Agent-Based Holistic Simulations of Bronze Age Mesopotamian Settlement Systems

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ABSTRACT

Archaeologists have begun to explore issues in past social behavior by incorporating new computer simulation techniques in their research. Among the popular approaches, agent-based methodologies are commonly used to answer questions involving the interactions of natural and social systems. Building upon such efforts, a new simulation engine is being developed for ancient Mesopotamia that can create highly complex simulation scenarios. This engine can investigate socioecological interactions by integrating multiple agent types and their associated behavioral models. Such an integration not only helps to address how socioecological systems, such as settlements, adjusted to their evolving social and natural environments, but numerous questions at varying social, spatial, and temporal scales can be addressed by the simulation platform.

RESUMO

Os arqueólogos têm vindo a começar a explorar questões sobre o comportamento social passado através incorporação de novas técnicas de simulação por computador. Entre as aproximações mais populares, as metodologias baseadas em agentes são geralmente utilizadas para responderem a questões que envolvem a interacção de sistemas naturais e sociais. Construindo sobre estes esforços, está a ser desenvolvido para a antiga Mesopotâmia, um novo motor de simulação que pode criar cenários de simulação altamente complexos. Este motor pode investigar interacções sócio-ecológicas através da integração de múltiplos tipos de agentes e dos seus modelos comportamentais associados. Essa integração não só ajuda a analisar como sistemas sócio-ecológicos, tais como assentamentos, se ajustaram ao seu entorno social e ambientes naturais, bem como inúmeras questões a várias escalas sociais, espaciais e temporais podem ser analisadas através desta plataforma de simulação.

1. INTRODUCTION

Increasingly, scholars have begun to see the need for modeling systems that can address the interaction of natural and social processes that shape any given ancient society. This need requires that modeling systems incorporate and simultaneously implement numerous types of natural and social models of behavior that function at variable temporal, spatial, and social scales. In addition, modeling systems needed to be adaptable to virtually any theoretical perspective in order to adequately address disparate views that scholar may have. Addressing this need, the Universities of Chicago and Edinburgh as well as Argonne National Laboratory have begun the creation of a simulation chassis, called ENKIMDU, which addresses socioecological systems in past societies (see project website at http://oi.uchicago.edu/OI/PROJ/MASS/introduction.htm for further detail).

2. DOMAIN OF STUDY

Currently, ENKIMDU is being created to address socioecological dynamics in past Bronze Age (3000-1200 BC) settlement systems in Mesopotamia, a region located in modern day Iraq and Syria. Among other questions, our research team hopes to address the resiliency of past settlement systems as they faced different levels of social and environmental stress.

3. SIMULATION TOOLS

The approach we have taken in addressing socioecological systems is agent-based and holistic (Wilkinson *et al.*, forthcoming). To create numerous types of interacting agents, or what are also called entities, we are using a generic object-oriented simulation framework called DIAS (Fig. 1). DIAS is an extensible framework that allows for an abstract description of the entity's behavior (i.e. behavioral models), with specific parameter states (e.g. weight, social status, soil qualities) evolved through separate portions of the framework that implement behavioral models (Sydelko *et al.*, 2001). In the DIAS paradigm, models of social or natural behavior do not interact directly with other behavioral models, rather behavioral interactions occur through the agent objects. Such a structure enables the ENKIMDU engine to have variable scalability and flexibility, since entity behavioral models can be added, adapted, or extracted without extensive recoding to the overall system.

In order to implement interactions between different types of agents, Argonne has coupled within DIAS a chassis called FACET, which allows for flexible and expressive agent-based behavioral models. In addition, the ability to address spatial aspects of a given simulation domain can be addressed by a tool called GeoViewer, which provides typical GIS functionality (Lurie *et al.*, 2001). GeoViewer is an object-oriented geospatial toolkit that can be interlinked to virtually any agent and its associated data and behavior. This essentially means that GeoViewer can be integrated with spatial models and applications for dynamic display of entities and their states.
In any simulation system it is also essential to incorporate external models, or models created by outside efforts, as increasing complexity of any given system is not always adequately or easily addressed by one project team. For instance, in our effort we have incorporated SWAT, which is a landscape modeling suite (Arnold *et al.*, 1998). This suite includes algorithms that calculate different plant phenologies, evapotranspiration, soil evolution, hydrological flow, and other landscape behaviors. SWAT also includes a Markov process weather generator that can be used to produce daily weather data for a given simulation scenario.

