The SAGE Community Coordinator: A Demonstration

Juliet Norton
jnnorton@uci.edu
University of California, Irvine
Irvine, CA, USA

Birgit Penzenstadler
birgit.penzenstadler@csulb.edu
CSULB
Long Beach, CA, USA
Lappeenranta University of Technology
Lappeenranta, Finland

Samantha McDonald
smcdona2@uci.edu
University of California, Irvine
Irvine, CA, USA

Emily Kang
kangee@uci.edu
University of California, Irvine
Irvine, CA, USA

Nora Koirala
norakoirala@gmail.com
CSULB
Long Beach, CA, USA

Rieko Konishi
riekok@uci.edu
University of California, Irvine
Irvine, CA, USA

Gabriela Pena Carmona
Gabriela.Pena@student.csulb.edu
CSULB
Long Beach, CA, USA

Jainee Shah
jainee.shah@student.csulb.edu
CSULB
Long Beach, CA, USA

Sebastian Troncoso
stroncos@ucsd.edu
University of California, San Diego
San Diego, CA, USA

Bill Tomlinson
wmt@uci.edu
University of California, Irvine
Irvine, CA, USA
Victoria University of Wellington
Wellington, New Zealand

ABSTRACT

Sustainable polyculture gardens thrive more effectively when they are designed with an awareness of other gardens in the community, as opposed to as individual gardens. However, the complex characteristics of plants, and their relations to other plant species in terms of needs and capacities, require a complex knowledge base not easily acquired by novice gardeners. We contribute a demonstration of our project, called the Software for Agricultural Ecosystems (SAGE) Community Coordinator, that helps manage the complexities of plant relationships and provides planting suggestions based on existing plants in adjacent garden sites. The research team collected the requirements and developed a preliminary demonstration of this system. This demonstration shows the feasibility of the idea and lays the foundation for a more comprehensive implementation of the SAGE Community Coordinator. By doing so, this paper explores the use of technology to foster the establishment of complex plant assemblages in urban and suburban areas to address the current and future limits of material resources derived from plants.

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CCS CONCEPTS

• **Human-centered computing → Scenario-based design**; **Interface design prototyping**; *Activity centered design.*

KEYWORDS

Agriculture, community, grassroots, permaculture, HCI, software engineering, sustainability, resilience, undergraduate research, prototyping.

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1 INTRODUCTION

For 2.5 million years, *Homo* physiological and sociocultural characteristics evolved for survival on Earth when their population and impact were relatively small [8]. However, "small" no longer characterizes the only remaining hominid species, *Homo sapiens*, in terms of either its population or its impact. *Homo sapiens* have induced significant changes to Earth's biogeochemistry by way of agriculture systems, and more recently, by way of our large consumption of fossil fuels and other natural resources [30, 50, 51].

Modern industrial agriculture has had alarming effects on ecosystem health and diversity [3, 4, 10, 25, 26, 28, 48, 49], as well as on climate change [7, 59], which in turn has impacted present and future productivity of the global food and agricultural system [8]. Applied pesticides and fertilizers contaminate the water, soil, and air, poisoning humans, animals, and microorganisms that agricultural production relies on [28]. Excess nitrogen in soil reduces plant diversity and reproductive success [28, 60]. Particular pesticides have been linked to a long term decline in bird and beneficial insect populations [48], including honey bees [26]. Agricultural run-off contaminates large bodies of fresh water used for irrigation, among other purposes, with toxins and blue-green algae blooms that wreak havoc on irrigation infrastructure [35] like the 2018 Lake Okeechobee algae bloom [22].

Modern industrial agriculture also exhausts the natural resources it needs to function. It depletes accessible groundwater resources, which take thousands of year to recharge, for irrigation [20] and degrades soil, which is also a precious and difficult to rebuild resource, through poor farming practices such as seasonal tillage [33]. These global changes strain the efficacy of all forms of food and agricultural systems, from small farm families to large industrial farming organizations. The agriculture industry suffers from ongoing significant declines in crop and livestock production from climate change induced stresses. Societies are struggling with availability of food and water during intensifying droughts and humans are facing food-, water-, and vector-borne disease [57].

These issues have propelled a decades-long effort by researchers, activists, institutions, and governments towards a more sustainable agriculture. However, creating and engaging in sustainable agriculture is challenging because it necessarily grapples with complexity from the natural ecosystems it must function within as well as the social ecologies that govern the morals, standards, and markets that shape the agrifood system. The most notable effort towards sustainable agriculture among institutions, researchers, and activists is to reframe agriculture as an agroecosystem [2, 18, 19, 21, 37, 40].

