Objectives/aims

Agriculture has the greatest footprint of any human activity, and much work has gone into improving its sustainability (Harwood, 2020). In modern conventional agriculture some hope to mitigate impacts/costs through optimization while in agroecology some hope to create holistic, resource-conserving methodologies for management. However, these two approaches to sustainable agriculture often come from different epistemological viewpoints; as a result, it is difficult both intellectually and practically to determine the "best" or even a "good" course of action in sustainable farming today (Jordan and Davis, 2015). While much work has gone into exploring complex cropping systems that provide more ecosystem services while producing the same amount of food, feed, fiber, and fuel as simpler systems (Tamburini et al. 2020), these systems are often idiotypic (Shaffer et al., 2000) and not transferable outside of the farms where they were trialed (Robertson et al., 2012). As computing has penetrated nearly all aspects of modern society (e.g., transportation, health and medicine, and human interaction), many have proposed to leverage computing to improve the sustainability and productivity of agriculture (Raghavan et al., 2016). We propose a way of merging individual farm-based solutions and accommodating different epistemological frameworks by borrowing tools from computer science---in particular, the notion of a *state space* (e.g., plant traits, cropping system) which can be explored by an *artificial agent*.

Conceptually, the state space framework puts conventional agriculture and agroecology in contact, by representing farm states, inputs and outputs, and goals/objective function in a single commensurable way. Recent stunning advances in the field of reinforcement learning (Li & Du, 2018) provide confidence that machine learning techniques can help human beings design and evaluate agricultural systems, spanning the gamut from precision-agricultural to agroecological, and to new systems heretofore unimagined. The use of state spaces makes it possible to make explicit previous conceptual designs (Jordan and Davis, 2015) by formalizing (mathematically) and es creating a simulation engine to search states based on different value propositions; this leverages computational power to search nearly infinite state space to identify promising designs, something this is not possible in real world time and limited by human imagination. This framework, combining human values, ecology and machine learning has the potential to break current paradigms and challenge assumptions to create new agriculture for a changing world. *We* *propose bringing together a wide range of researchers from a range of disciplines including agriculture, computer science, philosophy/ethics, geography, and robotics, to set a broad research agenda based on the state-space framework.*

The state-space approach builds upon existing farm-scale modeling approaches within agriculture (Shaffer et al., 2000), which prohibit deeper integration between computational thinking, software systems design and the traditional agricultural disciplines of plant breeding, agronomy, and agroecology. Further, these approaches do not often consult ethicists when designing systems. Here, we propose a forum to explore how advanced techniques from machine learning and agent-based modeling might be integrated with plant genotypic and physiological models to understand how underlying processes result in emergent phenotypes, cropping patterns, and agroecosystem services. Bringing these different disciplinary perspectives together allows for a reconceptualization of the fundamental assumptions that drive agroecosystem development.

Why these three modeling communities?

- Machine learning is good at predicting poorly related inputs and outputs
- First-principles physiological models explicitly account for physical processes
- Agent-based models are good for modeling emergent phenomena

Goals

We hope to develop a common transdisciplinary language surrounding:

- Advance conceptual issues
- Design a strategy to develop, deliver, and sustain a transdisciplinary training program

Approach

We propose to hold two meetings. The first will be with the core group of six researchers representing four distinct disciplines. This group will develop a white paper and identify an additional 6-10 researchers to be brought for a second meeting. During this second conference we will work toward a consensus for data generation to drive generalizable, first principled models that can predict novel agricultural system outcomes. This includes highly diverse systems as well those designed using a computational-ecological perspective. Our approach includes both a description of how existing plant varieties can be deployed for these systems and suggests pathways for land managers to develop new landscapes. We aim to fully bridge the gap between computing and agriculture by applying a deep understanding of computational abstractions to the design and modeling of agricultural systems and bringing ecological and geospatial perspectives to the computational and technological problems that must be solved. This method of abstraction would allow for any system, plant, animal, or unforeseen systems to be computationally derived so that millions of potential systems can be distilled into a few testable operations.

Furthering the aims of the AG2PI

This project fits directly into the AG2PI goal of building "*cross-kingdom research communities to address the challenges of genome to phenome (G2P) research*" and explicitly explores the objective "*Motivate agriculture-focused analyses of AG2P from ethical, legal, social, ecological, and economic perspectives*", the flexible agent-based modeling framework that will be co-developed by researchers from the plant sciences, geography, computer science and philosophy will provide a flexible framework to understand potential new unforeseen agroecosystem models. Directly relating the value propositions defined in strong ethical frameworks will provide a clear way to explore novel agroecological space, this novel space provides an opportunity to create untested combinations of plants and animals that can fulfill different human needs. If the project succeeds there will be a new way to create expectations for novel agroecosystems. Combining conflicting approaches in contact with one another and letting machines explore design space allows computing power to be put to bear to imagine new scenarios. Models provide simplified versions of the world; they are incomplete, but they provide potential representations of the state of the system. They can represent what we want for the ideal world, the worst-case scenario, and everything in between. By modeling for specific value propositions, the requirements for transitions between different states can be defined. This will enable promising designs (agroecological states) to be empirically tested and physically optimized in the attempt to get them adopted in the most appropriate geography.