4. AGROPASTORAL MODELS

Bronze Age Mesopotamian settlements, like many other early societies, heavily depended on agropastoral activities for their economic sustainability. These activities, as well as their variations, can be modeled using the DIAS system. The Field Crop Management Model (Fig. 2) is one such model that highlights the different anthropogenic steps that are implemented during the agricultural year. During each agricultural step, a specific field needs to be maintained by the human agents in order to produce a crop. The different human agents involved (labeled as work crews) incorporate resources such as plows, seed, and labor in their behaviors. These actions alter the field agents' states such as their biomass. Furthermore, at each step, environmental actions produced by SWAT also transform the field agents. As the landscape is evolved through human and natural behaviors, the field provides data feedback to the human agents, which enables the human agents to decide how and when to implement subsequent steps in the model (Wilkinson *et al.*, forthcoming).
Concurrently in ENKIMDU, human agents can maintain livestock groups of sheep and goats. One model that enables livestock to forage is shown to indicate the different step-by-step actions that are in this FACET model (Fig 3). Unlike the agricultural model, this model begins anew each day, while the agricultural model addresses the entire agricultural season. Like agricultural practice, however, decisions are dynamic and continuously evolving as circumstances change; in this case specific event times can be measured in minutes and hours. In general, herding groups prefer to graze in fields that have high biomass and are located nearest to the site. However, as field states continuously change, for instance biomass is removed and animal manure is incorporated into the fields, livestock groups frequently change grazing areas.
Both the agricultural and livestock grazing models acting together can be viewed using GeoViewer (Fig 4). This example is from one particular hour during the early fall in a settlement and its associated fields in northern Mesopotamia. Notice in the example that the livestock herds are grazing near the settlement, indicating that the surrounding fields have not been depleted. Meanwhile, the work crew agents are performing the early stages of the agricultural cycle, mainly clearing and plowing. All of the agents are impacting the evolution of the fields, while the feedback produced by the evolving fields influences the decisions made by the agents in future steps.

5. UTILITY FUNCTION IN EXCHANGE SYSTEMS

Agriculture and pastoralism were not the only major economic activities in Mesopotamia. Reciprocal exchange of various commodities certainly played a major role. In ENKIMDU, we have created an agent utility function that enables agents to decide which exchanges are useful given specific needs, goals, and market conditions (Fig. 5) (Hogg and Jennings, 2000). This utility function, like the other behaviors in ENKIMDU, can be utilized simultaneously with other models included in a simulation scenario.
Exchange events can be launched by both food stress and economic opportunities perceived by agents. The utility function algorithm is highly flexible to the specific context of the agent, thus factors such as religion or other social circumstances can affect agent choices. Essentially, agents evaluate different exchange items and quantities by using their context maps, which provide relevant information such as market conditions, needs, goals, and possibly other factors that affect how the agents value items. Each agent will attempt to obtain the commodity of greatest benefit for their utility function; however, each item and its quantity requested are evaluated by other agents who must consider exchanges based on their own utility function. If the item of greatest benefit cannot be obtained from other agents, then other items that provide significant benefit are sought after. When an exchange is finally made, all involved agents can determine the next appropriate time to look for further exchanges. Thus, similar to the agricultural and pastoral models, exchange models are driven by discrete events based on agent choice, enabling the agents to control when specific behaviors are implemented.
In Figure 6, the utility function is utilized in a multiple family household's reciprocal exchanges. The top half of Figure 6 shows the household's kin relationships, trading partners, and resources in the form of livestock, grain reserves, and field shares. In the bottom half of Figure 6, reciprocal exchanges can be seen. Such exchanges include grain, livestock, wool, and silver commodities. In day 22, for example, there is an exchange of a sheep for grain, while in day 151 the household

provides grain for wool. Other notable occurrences include natural events such as birth and death based on demographic probability tables.

6. CONCLUSION AND FUTURE DIRECTION

Although our simulation effort is still far from producing all or even many of the relevant mechanisms affecting socioecological dynamics in ancient Mesopotamia, this brief overview of the ENKIMDU engine and its enabling technologies makes it clear that archaeologists have the ability to create complex agent-based simulations that can test varied socioecological interactions. The descriptions and examples presented highlight ENKIMDU's flexibility, scalability, and ability to produce expressive and socially plausible modeling results by incorporating numerous types of agents and their associated models of behavior. Questions addressed by the platform can be general and relate to the overall system (e.g. how a settlement adapts to a given environment) or a specific dynamic (e.g. a certain market behavior or household's evolution). As ENKIMDU covers even broader territories encompassing numerous settled and migrant populations, the ability of the system to concurrently address questions that cover various spatial, social, and temporal scales will continue to make the platform relevant for testing various archaeological theories at these scales.