An agroecosystem, sometimes called an agricultural ecosystem, is defined as a site or integrated region of agriculture production understood as an ecosystem [21] and is characterized as "a hierarchy ascending from the level of the individual plant or animal all the way to national systems linked by international trade" [9]. Sustainable polycultures are the foundational elements of agroecosystem designs by many grassroots sustainable agriculturalists, particularly those who practice permaculture [41]. Sustainable polycultures are assemblages of complementary and mutually beneficial plant species, typically composed primarily of perennials, and are one kind of food- and other provision-producing construct in an agroecosystem. In terms of ecosystem organization, a sustainable polyculture is equivalent to a community of living organisms within an agroecosystem, meaning an assemblage of various species living together in a particular place and interacting with each other. Sustainable polycultures have species in many vertical layers, optimizing the uses of space and services from other plants like shade or soil stabilization. Depending on the species they are comprised of, sustainable polycultures come into maximum effect decades after they are planted, making them ideal for people attempting to address plant-based resource issues both in the present and in the long-term.

Sustainable polyculture design, and agroecosystem design more broadly, are complex processes entailing the organization of spatial, trophic, pathological, and facilitation relationships among plants and between plants and other ecosystem factors in the context of human sociotechnical infrastructures. In other words, a sustainable polyculture should foster the positive interactions among plants and address the interference plants may have on each other.

While some sustainable grassroots agriculture efforts are practiced in farm and large personal or public property settings, many such efforts are limited in space and resources — occurring in urban backyards, apartment and business patios, rooftops, and the margins between side walks and roads, and cared for by people who are not food-growers by profession, with moderate or little financial budget and time. When people are attempting to engage in grassroots sustainable agriculture in effort to produce their own food and other plant-based material goods in such small spaces, they cannot design a sustainable polyculture that provides them a breadth of goods nor robustly support the species within the small space available to them. A sustainable polyculture system may require a community effort across individual gardens, thus requiring collaboration among many gardeners to collectively coordinate their efforts. This project works towards addressing issues of cross-polyculture coordination by demonstrating how an information system could support the collaboration and management of complex, multi-site sustainable polycultures.

This project builds upon the concept of the Software for Agricultural Ecosystems (SAGE) Sustainable Polyculture Composer [42, 43] to coordinate the design of sustainable polycultures in green spaces that are split up by physical and/or social barriers such as fences delineating different ownership. In this paper, we introduce the SAGE Community Coordinator (SAGE-CC) as a demonstration for facilitating the present-day collaborative creation and utilization of sustainable polycultures, and agroecosystems broadly, by neighboring property owners who have limited space and resources to create a robust and thriving system. We use the term demonstration because this implementation is a rudimentary example of what the SAGE-CC could achieve. The demonstration is rudimentary in its limited implementation of features and use of fictitious plants due to the time and resource constraints of the educational context it was developed within.

Envisioned as a tool to map and plan community polyculture, SAGE-CC could help address the informational barriers and complexities of producing a polyculture systems, as documented in the first author's PhD Thesis [41], through community-wide collaboration. In turn, increasing the implementation of sustainable polyculture systems could offset the agrifood sector's dependency on large-scale agricultural systems and increase plant species diversity in urban and suburban ecosystems. Using Google Earth and ArcGIS, agroecologists Taylor and Lovell [54] estimate that the production area of home gardens in the Chicago metro area is three times larger than community gardens. They suggest that this means there are opportunities for scaling up existing production networks to include home food gardens. A fully developed information system such as the SAGE-CC has the potential to increase food and other plant-based material productivity in urban and suburban residential green spaces over a long time horizon.

The goal of the research presented in this paper was to specify the requirements and develop a first demonstration for the SAGE-CC. The concept and the requirements for the SAGE-CC emerged from exploratory action research the first author conducted with two grassroots sustainable agriculture communities [41]. The outcomes of this research include defined requirements, a design, and an initial demo of our project.

The following sections introduce related work, provide the research design for the demo, report on the process and results, detail a discussion of the implementation, explain limitations to the research, and point out future work and conclusions.

2 RELATED WORK

2.1 LIMITS

The central topic of the LIMITS workshop and the research community around 'Computing within Limits' [39] is an uncertain future with limitations of material goods. Before the workshop was founded, Pargman and Raghavan [47] leveraged prominent ecological thinking from outside of computer science to inform what sustainability means in the context of computing. Pargman and Raghavan concluded that it means adapting to a reality of limits, of trade-offs, and of hard choices. Even earlier, Tomlinson et al. [56] and Tomlinson et al. [55] raised the importance of considering the material limits of a future defined by socioeconomic collapse and climate change. As Dillahunt [11] described, "HCI researchers and technologists [not only] have the ability to shine a light on society's problems, [but also to] provide platforms that enable individuals and groups to act on today's problems."

