The Computational Research on the Ancient near East (CRANE) Project: An Archaeological Data Integration, Simulation and Data Mining

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Abstract: Archaeology has emerged as one of the most dynamic and innovative disciplines in the humanities and social sciences, employing a truly interdisciplinary, collaborative approach and a continually expanding array of analytical research tools. Computer aided analysis of archaeological data is remarkably challenging given the heterogeneous nature of the material. Archaeologists generally aim to discover patterns, spatial relationships and other associations between different traits of the archaeological record. However, given the idiosyncratic and highly personal nature in which archaeological data is collected and analyzed, identifying these patterns and relationships offers many challenges. The Computational Research on the Ancient Near East (CRANE) initiative seeks to build an international multidisciplinary research collaboration, comprised of archaeologists, computer scientists, and paleo-environmental specialists, with the capacity to leverage a burgeoning corpus of data from a number of archaeological sites and fundamentally transform our knowledge of the civilizations of the ancient Middle East. The CRANE initiative is developing a sustainable, scalable, user-driven vehicle for large-scale data management and cross-project data integration, to harness the full evidentiary range produced by this uniquely rich cultural legacy. At the same time we are developing tools for data mining techniques, and to analyze simulate ancient societies using agent-based models of behavior.

1 INTRODUCTION

Over a century and a half of archaeological research in the Near East has documented the emergence of the first sedentary communities, the origins of agriculture, the development of the first state-level societies, and the first interregional commercial and political networks (Redman, 1978; Wilkinson, 1994; Akkermans and Schwartz, 2003; Yoffee, 2005; Edens and Kohl, 1993; Marfoe, 1987; Stein and Blackman, 1993; Wattenmaker, 1994; Wattenmaker, 1998a; Wattenmaker, 1998b; Mazzoni, 2003). Yet its contribution to a deeper understanding of the long-term growth and development of human communities and their interaction with the natural environment has been hindered by a less-than-ideal publication record and the lack of any real analytical framework that incorporates the full array of data produced by this uniquely rich cultural legacy. Furthermore, the present wars in Syria and Iraq have left the completion of many projects impossible for the foreseeable future, further hindering final publications, leaving data sets in limbo.

Advances in the collection and analysis of archaeological data mean that, in many respects, we have never been in a better position to pull together the often heterogeneous and idiosyncratic published and unpublished datasets, and understand the nature and scope of these social, political, economic, and ideological transformations in the ancient world (Kansa, 2005; Kansa, 2010; Kansa et al., 2005; Kansa et al., 2007; Petrovic et al., 2011). Yet such efforts are often hampered by the challenges of integrating the datasets (which are often at varied

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spatial and temporal scales) which would be capable of resolving short term actions or long term processes spanning the millennia of data we have in the Ancient Near East.

Large-scale data analysis has become increasingly common in humanities scholarship, with researchers increasingly disappointed by the impoverished results they receive when querying multiple datasets that have only superficially shared data structures, an all too familiar problem when using internet search engines such as Google. The poor quality of large-scale query results, typically of textual data, reflects the difficulties inherent in machine processing of natural language and other kinds of 'artificial intelligence' (Abiteboul et al., 2000; Ling and Dobbie, 2004; Dreyfus, 1992). The Computational Research on the Ancient Near East (or CRANE) Project, directed by Tim Harrison of the University of Toronto and funded primarily by the Social Sciences and Humanities Research Council of Canada, is an international collaboration that takes up these challenges through the integration and analysis of data from a number of archaeological projects working within the Orontes Watershed of modern Southeastern Turkey and Northwestern Syria.

The underlying rationale for the CRANE Project is to build an international collaboration of researchers who will leverage these data to model and visualize the interplay of social, economic and environmental dynamics at various spatial and temporal scales in order to shed light on the rise and development of complex societies in this important region. This research will also provide insight into a number of pressing contemporary issues, including the ecological impact of human activities, the socioeconomic and political impact of climate change, the long-term health consequences of human dietary practices and subsistence strategies, and the role of cultural conflict in affecting social and political change.