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FIGURES

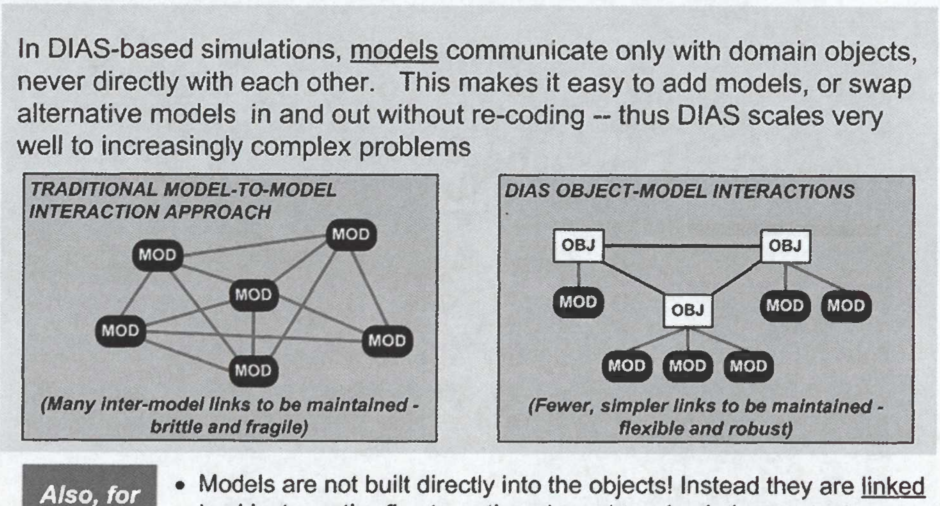

Fig. 1 – This figure shows how agent objects (shown as OBJ above) interlink with behavior models (shown as MOD).

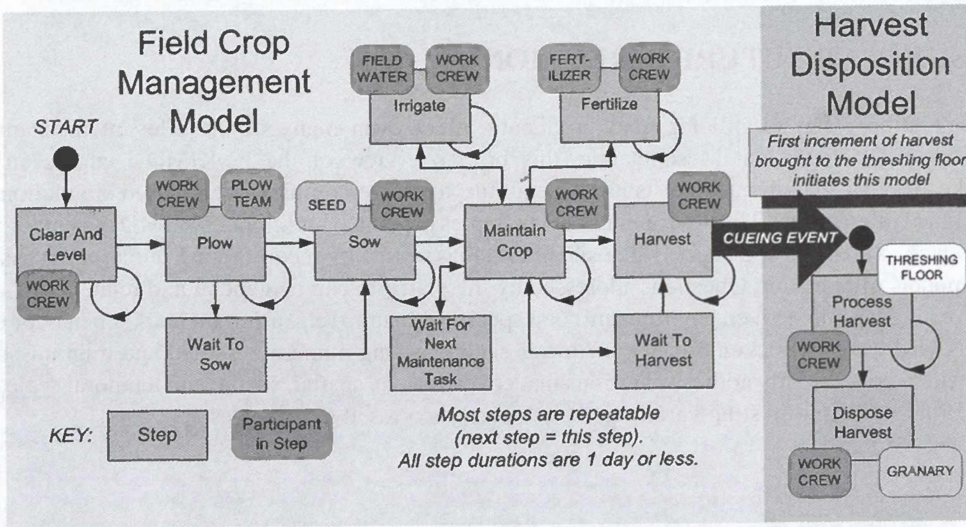

Fig. 2 – Although most of the steps are deterministic in this model, mutability is allowed by the feedback received and alternative behaviors implemented.