Communities similar or related to permaculture first received attention at LIMITS in the work of Gui and Nardi [24] in which they describe knowledge, psychological, and social limits that hinder people from participating in sustainability and how these communities succeeded or failed in countering those limits. More recently, Liu et al. [34] introduced permaculture as a way of emphasizing the limitations of and an alternative to the control model (i.e., one that maximizes labor and efficiency) employed in much HCI research.

A different aspect of food-related research was explored by Muralikumar et al. [38] where they proposed a framework describing how food tracking systems can be designed to promote sustainability. They presented case studies of two platforms that support transparent tracking of products along the supply chain. From a provider perspective, Zheleva et al. [62] investigated and characterized the information and communication technology demand of smallholder agriculture based on traffic analysis of farm Internet use. Finally, relating to the SAGE-CC project's secondary aim to coordinate the utilization of products from collaborative sustainable polycultures, Pargman et al. [46] analyzed the practice of sharing and concluded that it needs to be approached with a dual focus on both sharing and limits.

2.2 Resource Distribution Systems

SAGE-CC aims to facilitate the distribution of ecosystem services and material goods, especially food, derived from collaborative sustainable polycultures. On a conceptual level, Ostrom et al. [44, 45] examined the domain of common-pool resources and offered approaches for managing such shared resources. In the agriculture domain specifically, the CGIAR Commission on Sustainable Agriculture and Climate Change argued that "major interventions, at local to global scales, to transform current patterns of food production, distribution and consumption" are necessary to achieve food security ([5], p. 4). They suggested a number of proposed actions, including creating "comprehensive, shared, integrated information systems that encompass human and ecological dimensions" (pp. 9-12). The USDA has offered that "[m]uch of America's existing food infrastructure doesn't work for local and regional producers" ([58], p. 20).

HCI and ICT research have broadly explored resource distribution systems. In the context of sustainability and food systems, Seyfang [53] investigated local organic food networks to apply theories of both sustainable consumption and ecological citizenship, and discusses the implications on policy and research. Dombrowski et al. [13] prototyped a location-based information system that helps in matching non-profit workers to individuals seeking support and in the distribution of food resources. They conclude that "designers should explore the wide variety of spatial patterns that must align and overlap such that ecologies of nonprofit organizations might synergistically work together to address pressing social needs." [13] A number of other projects at the juncture of food distribution and technology have also been undertaken, including using simulation to optimize operations in food-distribution warehouses [23] and regional food hubs [36], and tracking disease outbreaks by modeling food supply chains [12].

3 RESEARCH DESIGN

3.1 Software for Agricultural Ecosystems

SAGE is the collection of software applications conceptualized and developed by the first author and her associates, including the other authors on this paper, to support the permaculture-practicing public's pursuit of sustainable agriculture by way of addressing their information challenges. The concepts for the SAGE applications, of which the SAGE-CC is one, emerged from five years of fieldwork with two permaculture communities in the United States. The SAGE Composer, formerly called the Plant Guild Composer [42, 43], was the first in the suite to be conceptualized and prototyped. Through this initial design and development process, the complexities of modeling plant characteristics and relationships, and obtaining that data in the first place, became the cornerstone challenges of SAGE. The first author lead a team of researchers in the design and development of the SAGE Plant Database, which supports sustainable polyculture design as practiced by the participating permaculture communities [41]. Best practices for acquiring and creating data for the SAGE Plant Database are currently under investigation. While these applications have been conceptualized or design designed specifically for the participating communities, we expect that other permaculture or similarly minded and practicing communities can benefit from the these applications or variances on them.

3.2 SAGE-CC Concept

The SAGE-CC coordinates the design of sustainable polycultures and other infrastructures within neighborhoods to form agroecosystems. It facilitates users' coordination in space, in time, and of many specific processes such as pollination. Some plants need nearby plants of the same species for wind pollination (i.e., anemophily) or animal pollination (i.e., zoophily). It also helps communities form strategies that rely on and encourage local food system production capacity, resilience, and satisfaction of food needs and preferences. With the SAGE-CC, users can make their outputs available for trade, purchase, or other transactional means.