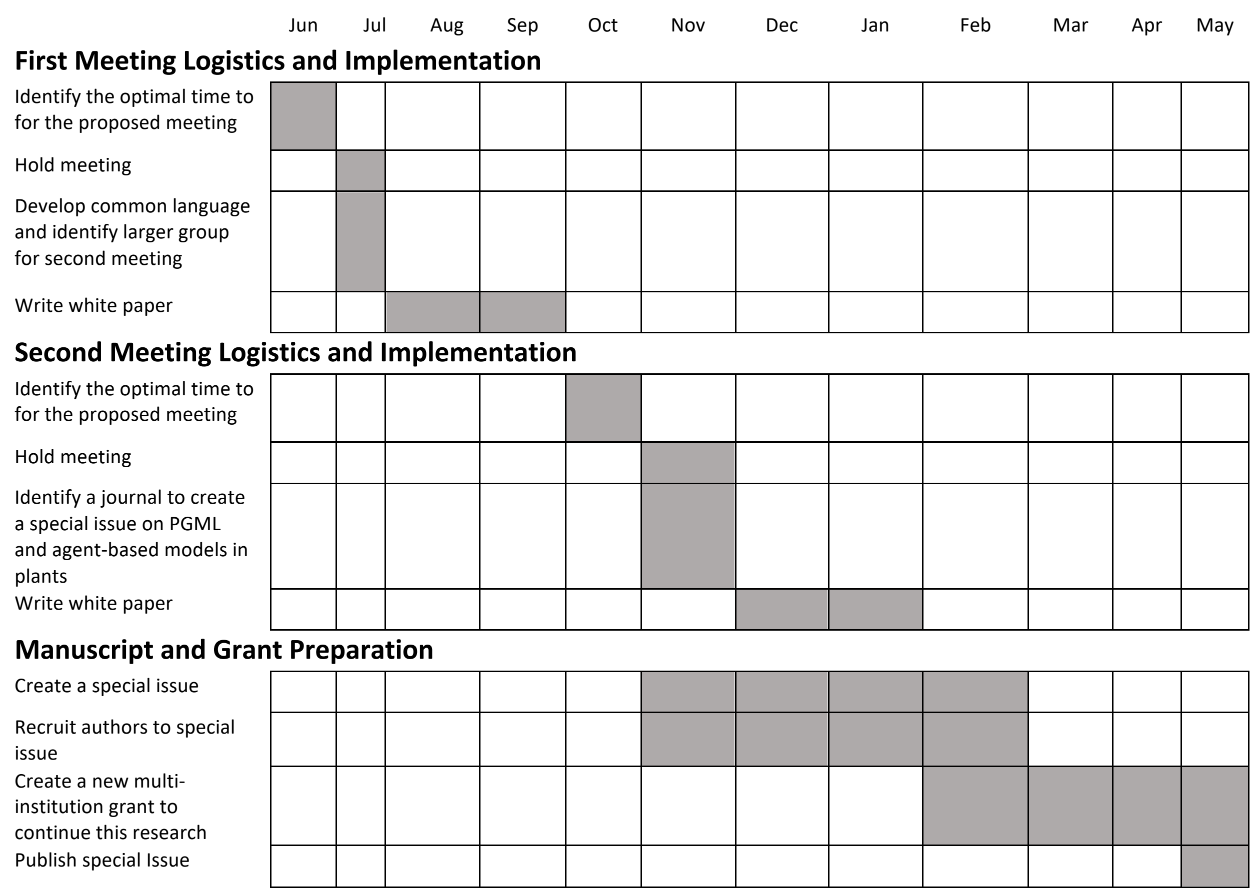
Expected outcomes & deliverables

- Discuss current /emerging needs surrounding graduate education in agricultural modeling
- Co-write a perspective of how PGML and ABM can be combined to address issues associated with agriculture
- Develop a special issue on ABM for agriculture
- Develop curricular goals for transdisciplinary courses that can be taught to undergraduates or taught as workshops to graduate students.

Qualifications of the project team

- Dr. Kantar has extensive experience in plant breeding and genetics. He is an associate professor at the University of Hawaii working on local adaptation and using agricultural data in different ways.
- Dr. Runck has extensive experience in agroecology and agent-based modeling. He has taken his work in geography and GIS and applied it to designing better data management systems for agricultural data.
- Dr. Raghaven has extensive experience in computer science and cybersecurity. He is an associate professor at the University of Southern California, and has been at the forefront of combing agriculture wit
- Dr. Wang is an ecophysiological modeler with formal training in plant breeding and genetics. She is pioneering new ways to integrate genetics with process-based models.
- Dr. Streed is an accomplished philosopher and ethicist and has extensive experience in computational models that include ethical components.
- Dr. Ewing is a cropping systems agronomist with the USDA. He has extensive experience in ecological modeling and understanding how ecology impacts crops.

Proposal timeline



Engaging AG2P scientific communities & underrepresented groups. Drs. Kantar and Wang each lead federally funded undergraduate research programs that engage underrepresented groups: USDA-REEU (grant no. 2020-67037-30665/project accession no. 2019-05082) and NSF IRES (grant no. 2106718) programs, respectively. These programs leverage different types of agricultural data and emphasize holistic thinking as it relates to agriculture and food security. Drs. Runck and Ewing are planning to use this work as a springboard for a new REEU program they are currently in discussions with the USDA tribal liaison to identify potential partners in Minnesota and South Dakota. This work will provide jumping off points for different systems that can be used to either empirically test predicted systems or further refine what different communities want their agriculture to look like.

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