CS486C – Senior Capstone Design in Computer Science

Project Description

Project Title: A user-friendly platform for visualizing tree growth

Sponsor Information:

Dr. Kiona Ogle, Professor

School of Informatics, Computing, and Cyber Systems
Ecological and Environmental Informatics (EEI) group

Email: Kiona.Ogle@nau.edu

Project Overview:

Climate change is impacting the physiology, distribution, and phenology of many plant and animal species, and such alterations are expected to escalate under future climate change. A large portion of the terrestrial biosphere is comprised of forested ecosystems, which cover nearly 50% of the land area, contain about 90% of the global vegetation carbon, and account for more than 85% of the leaf area that mediates carbon and water exchange between the biosphere and atmosphere. Thus, feedbacks between climate and forests are critical to understanding and forecasting impacts of climate change on the biosphere. Importantly, a physiological representation of tree growth, carbon allocation, and mortality is essential for predicting the effects of climate change on forest structure, diversity, productivity, and carbon dynamics.

To meet this need, the Ogle lab has developed a modeling framework that links tree function and form. A goal of our research is to extend this data-driven, computationally intensive model to many species, laying the foundation for future work aimed at understanding climate change impacts on forest dynamics for forests in the US.

We refer to our tree growth model as the **Allometrically Constrained Growth and Carbon Allocation (ACGCA)** model (Figure 1). The ACGCA model is able to describe a range of growth conditions that are consistent with real tree behavior (i.e., healthy, static, shrinking, recovering, recovered, dead). The ACGCA model is based on a coupled set of discretized differential equations that describe how different carbon and biomass pools change (shrink or grow) over time, including leaf biomass, stem biomass,

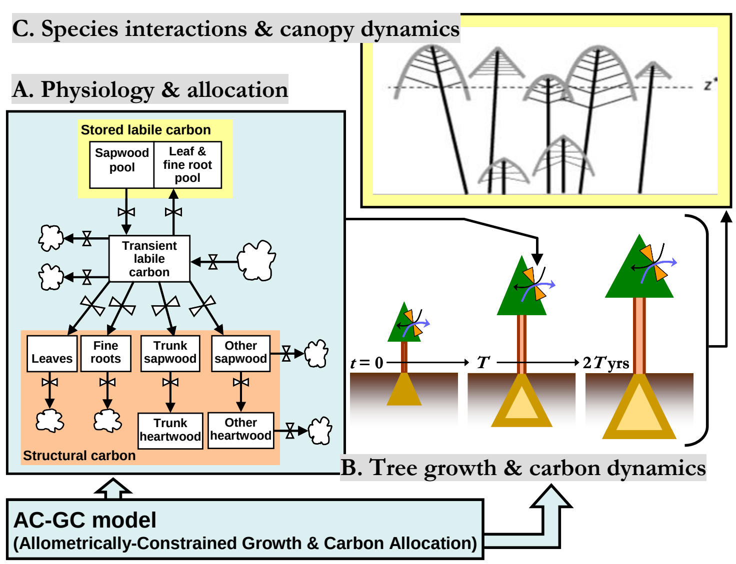

Figure 1. Schematic of the ACGCA model. **(A)** The system diagram illustrating the different state variables (compartments or pools) in the model, and the inputs to and outputs from each variable. A system of discretized differential equations governs the dynamics (size, in/out flows) of these compartments. **(B)** Very simply graphical representation of tree growth over time. **(C)** The ACGCA model can be embedded in a "forest simulator" to describe competition among individual trees and emergent forest dynamics (not part of this project).

root biomass, branch biomass, and labile carbon pools in each of these compartments (leaves, stems, roots, branches). The roughly 200 equations that make-up the ACGCA model are currently programmed in both Matlab and C, and we have developed an R package that serves as an interface between the model code, driving data, and other user inputs (e.g., parameter values). We have successfully used the ACGCA model and its code base in a variety of projects, which have led to three publications in scientific journals and a PhD dissertation.

The problem

Unfortunately, the model has not been used much by other researchers or educators, likely because the current implementation is not particularly user friendly; it requires command line parameter entry and invocation of the model code, and output is purely numerical. We recently developed the R package, which we hope would make the ACGCA model more accessible to users. However, users are still required to have working knowledge of R and must write their own code to evaluate and display model output (e.g., to plot and visualize predicted tree growth patterns). What is needed is an accessible, easy-to-use GUI that will allow any scientist anywhere to easily explore the ACGCA model in a dynamic interactive fashion.

The objective of this project is to develop, validate, and deploy a user friendly, web-based interface for the ACGCA model that will make it accessible to a diverse group of potential users. Users should be able to access the web application to dynamically explore how various parameters influence tree growth, i.e., the interface should allow users to enter/adjust the values of various parameters and visually see the predicted effects on tree growth and vitality. Our target user audience is three-fold: (1) researchers that are interested in and that study tree growth and forest processes (e.g., forest ecologists, tree physiological ecologists), (2) forest managers that need to understand the factors affecting tree growth to make decisions about managing natural, managed, or planted forest stands, and (3) educators and students (e.g., the ACGCA model could be used to demonstrate concepts related to tree physiology and growth in undergraduate and/or graduate courses).