Human values are paramount in this research. When faced with the suggestion that farms of the future should blend with human values, Wendell Berry [6, p. 79] responded:

> "To propose to blend such a farm with human values is simply to acknowledge that it has no human values, that human values have been removed from it... If human values are removed from [farm] production, how can they be preserved in consumption?"

In designing the SAGE-CC, we aim to support the values of grassroots sustainable agriculture communities, which is are rooted in environmental sustainability and sociocultural equality [41].

Ekbia and Nardi [14] explore financial and information resource distribution from the point of view of social inequality. In their paper they introduce the concept of heteromation, which is the process of accruing profit by way of aggregating value from free labor. The SAGE-CC aims to foremost support the people participating in the collaborative agroecosystem, and aims to avoid fostering opportunity for heteromation that could perpetuate food and resource inequality.

Free and Open Source Software (FOSS) is developed under licenses that provide users with the right to run, modify, and distribute source code of the software. Popular examples of Open Source Software are Firefox, Android, Apache, PostgreSQL and Eclipse. The SAGE-CC is conceptualized as FOSS so that it provides equal opportunity for all people to access the coordination services and underlying plant data it provides, in addition to enabling other communities to copy the platform and transform it into something more suitable for their needs.

3.3 ExploreCSR

The Google ExploreCSR (short for: Explore Computer Science Research) workshop at CSULB themed “Computing for changing the world for the better” was a 3-day event held in February 2019, designed to introduce undergraduate students to research. The 90 participants came from six universities across Southern California. The program was composed of a number of keynotes, panels on the journey of a PhD student and graduate school, and a series of working project sessions where students worked closely with a faculty member and graduate students on a selected topic. The nine teams were each composed of 5-7 undergraduate students, 1-3 PhD or Master's students, and a professor.

There is an extensive list of benefits to student participation in Humanitarian (H)FOSS [16]: technical skills, professional skills (communication norms, critical thinking, team building), learning within a professional community, distributed development, project complexity, an agile development process, social awareness, resume building, and motivation. The humanitarian purpose of HFOSS projects are particularly effective at attracting women and other under-represented groups to computing majors [15, 27].

In addition, FOSS culture has several characteristics that make it suitable for student participation [16]: communal development, openness, transparency, open licensing, distributed global environment, and a meritocratic process. Ellis et al. [16, 17] conducted a family of studies on how integrating HFOSS impacts undergraduate students' self-perception of motivation, software engineering learning, and career aspirations. The project at hand was used to introduce students to developing FOSS in research.

3.4 SAGE-CC Team

The first three authors designed and conducted an undergraduate research education workshop at ExploreCSR. The initial concept emerged from the first author's doctoral research [41], of which the tenth author was the advisor. The team of undergraduate students, the fourth through ninth authors, chose to work on the SAGE-CC project at ExploreCSR. The team of undergraduate students was composed of students across all stages of their curriculum, from first to fourth year, and included various backgrounds across STEAM[1], for example computer science and biochemistry. Their programming and design experience varied widely, from novice to experienced.

4 DESIGN, IMPLEMENTATION, AND RESULTS

Over the course of the three-day workshop, we elicited and specified requirements, designed the user interaction and data model, implemented a demo, and presented the results to ExploreCSR participants.

4.1 Requirements Elicitation

In the first working session, we established the central requirements and constraints for the system. The initial user interface idea stems from the vision of a canvas that represents the garden territory. Existing plants would be drawn onto the canvas in one color, and then the system would make suggestions based on the characteristics and needs of the individual plants according to their layout.

Given the strict time limitations for the development of the demonstration, the team decided to limit the plant database to ten fictitious plants with a concise set of characteristics. The definition of real plant characteristics and the specification of plant relationships is a complex and disputed topic of study in agriculture and other plant sciences that we are addressing in the further-developed components of SAGE [41], however addressing those contexts and challenges was beyond the scope of what we could achieve in a 3-day workshop. The fictitious plants represented approximations of real plants with intrinsic characteristics, needs and tolerances (inputs), and products and services (outputs). To facilitate creativity in our definition of fictitious plants and relationships, we chose a blended theme of fantasy and programming. A “Troll Tree” is an example of a plant on the fantasy end of the spectrum, while the “C++ Coconut” is an example on the programming end of the spectrum. The full set of fictitious plants is described in Table 1.