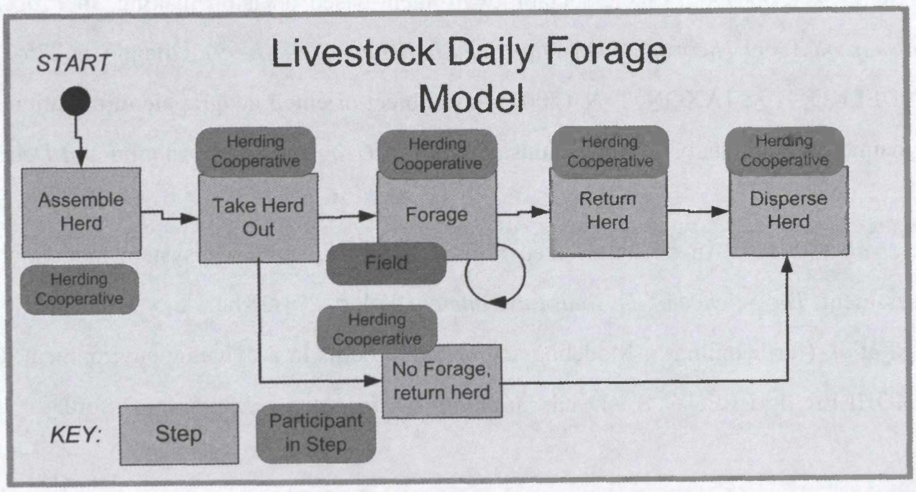

Fig. 3

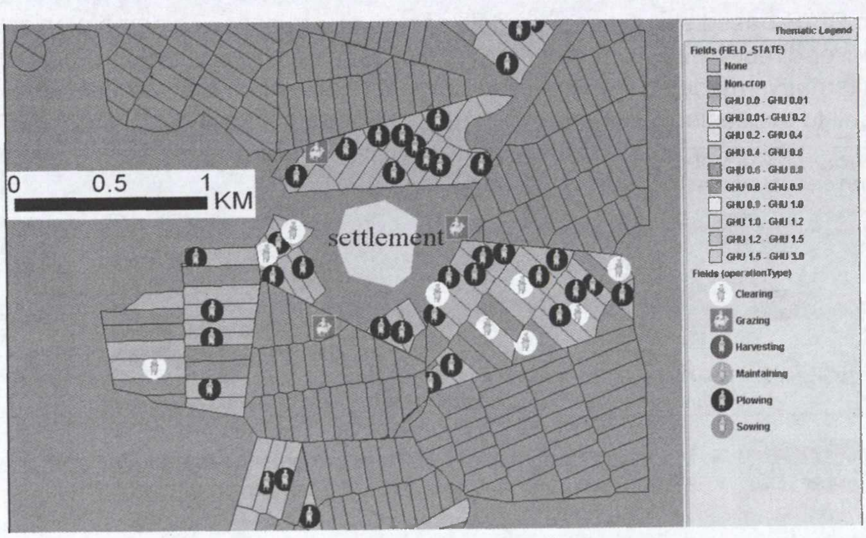

Fig. 4 – Image showing different work crews (shown as person symbols) and livestock groups (shown by the grazing symbol). The GHU key on the right indicates the plant maturity levels in the fields.

