The Hohokam Water Management Simulation:
Collaborative Modeling of a Complex Coupled Human/Environmental System

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Background

The Hohokam built an extensive canal system around the Salt and Gila rivers, and employed irrigated agriculture for well over a millennium before disappearing just prior to Spanish contact. Archaeologists can tell us much about the physical remains of the Hohokam, but the scale at which they organized the labor to build, repair, and maintain the canals, and the way they managed the canal system and balanced the requirements of various crops in order to survive in a challenging climate, remain unexplained. The problem can be approached from widely varying timescales and with coarse or fine resolution into the options available to the Hohokam (i.e. a diverse spectrum of plants or monocrop maize agriculture). The HWM Simulation is able to bring together the disparate data on plant varieties and their requirements, and allow these to be tested in a simulated environment in which hydraulic properties of canals, nutrient transport, and soil quality are all modeled. Further extensions explore the labor requirements for all aspects of the irrigation program.

The project has been guided by a modeling philosophy that incorporates several overarching, and interrelated, themes: **Collaboration**, the challenges of research on **Complex Systems**, a **Communicative** approach to modeling, and **Auditability**. These themes crosscut each other; many of the elements, detailed at the far right, support more than one of these themes.

The focus of this poster is on the structure of the simulation architecture, and not on results. It showcases elements that are potential contributions to archaeological and ecological modeling in general, and in particular to a new interest in building cross-comparable and interoperable models of human-natural systems; the HWM system includes many elements that are very well suited for meeting the challenges of such a project. The simulation is in the late stages of testing and deployment; users will be introduced to the simulation and be allowed to run experiments on it in the coming months.

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Collaboration

Our modeling philosophy is built on a collaborative approach. Rather than create a one-shot model for one person, we incorporate the problems of interest to a number of scholars, and share both the formulation of these problems and the activity of experimentation among them. This imposes a high bar: input and output data are to be available to all members of the community, and in a way that allows them to pursue their disparate approaches. The benefit is that the model is a repository for their efforts and their results, and a framework within which further work could be developed. It is thus not a one-time achievement, but a sustained and continuing one, that grows along with our knowledge of the problem.

This approach either demands or is supported by all the elements shown at right.

Complex Systems

Our approach assumes that Hohokam social organization can be treated as a complex system. This implies that unexpected dynamics may have played a role and must be accounted for within the simulation. It also implies that it we should not attempt to simulate what the real past was like, but rather to allow ourselves to ask 'what if' questions about possible alternative trajectories- to pursue, for example, speculative or even unlikely scenarios. Our effort is to find how likely the Hohokam florescence was- whether it came about against dramatic odds or whether one could have changed a wide array of initial conditions and the same basic trajectory would have been followed.

The complex systems approach is especially supported by elements B, E, F, and I at right.

Communication

One of the essential functions of a model is to communicate. The communicative aspect of the HWM Simulation can be seen in nearly all of its elements; the sharing of information (input and output data) is one easy example, but others, such as the common vocabulary established by the cartoon (and the process through which it was created), and the clarity and accessibility of content and output, are also important.

Perhaps more important, we view the process of simulation as one part of building archaeological arguments and knowledge. Simulation results pose special data management challenges, and hence means of integrating them into broader discourse are built-in.

See elements A, C, D, E, F, G, H, J, and K at right.

Auditablity

Simulation results must meet the burden of replicability and reproducibility; this is a challenge even in one-shot simulations, but in the HWM System, extensibility is built-in, code changes are expected, and the problem of replication becomes even more challenging. An extensible architecture permits this in the HWM Simulation, and is coupled with a data structure in which all input data and output data, including descriptions of the versions of code in place, are kept in the central database. A complete audit trail for all the input data from any simulation run to its output data is preserved.

See elements C, D, E, F, G, H, J, and K at right.

A The 'Cartoon'

Recognizing that all modeling is an abstraction, we endeavored to find the elements of the Hohokam system that were common across multiple perspectives on the problems of interest to archaeologists. The result was a 'cartoon' of the processes of the Hohokam irrigation system, that had the following elements

- Water flows through canals
- Nutrient is carried with the water
- Water is deposited on fields
- Canals fall into disrepair and silt up
- The amount of water available for canals varies from year to year
- Water on fields meets the water needs for plants; these vary
- Nutrients are deposited into the soil on the fields
- Plants grow and are harvested
- Plants are stored and provide food that fuels labor
- Repair to canals requires labor
- Expansion of canals can take place, but also requires labor

Each of these (inter alia) was modeled by a part of the HWM Simulation algorithm. Together they form a framework within which important questions could be answered; however, they also define the limits of the questions that can be explored.