The fictitious plants exemplify the dependencies and constraints that a natural plant environment would exhibit, just simulating such a network of relationships on a much smaller scale. For example, the Dragon Root, which is fictitiously cultivated for medicinal use, needs fire germination, and therefore other plants that are highly flammable, like the Unicorn Wheat, might need a barrier

[1]Science, Technology, Engineering, Arts and Mathematics

Name	Layer	Needs/Susceptibility	Human Uses	Ecosystem functions
Lazy Lichen	ground cover	needs tree	acoustic (it snores)	provides bark protection
Unicorn Wheat	tall grass	susceptible to fire	medical	deters glimmer snails
Troll Tree	tree	needs troll buddy, needs bark protection, needs troll food	guardian	deters humans from planting incompatible plants
Moon Flower	ground cover	needs nitrogen	aesthetic	provides moon-water
Dragon Root	root	needs fire for germination	medicinal	provides soil stabilization
Sparkle Berry	bush	susceptible to glimmer snail, susceptible to tangy fumes	edible	attracts butterflies
Code Corn	tall grass	needs tangy fumes	laptop fuel	provides climbing structure
C++ Coconut	tree	needs nitrogen, needs pollination from butterflies, susceptible to tangy fumes	laptop fuel, edible	provides troll-tree food
Buzzing Beans	vine	needs climbing structure	edible, fireworks	attracts bees, provides nitrogen
Tutti Fruit	tree	needs pollination from bees	edible	provides tangy fumes
Boba Bush	bush	needs moon-water	medicinal, edible	deters fire

Table 1: The ten fictitious plants of the SAGE Community Coordinator demo.

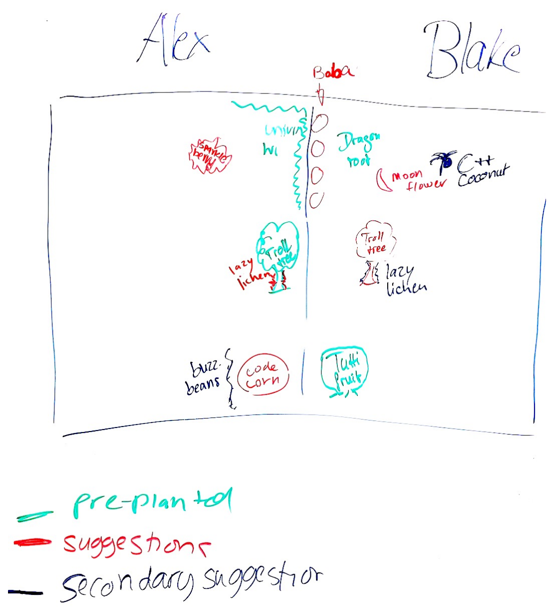

Figure 1: Whiteboard sketch of the adjacent garden patches.

of protection if planted in close vicinity. A row of Boba Bush can create such a barrier, as a particularly wet, fire-retardant plant.

4.2 User Interaction and Design

The vision for the user interaction is to have a map view of the gardens where a user can drag and drop plants. Figure 1 depicts the adjacent gardens of the two fictional users Alex and Blake. Alex has planted Unicorn Wheat and a Troll Tree, and Blake has planted Dragon Root and a Tutti Fruit. However, for the first demo, we decided due to time constraints to simplify the visualization and display the plants in a list that included the corresponding plant images.

Subsequently, we identified the analysis steps that had to be resolved by the SAGE-CC algorithm. They were documented in simplified pseudo-code walking through an example usage scenario.

(1) Make list of both the user's plants and their neighbor's plants already existing in context, including their needs, vulnerabilities, and ecosystem functions.
(2) For each plant in your neighbor's yard, evaluate its needs in context:
   (a) Go through the needs of your neighbor's plants and check if satisfied by ecosystem functions currently provided by the user's plants in context.
   (b) If not satisfied, look up companion plant(s) in the existing plant database that would satisfy the need of your neighbor's plant. Add that plant plus rationale ("Plant X helps Plant Y with Z.") to list of suggestions for the user's garden.
(3) Display a list of plant suggestions to user for their yard that would benefit the plants in their neighbor's yard.

Then we developed the data model (see Fig. 2) to hold all required information in the database in seven tables for the plant and ecosystem data. Plants in the database are in reference to a type or species, not a specific manifestation of a plant. Each plant had a unique name and layer (e.g., ground cover, tree). Plants could have multiple human uses, and were therefore stored in a PlantHumanUse table with references to the Plant and HumanUseProp ids. A plant could also have multiple ecosystem relationships in the PlantEcoRelations table, each consisting of an ecosystem relationship property (EcoRelProp) and value (EcoRelValue). The ecosystem relationship properties and values were defined as follows:

- Ecosystem Relationship Property: Bark Protection, Glimmer Snail, Fire, Nitrogen, Tangy Fumes, Moon-Water, Bees, and Butterflies
- Ecosystem Relationship Value: deterrent, susceptible, needs, attracts/produces

The PlantEcosystemRelationships table allowed for logical pairings such as "Code Corn needs tangy fumes and Tutti Fruit provides tangy fumes."

