily visual in nature and *AARON* has no mechanism for live feedback, though Utterback's incorporates feedback as the motion of visitors directs the drawing process. *AARON*'s images are shown as static works, the final results of a computational process, while *Untitled 5* is rendered as a dynamic, shifting project. Cohen was often careful to not attribute independent creativity specifically to *AARON*, preferring to think about *AARON*'s work in terms of degrees of autonomy [32]. Sidestepping the contentious debate about what constitutes creativity, it is clear that the images that are generated by both *AARON* and *Untitled 5* have degrees of uniqueness and can be seen as art machines producing novel forms.

Beesley's *Hylozoic Ground* (2010) brings together these elements of novelty into a single work. The work is at once performative and constructive: its various moving, breathing, and flickering elements incorporating sensory information from the sculpture and the human visitors while its protocell structures build material from chemical reactions with hydraulic flows [29]. Later iterations incorporate explicitly explorative machine learning algorithms to motion that changes over time as well as in response to feedback [**Beesley2016a**]. The sculptures are explicitly ecosystemic with static and dynamic sculptural components grouped into species and organized into niches throughout the exhibition space.

Subtle Emergences is an interactive installation in which spotlights, hanging fabric robots, and sonic copper sculptures imbue a dimly lit gallery with subtle motion and sound [30]. The space is almost cave-like and forms a space for meditation on the concepts of emergence and complexity in the context of a robotic ecosystem. The actions and reactions of the sculptural elements in *Subtle Emergences* hover between a state of order and randomness. They are not regular, but they are directed. They are not random, but they are difficult to predict. A visitor's movements do not absolutely control the lights and motion, but they direct it, nudge it, and shape its trajectory.

In this directed randomness, it mirrors the shaping of ecosystems and the development of species. Evolution by selection — natural or artificial — is a series of random events partially ordered by the selective pressures of the ecosystem. In all of these works, technological beings in both physical and virtual forms are being given the role of co-creators, co-generators of novelty. They are generating new patterns of behaviour within themselves and the people around them; they are generating new images and audiovisual environments; they are generating new virtual forms to be printed and brought into physical existence.

Subtle Emergences envisions a human-robot version of this type of system. The robotic sculpture elements move about and visitors traverse the installation space, each gently shaping the behaviour of the other. The movements are slow, so the shifts are viscous, their changes barely perceptible. But on evolutionary timescales[10], they progress rapidly. In the field, shifts take place over seasons, decades, centuries and millennia.

Perhaps in those fields there is a role for this type of slower, less calculated robot. Perhaps the migration of decedents of these robots — robots that are creative, evolving, and emergent — out of the gallery and into the wild might help trigger the rediversification of some of the most monocultured spaces.

Evolving Species One

Figure 2: A hanging robot, considered an early prototype for *Evolving Species One* is observed in the installation for *Beyond Digital — Towards Biological* research residency at the Chronus Art Centre in Shanghai, China in December 2017.

This migration is precisely the premise of the ongoing research project *Evolving Species One*. The project envisions a shift in agricultural practices from large-scale industrial agriculture to multi-scalar agroecological environments populated by biomimetic robots. These robots inhabit the agroecosystem alongside its fauna and flora and perform roles now filled by massive machines and human gardeners in the

[10]At least evolution that takes place in the analog world.

manner in which they would be performed by non-human animals. They distribute seed alongside composted waste and nutrient-rich liquids as they traverse the ecosystem. Their movements gently shape the landscape, creating and shifting habitats as a beaver shifts the rivers with a dam [33]. They monitor the environment and help to harvest tubers, seeds, berries, leafy greens, fruits, and vegetables as they ripen.

That is not to say that there are not already efforts to try to miniaturize agricultural robots. Tertill [34] is a Roomba-sized outdoor robot that kills weeds using a miniature "weed-whacker". It identifies weeds by height — if it is short, it must be a weed[11]. Another, FarmBot [35], draws inspiration from CNC milling machines and features a robotic arm that can traverse a planter bed and perform essential gardening functions like seeding, watering, and harvesting. These efforts are interesting steps away from conventional approaches to farm and garden mechanization, however, they and other related efforts tend to be limited in scope (Tertill) and still set in notions of gardens as well-ordered grids (FarmBot).