The work of the CRANE Project is guided by a number of specific research objectives, including the integration of digital data from multiple archaeological research projects - both legacy and active - that use different terminologies stemming from different research traditions and methodologies; the development of a core cultural, paleo environmental and chronological sequence for the Orontes Watershed; the creation of protocols and analytical tools to facilitate broad access to this information; the modeling of emergent and inverse simulations of ancient social practices and related human-environment dynamics based on parameters supplied by empirical data; the creation of spatially accurate and realistic 3D visualizations of reconstructed ancient landscapes and human activity based on empirical data and the output of simulated scenarios; the creation of research opportunities and training in advanced archaeological analysis for university students at all levels and junior scholars.

2 THE ORONTES WATERSHED

In its current stage, the CRANE Project is addressing these objectives through a focus on the Orontes Watershed in southeast Turkey and northwest Syria. The Orontes valley represents the northern most extension of the Greta Rift Valley, and is dominated by the Orontes river, which finds its headwaters in the Lebanese mountains, flowing north reaching the Mediterranean Sea in the Hatay region of south Eastern Turkey, which is in turn fed by a hydrological system fed from as far north as the Maraş plain, encompassing a drainage basin of around 24,000 km^2 (Fig. 1).

Figure 1: The Orontes Watershed.

Over a century and a half of archaeological survey and excavation throughout this region has brought to light one of the most important cultural sequences in the ancient Near East. As a cohesive geographical unit and a cultural microcosm of the broader Near East, it represents an exceptional initial test case. Our present efforts are concentrating on the integration of data from five important sites in this region, Tell Acharneh, Tell Nebi Mend, Qatna, Tell Tayinat and Zinçirli Höyük, as well as a number of archaeological surveys, and is presently set to expanding to include other sites in the greater region. These projects represent a diverse set of not only of archaeological data, but excavation and recording methodologies, different taxonomies for the collected data, in which the level of detail and quality of the data varies greatly within the individual projects, let alone between the projects.

2.1 OCHRE Data Integration

Data integration is an essential component of CRANE and presents a significant challenge in trying to incorporate the heterogeneous datasets from various projects into a single query able environment without imposing a uniform taxonomy. Archaeological data can be quite diverse and significantly variable; including architectural, artefactual, or ceramic data, which can be represented by drawings, photos, vector, or textual data of measurements and/ or descriptions. Furthermore this data is highly interpretive, which can change over an excavation season, with post-excavations analysis, or with changes in theoretical approaches, all of which must be coherently documented. Making meaningful links between these disparate datasets is an immense challenge, and one that can only be undertaken with The Present Advances in Computing. the Collection of This Data in a Centralized Networked Legacy Protected Location Allows for the Preservation of the Record of Archaeological Excavations in an Electronic Format for Present and Future Scholars or Even Eventually the Public to Utilize.

to Meet This Challenge, Our Current Data Integration Efforts Focus on the Use and Enhancement of the Online Cultural and Historical Research Environment, or OCHRE, a Powerful, Multi-User, XML Database System Developed by David and Sandra Schloen of the University of Chicago (Schloen 2001). in the Figure 2 the OCHRE System Architecture Is Presented. OCHRE's Item-based Approach Is Highly Flexible, and as Relatively Few Concepts and Relationships Are Predefined, It Enables It to Operate at a Much Higher Level of Abstraction than Formal Ontologies Employed by Other Such Data Frameworks. Its Generic Ontology Is Also Inherently Extendible, Allowing CRANE Researchers to Construct Their Own Lists and Hierarchies of Data Items, and Their Own Taxonomies to Describe Those Items, but More Important for Us Allows Us to Create Thesauri to Link Equivalent Categories across Participating Projects. OCHRE Displays and Manages Data Items Spatially through the Use of an Embedded Java SDK by ESRI Which Allows for the Full Visualization of All Data Housed within the Database. CRANE Is Collecting and Integrating Data from the Orontes Region at an Unprecedented Level and Developing New Tools to Leverage These Data. Modern Data Mining, Modeling/Simulation and Visualization Techniques Are Being Used to Transform the Data into Information That Helps Researchers Better Understand What Happening in the Region in the past and Present It in More Meaningful Ways to the General Public.