Furthermore, we needed a table to model the user properties and another for the yard. The user and yard tables represent an instance of a plant model. In other words, they allow for the representation that plant species or types could be in multiple yards, and yards could have multiple kinds of plant. The User table specified the

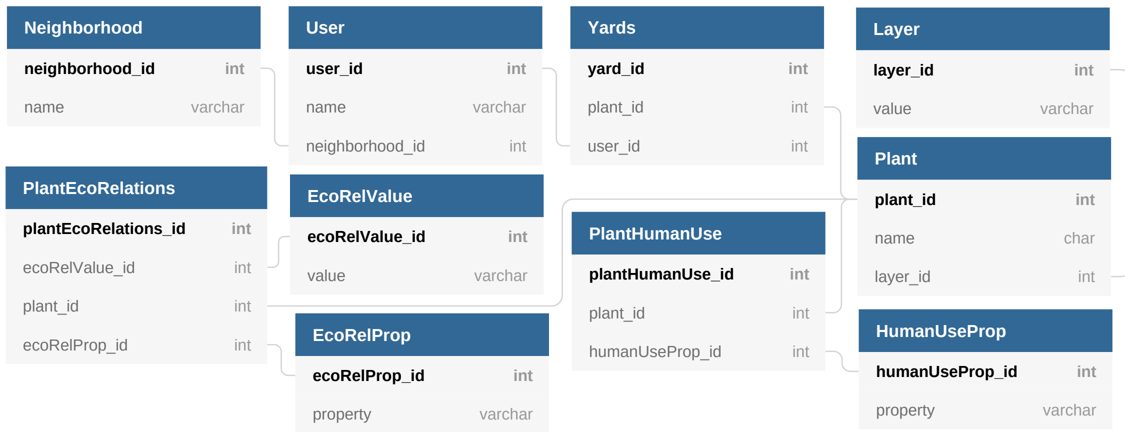

Figure 2: Data model of the SAGE-CC.

user's name and neighborhood, while the Yards table records each instance of a plant in a yard with references to a Plant id and User id.

Finally, the Neighborhood table allows the algorithm to determine the user's neighbors and therefore search their yards for potentially beneficial and detrimental relationships with plants in their yard. In summary, these nine tables provide a concise representation of information from which to infer suggestions for which plants the user should add to their yard.

4.3 Implementation of the Demo

The framework we used included a technology stack of Django, a Python 3 and HTML web framework, with a PostgreSQL database. We created a data model in Python that was then translated into database tables for the SQL server, according to Fig. 2. The Python server script would load the existing gardens into the starting page, and the page would display a button "Show suggestions" that allowed the user to request suggestions to complement the existing plants in both gardens. The response would re-list the existing plants and make additional suggestions for what else to plant. The screen shot of the demo in Fig. 3 shows a suggestion to plant a Boba Bush (to protect the Unicorn Wheat from the fire the Dragon Root needs to germinate).[2] In a future iteration, the results would include a map view of where to best place the additional plant, and a rationale of why this plant is suggested.

Several undergraduate students (who are authors on this paper) worked in pair programming teams, committed their code to the joint Github repository[3] and presented the demo as well as their insights and lessons learned at the final day of the workshop.