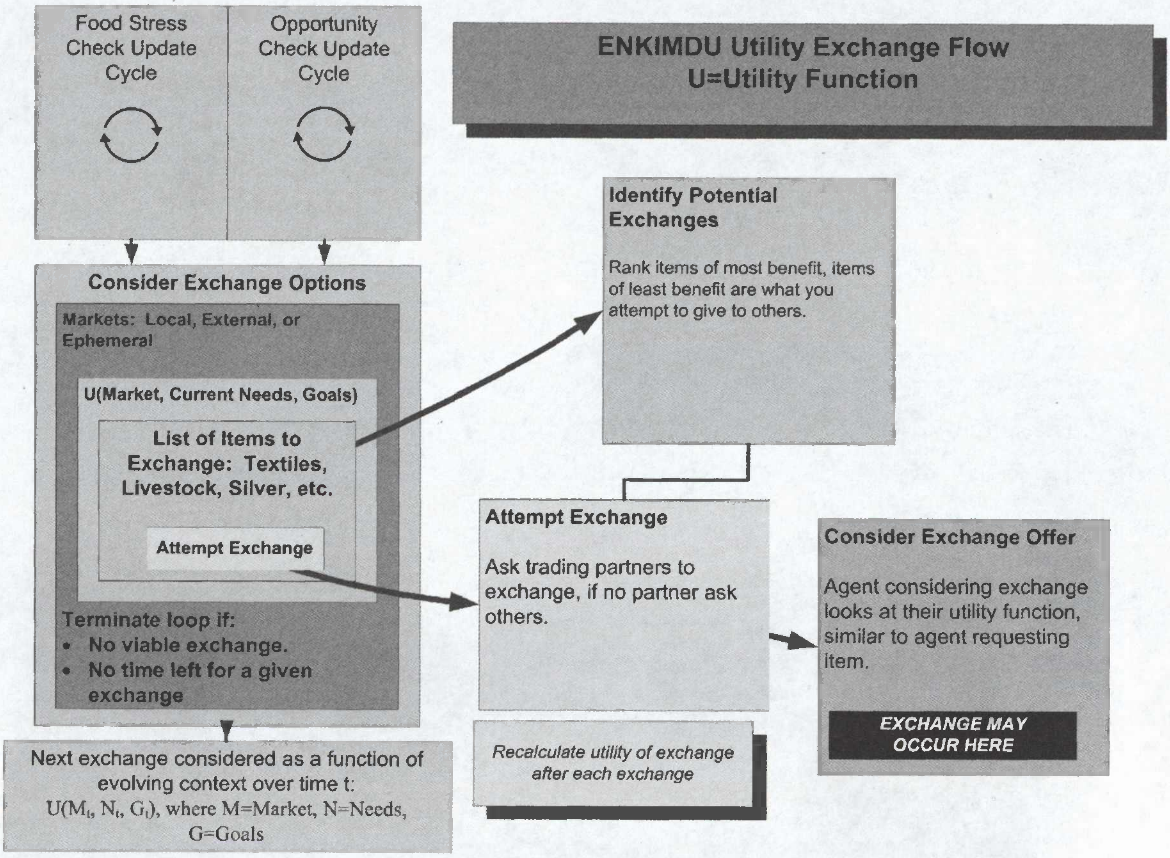

Fig. 5 – Figure showing the flow of the utility function, from an agent requesting an exchange to another agent accepting an exchange.

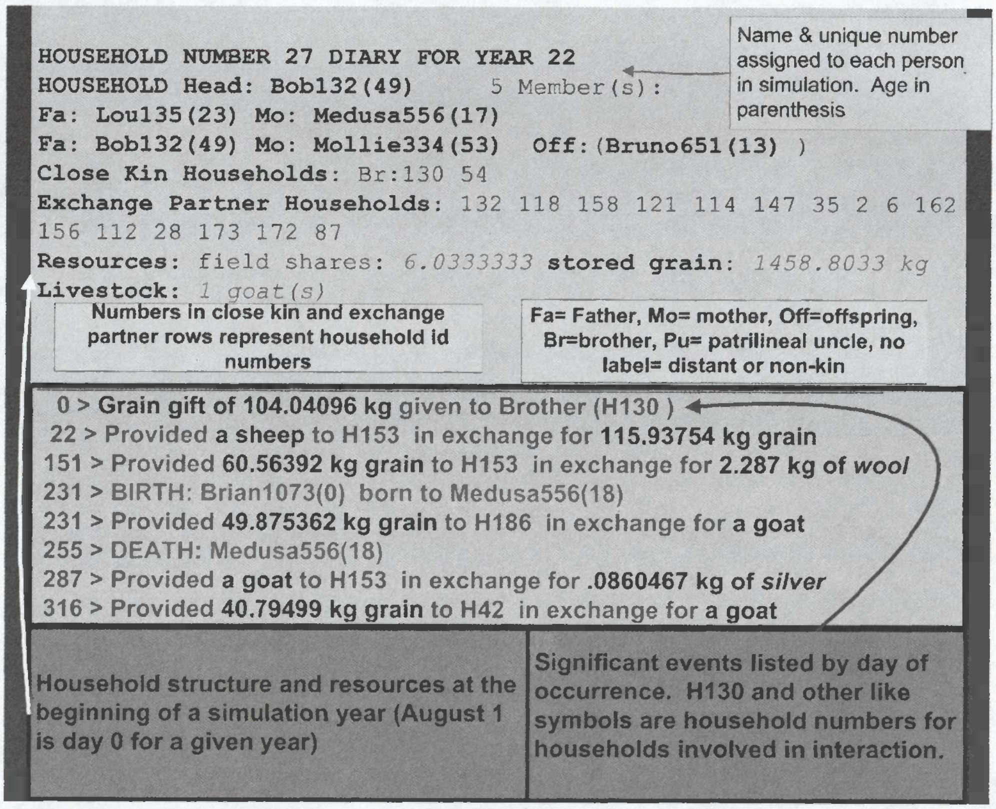

Fig. 6