The specific objectives and approaches of this project include:

Basic features (minimal viable product):

- Develop a web application that provides a dynamic interface to the ACGCA model; this could be through re-implementing the model in an internal module, or somehow serving as a GUI front end driven by the existing Matlab or C code in the background. The interface should be easy for non-computer-savvy users to use and visually appealing.
- Allows dynamic exploration: users can easily enter parameter values (or perhaps have sliders allowing users to adjust them within realistic ranges) and "click GO" to re-run the model to explore the results. The parameters represent different biological "traits" that govern tree growth, and different numerical values can result in different growth patterns, and can mean the difference between a healthy growing tree versus one that dies quickly.
- The resulting model output should be shown as some simple visualization of predicted tree health over time, as well as being downloadable as a numerical file.
- A particular set of parameter values is meant to describe an individual tree, and upon clicking "GO," the model will simulate how that tree grows over a specific time period (also input by the user).

Additional features to make it a fully useful product:

- A more advanced interface should be able to simulate growth patterns for multiple trees (i.e., multiple sets of parameter values).

- It would be useful if the user could also have the option of uploading a data file with the (30+) parameter values, instead of entering them using the GUI as outlined above. Users should also be able to "save settings", saving a particular parameter set into a data file (e.g. XML, JSON), which could be mailed to and uploaded by other users to explore.
- An improved and more detailed visualization of tree growth/vitality; something more interesting/ interactive than the basic visualization required in the MVP. The results should be available in a nice viewer, e.g., with a time slider along the bottom allowing the users to (a) "play" the time sequence so that the slider moves on its own through the time series, with the tree visualization changing accordingly; and (b) the user can move the slider manually. This could be achieved with automated arrangements of a series of 2-D images of a tree as well as scaling those images to create a time series that visualizes changes to the tree over time. During stressful periods, the tree may drop leaves or branches while maintaining its height, and the visualization tool should be able to capture these "pruning" periods.
- If the user elects to simulate growth of multiple trees (different sets of parameter values), visualizing or plotting tools should be developed to "overlay" or compare the predicted growth patterns of the different trees.

Stretch goals: Finishing the project with flair

- We envision developing a teaching module that would leverage the ACGCA model and the newly developed web-based interface. The target audience is a senior-level undergraduate or lower-level graduate course in forest ecology, plant or tree physiological ecology, or general plant ecology. Ideally, we would publish the teaching module in an educational journal.
- Publish the web-based interface in tandem with the R package. We are currently using the R package in combination with a large dataset on tree heights and diameters (collected by the US Forest Service) to determine how tree species in the US differ in their growth parameters and growth strategies. The R package is coupled with a sophisticated statistical algorithm that "finds the best set" of parameter values given the observed height and diameter data. Once we have these parameter values, we could use the web-based interface's visualization tool(s) to demonstrate how these parameter values lead to different tree growth patterns.

Knowledge, skills, and expertise required for this project:

- Use of high-performance computing facilities (we may explore using the Monsoon computing cluster for running the ACGCA model). Running this product on Monsoon will require detailed security review by the Monsoon group. For development, the team must create a means (perhaps simulated) to test and develop the GUI on a normal server (e.g. hosted on student dev machines).
- Will need to develop familiarity with Matlab and/or C, especially as run as a back end to drive web-based GUIs.
- Knowledge of modern Web2.0 wep app development and relevant frameworks and techniques, as well as relevant programming languages (JS, Java, Python, etc.) as needed based on frameworks chosen.
- Development and user testing of user-friendly graphical user interfaces in web-based systems.

Equipment Requirements:

- There should be no equipment or software required other than a development platform and software/tools freely available online.
- If Monsoon is used, access to Monsoon will be provided by the client in the later development phases, when a beta-prototype is available to testing on the real high-performance platform.

Software and other Deliverables:

- The software application described above, deployed on a web-server and tested successfully with real data and representative users. Ideally, it will be installed and operational on Monsoon, after security review by Monsoon staff.
- Must include a complete and clear User Manual for configuring and operating the software; ideally this would be available online for web users.
- System Administrators Manual, with detailed instructions on how to install and configure on a webserver.
- A strong as-built report detailing the design and implementation of the product in a complete, clear, and professional manner. This document should provide a strong basis for future development of the product.
- Complete professionally-documented codebase, delivered both as a repository in GitHub, BitBucket, or some other version control repository; and as a physical archive on a USB drive.

Relevant References:

- Fell M., J. Barber, J.W. Lichstein, and K. Ogle (2018). Multidimensional trait space informed by a mechanistic model of tree growth and carbon allocation. *Ecosphere,* 9(1):e02060. abstract
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- Gemoets, D., J.J. Barber, andK. Ogle (2013). Reversible jump MCMC for inference in a deterministic individual-based model of tree growth for studying forest dynamics. *Environmetrics*, 24: 433-448. abstract
- **Ogle, K. and S.W. Pacala (2009) A modeling framework for inferring tree growth and allocation from physiological, morphological, and allometric traits. *Tree Physiology*, 29:587-605. abstract