Evolving Species One draws inspiration from experiences working on *Subtle Emergences* and recent versions of Beesley's sculptural installations. These installations consist of a population of robots evolving alongside humans in a set of constantly changing environmental conditions. In the same vein, *Evolving Species One* envisions robots evolving in an ecosystem that is subject to human concerns about food and systemic concerns about maintaining a resilient growing environment. It aims to treat an agroecosystem as a complex space from which interesting new crop varieties may emerge that must be conserved and cared for in addition to caring for existing crops.

Evolving Species One is specifically concerned with the design and evolution of the first robot species to inhabit such an ecosystem. What morphology will it have and what morphological features will be evolvable? How will it locomote around an agroecosystem and how will it make sense of the surroundings it finds itself in? Hints at the answers to these questions are beginning to emerge through practice-based explorations[12] and forthcoming papers [36]. Another question unfolds in the context of this discussion on the purity, hybridity and diversity of seed lines: How might such a system generate and encourage the development of a diverse seed stock in the field?

Most of the existing diversity of crops can be found on the fields of small farms that have saved and shared seeds within a local community for generations [6]. These varieties are called *landraces* indicating that they are not formalized, static *breeds*, but they are distinctive-yet-dynamic populations of a crop that has evolved in a particular locale with all of the associated microbes, symbionts, parasites, nutrients, and farming practices. These landraces exist because, for generations, farmers have selected and planted seeds from a previous crop, often alongside its wild relatives[13] [37].

The system of industrial agriculture has divided these labours — growing crops and producing seed — such that crops no longer spend multiple generations in the same field [1]. In any case, crop diversity in an industrial farm is a threat to the efficiencies of mass mechanization. Crop breeds have usually been selected for a range of

[11] Small plants can be spared a gruesome fate by surrounding them with a small guardrail.

[12] For example at the Beyond Digital – Towards Biological research residency at the Chronus Art Centre in Shanghai, China (`http://www.chronusartcenter.org/en/bdtb/`).

[13] Crop wild relatives are the closest non-domesticated relatives to farmed crops, often found in abundance near the region where the crop was first domesticated, termed the *centre of origin* by Vavilov [37]

reasons including their ease of harvest, but lately, machine requirements have driven crop selection in some novel and surprising ways. On one California farm where heads of lettuce were recently harvested by workers on hand and knee, a robotic harvester now uses a water jet to slice the heads of lettuce off their bases and pulls them up to standing level for workers to process and sort [38]. In addition to changing the working environment, this has led to a need to change the variety of lettuce to one that grows in more of a bulb-shape to give the cutter more clearance to avoid cutting the valuable lettuce leaves. Diversity here would be a detriment to the mechanically efficient harvesting process that the farm has invested in.

But this attitude assumes that mechanical efficiency is the ultimate goal of farming technology. Here, the crop must be of a pure variety designed and chosen to suit the available technology. *Evolving Species One* subverts that paradigm by imagining crops and robots in co-evolutionary societies that feature a diversity of species and internal diversity within species. Interspecies diversity helps to create an ecosystem in which many niches are exploited and filled — an ecosystem that is ecologically efficient [39] in contradistinction to the mechanical efficiency of industrial farms. Intraspecies diversity ensures that both crops and robots are adaptable and resilient over the long term as there is a gene pool from which to incorporate adaptations to changing conditions over generations — whether those changes are related to climate, predation, pests, or other factors.

This diversification is likely to be a slow process, requiring many crop, robot — and possibly human — generations. The initial planting will see a wide variety of related crops planted in a single ecosystem[14] to sow the necessary intraspecies diversity. The robots will have to be at once attentive to features that make a plant desirable for humans, but also to factors that render it a valuable component of an ecosystem, and so the maintenance of diversity in the face of a lack of obvious utility.

Conclusion

Machines are often seen as tools of regularity. A laser printer can reproduce the same document over and over with little variation. Cruise control keeps a car at a predetermined speed. A lawn mower keeps grass cut to an exact height.

However, as machines have become smarter and more generalized, they are able to handle difference and diversity more effectively. 3D printers can print a wide range of physical objects. Cars have begun to take into account their surroundings and adapt their cruise control speeds to match the car in front of them. But these generalizations have not really made their way into farmers fields and agricultural systems. A thresher can still only process wheat that grows at a certain height.

Perhaps it is because these systems are so irregular, consisting of webs of relationships that are nearly infinite in their complexity. Using gallery-based artwork as inspiration, *Evolving Species One* has begun to explore that space, trying to evolve a robot to inhabit an agroecosystem. In doing so, it proposes the question: How can robots help to select and then preserve diversity in the crops that it lives among?

[14] Alongside many unrelated species.

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