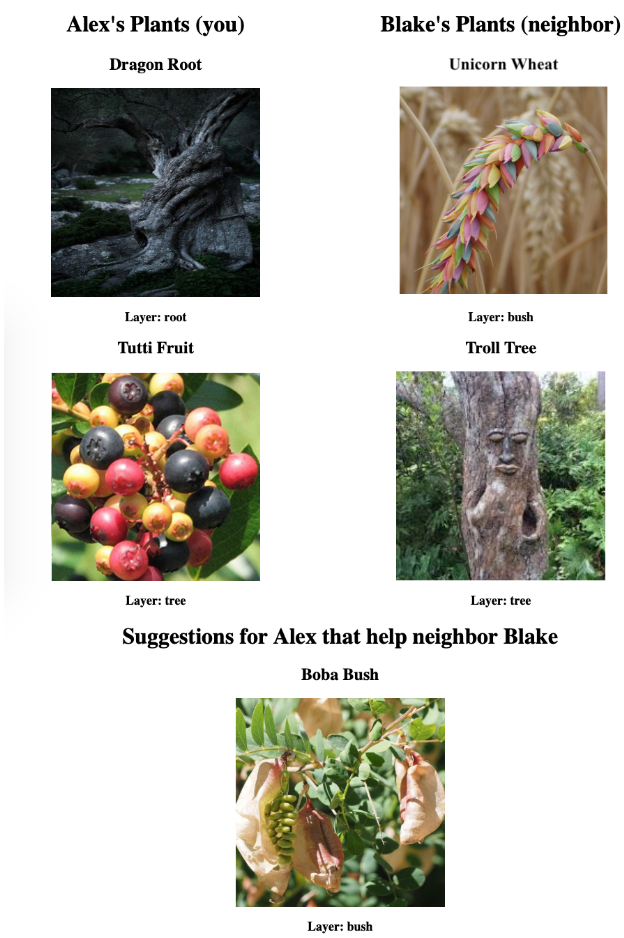

Figure 3: Screen shot of the demo.

[2]Demo uses images under the fair use terms for education and research. Dragon root: https://unsplash.com/photos/NNC8Y1H223k Tutti fruit: https://www.pinterest.com/pin/598134394234034806 Unicorn wheat: https://wallpaperstock.net/rainbow-wheat-wallpapers_w52863.html Troll tree: https://www.facebook.com/trollbeadswestfarms/photos/troll-tree/1233230756719296/ Boba bush: https://pxhere.com/en/photo/548981

[3]https://github.com/julietnpn/sage_cc

5 DISCUSSION OF INSIGHTS

Through the development of the SAGE-CC, our team identified a series of insights and actionable strategies that lay the foundation for our future implementation to improve the likelihood of success for the system.

5.1 Tackling Information Complexities

During our initial conceptualization of the data models, the undergraduate student authors, who were newcomers to this domain, were surprised by the level of complexity required to capture and maintain plant information. The students recognized that potential users of the SAGE-CC could be overwhelmed by plant information. Details such as the arc of the sun, the exact placement of plants relative to their ecological relations to other plants, the introduction of animal or fungi species, and plant arrangement across gardens are important but onerous details to capture and define. Once plant information is in the SAGE-CC, it is an equally complex task to choose what plant information and suggestions are most appropriate for the community and their immediate needs. If we want a high level of use of Sage-CC, it must maintain information resourcefulness without overloading users with excessive plant information. Although the undergraduate student authors recognized complexity challenges in the context of the SAGE-CC development, they are are challenges adopted from the SAGE-Composer, which the SAGE-CC extends, and are flagged issues for future work.

5.2 Encouraging Community Collaboration

Motivating collective action amongst neighborhood communities can be difficult to accomplish, and the SAGE-CC needs participation from multiple neighbors to function. Some community members may not wish to participate. Other members may restrict their participation to minimal or selective levels of involvement to support neighboring gardens. Community members may also wish to keep their land information private, unwilling to provide data about their plants that could be critical to the support of species in neighboring gardens. The SAGE-CC should provide opportunities for various arrangements of garden information according to data privacy and sharing expectations across different communities. Thus, the SAGE-CC must be able to account for diverse needs in the community.

Furthermore, we suggest that the SAGE-CC should not only coordinate pre-existing neighboring relationships, but also connect new relations among neighbors and provide a space for involvement and education across the community. For example, an iteration on SAGE-CC would also coordinate the exchange of surplus goods from the sustainable polycultures. Neighbors can form new relationships in the trade of their products and possibly encourage the future coordination of their yards. Our system also encourages community collaboration and education by allowing neighbors and communities to help each other's gardens. SAGE-CC encourages neighbors to help each other, which will aid in fostering and reinforcing a sense of community. The SAGE-CC also creates a transparency of the participating communities' gardens allowing neighbors to learn from each other and exposes its users to different types of plants and horticultural techniques. Potentially, our system could evolve to include a social platform to further facilitate the exchange of ideas and goods.

5.3 Providing A User-Friendly Collaborative Experience

The need for a user friendly system that tackles the challenges of working with complex plant data was frequently discussed by our team. Future iterations of this system should be designed in a way that provides an appropriate level of information for each participating community. The Sage-CC should offer an experience that is inviting for all community members to partake — it must balance complex agroecosystem information and users' limited understanding of gardening, with an easy-to-use design.

Our first iteration of the demonstration provided a low-level conceptualization of neighboring gardens to show how one suggested plant may improve the collective success of two gardens. In the future, the system needs to account for a much larger set of plants and suggestions for neighbouring gardens. We plan to return to our initial interface design of a canvas map view of the gardens in order to display a larger set of plant information. A challenge to this design is ensuring that all plants and plant suggestions in a multi-layer ecosystem are provided via legible digital representations. These representations will guide user actions in their gardening design and techniques.