B Agent-Based Modeling

In Agent-Based Models, multiple programmatic actors assess their positions from unique points of view, and make decisions based on their own goals. The dynamics of systems that result from several independent agents can be unpredictable; under some conditions, ordered systems appear from the otherwise uncoordinated action of these agents.

The implications for the Hohokam case are simple: is a central authority necessary to direct and manage the canal system, or can independent actors, pursuing self-interested goals, engage in cooperative arrangements that allow a large-scale canal system to be built and operated? The implications for the nature of the Hohokam polity, and for venerable theories on the rise of states in irrigation-oriented societies are apparent.

Because of the collaborative approach emphasized in our project, the vocabulary in which the simulation is expressed is also available for the agents in the model. Hence, a programmatic agent is able to perceive the same information that a user can extract from the model, and a user may instruct an agent to follow strategies that are expressed in the same vocabulary he himself uses when controlling the simulation.

C Database

All Simulation information is stored on a central server. The structure of the database organizes input in accord with the conceptual structure of the simulation elements; output is recorded for all runs in a way that keeps input and output securely linked.

D Online

The simulation is distributed online in a web site. Input data and output data are both available, in full, through this site. The web site serves as both documentation and interface to the simulation, and provides a number of functions for managing and running simulation data and experiments. Because it is online, all team members have full access to these data.

E Plant Dataset

The HWM Database contains a collection of information on plants that can be used in the simulation. Plant information includes growth stages and resistance to drought, as well as potential yield. Plant data may be based on empirical data or be entirely hypothetical. Plants can have multiple varieties that differ in their characteristics but be used interchangeably as appropriate in the simulation.

F Narratives and Histories

'Histories' are sequences of instructions that occur at specific times during the simulation. Histories are composed of 'Narratives', which are interchangeable sequences that can be moved within Histories. For example, a 20-year drought 'Narrative' can be created, and placed at 600 AD, or 700 AD, or 1100 AD. This provides a way to examine a range of 'what if' questions about alternative trajectories for the Hohokam system.

G References

Users can enter references that serve as a bibliography for the project. Input data can be linked to references, allowing for the construction of a complete chain from empirical data to simulation output.

H Comments

Users can affix comments to any simulation element. Hence configurations of input data can become topics of discussion. The comments added become part of the record for any simulation that uses the commented element. A single comment can be applied to multiple elements, linking them (i.e. for comparison).

I Interactive

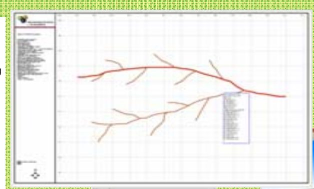
The simulation can be run interactively over the web. The user can view the simulation state and modify parameters while in progress. A transcript is recorded and is available to all team members. Simple interface controls provide access to all simulation commands.

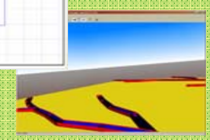
J Maps in 2D and 3D

Maps provide a graphic and intuitive way for users to see the state of the simulation. 2-D maps that include gridlines, contour lines, and topography are provided. Pop-up menus reveal the status of canals (including water flow and relevant hydraulic measures) and fields (including crop maturity and productive potential). 3-D maps provide an immersive landscape, but also include the same information as 2-D maps.

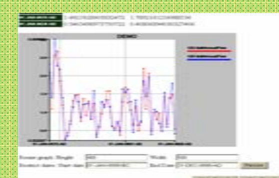
Maps proved crucial in demonstrating the simulation to users and others; tables of numbers failed to convey the simulation's content with the same immediacy. 3-D maps provide a way to consider the multiple viewpoints agents have on the landscape.

2-D maps use SVG, and 3-D use X3D; both are xml based, declarative representations of the simulation's content





K Analyses and Summaries



Built-in and on-line tools allow users to pull data from multiple runs into Analyses; Analyses can be grouped together to form Summaries. Summaries make complete arguments, and include the complete audit trail from input data to output, as well as references and comments.

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