6 LIMITATIONS

This project had limitations in time, complexity, and scalability. In this section we elaborate on those limitations and how we foresee them being addressed. The project is not fully developed, however, this initial demo of the system successfully shows that it is possible to build a system that can help communities and neighbors coordinate their plants if real plant data were available.

6.1 Time

First, the SAGE-CC was designed and developed during a three day workshop, limiting our time to develop and test full components of the system. The system has not been tested by potential users because it is still in its working stages, and will require further development for testing and implementation. In a less restricted window of time, we would have proceeded to integrate the functionality with the existing SAGE Sustainable Polyculture Composer user interface and connect it to the garden map canvas, so users can drag and drop plants and suggestions would pop up as envisioned in Fig. 1. When this functionality is added onto to our initial demo, we can then have users test SAGE-CC as our first prototype. If our team finds that the users' benefit from SAGE-CC, we can then continue to work on the steps outlined in section 7 (Future Work).

6.2 Complexity

Second, the SAGE-CC only works with fictitious plant information that we used to provide a low barrier to design and development for the team. It does not use real life plants that have more complex needs and relationships within an ecosystem. For expanding the SAGE-CC to the complexity of a real plant database, a more complex data model would be required to depict these more intricate relationships and multiple constraints. The evaluation of a given context would also require multiple objective optimization [29, 61]. An additional factor for complexity is the high number of variables in a natural ecosystem, from weather patterns to soil composition to wind, rain and sun exposure.

6.3 Scalability

Third, as a consequence of the increased complexity when using real data, there would be high requirements for scalability, as the evaluation of database requests would entail the need for efficient algorithms. Related work that to be considered for this are evolutionary and genetic algorithms [1, 31, 52]. The current algorithm is not designed for high efficiency, so for scalability, the matchmaking of the algorithm could be improved as well as the database design, but the idea behind the current implementation scales.

6.4 Imaginary plants

The fictitious plants, their characteristics, and the relationships among plants are rudimentary representations of real plant characteristics and relationships. While the inter-plant relationships of the ficitious plants are simplified in comparison to naturally occurring plant relationships, the approach scales for more complex plant networks with a higher number of relationships as formed by permaculture practitioners that participated in the formative research for the broader SAGE suite [41]. Members of these communities did not typically collect plant and context data required to form more complex relationships, instead they grappled with these relationships in their designs and practice at a conceptual level. However, most inter-plant relationships are to some degree fuzzy and thus are not responsive to a straightforward analysis as most commonly practiced by the target users and represented in this demonstration. The question of whether it is possible to map out all plant characteristics and potentially arising relationships onto one conceptual model and in such a way that can support the work of the participating communities has been treated extensively in the first authors PhD thesis [41], but remains open.

7 FUTURE WORK

In a short time period, we were able to quickly develop a prototypical system. We generated our design requirements, provided exemplar plant data, developed a simple interface, and demonstrated our working project to a workshop. Full implementation is feasible, and we laid the groundwork for future development. The SAGE-CC has the potential to encourage collaboration and collective sustainable polyculture gardening amongst neighbors in a community. The first step of our future work is to develop this system for a working database of real plants. For example, the SAGE Plant Database can provide the SAGE-CC with a robust set of plant information specifically for sustainable polyculture design [41]. The plant data in the SAGE Plant Database will facilitate the collaborative sustainable polyculture design interactions among actual people and their neighbors to test the usefulness of the system in practice.

Furthermore, the software could introduce additional features such as automation of the mapping of existing food gardens through previously collected data and land imaging. Depending on how much image recognition could be refined (see related work on Leafsnap by [32]), this might significantly decrease the initial effort of users to have their garden in the system. Such automation can be utilized to establish existing knowledge of land use around a communication before introducing additional plants to the systems.

8 CONCLUSION

Modern agriculture has alarming affects on ecosystem health and diversity, which in turn negatively impact the productivity of agriculture, among other systems. By supporting local agroecosystems through the development of our information system, we bring gardeners and local communities closer to sustainable forms of food and material production, moving away from production methods that harm the surrounding ecosystems. Our development of the SAGE-CC demonstration offers a stepping stone towards supporting these changes to production. This system will allow less experienced gardeners to work together to integrate sustainable polycultures into their local communities, bringing them closer to sustainable methods of production through the sharing and distribution of local resources. By doing so, it will hopefully allow communities that use it to become more resilient to the disruptions that a future of limits is likely to bring.

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