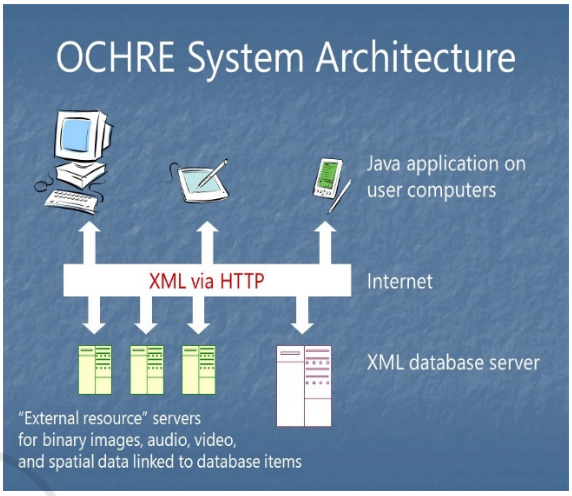

Figure 2: The OCHRE System Architecture.

2.2 Crane Subprojects

The over-arching nature of CRANE results in a number of inter-related sub projects. What follows is a brief description of a few of the relevant subprojects that focus on Geographical Information Systems. For a full description of the various CRANE subprojects and how they are integrated, see (CRANE 2016). One of the primary projects initiated was a comprehensive inventory of all sites identified in the Orontes Watershed to serve as a backbone to the project, a scaffold upon which many of the sub-projects hang. We presently have identified over 4100 sites in the greater Orontes region, delineated by their geographic location, chronological periods, linked to an exhaustive bibliography. OCHRE's API Integration with the French PaleoSyr Project (ANR-PALEOSYR 2014), has given us access to an incredible array of additional data for the various sites, including descriptive, chronological and other archaeological metadata. These data have been shared with ASOR's Cultural Heritage Initiative (ASOR 2014) – to aide in the construction of a more comprehensive database of sites in Syria and Iraq to help with management of the destruction of Cultural heritage monuments from the civil wars in the region. Integrating remotely sensed imagery, historical maps of the regions, along with thematic maps (including soil, geology, hydrology, elevation and slope etc) were all integrated into OCHRE, and utilizing the GIS capabilities of OCHRE (Fig. 3).

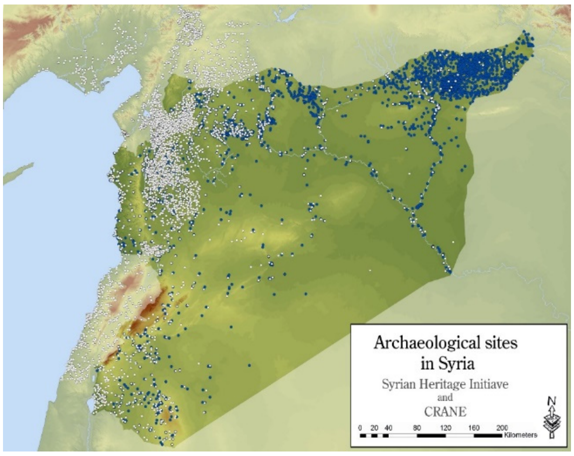

Figure 3: A map with GIS.

2.3 Simulation Modeling

One important objective of the CRANE project was to ultimately be able to utilize the various assembled georeferenced archaeological and environmental datasets from within the Orontes watershed to examine human-environment interaction through the modeling of both natural systems and social processes, as well as investigate the interplay and interaction between these two sets of variables in contributing to emergent social complexity.

As a result, a secondary sub-project developed as part of CRANE was to implement a program of agent-based simulation modelling built on an earlier research initiative entitled "Modeling Ancient Settlement Systems" (Wilkinson et al., 2007), which used holistic agent-based simulation techniques to explore socio-ecological questions in ancient Mesopotamia. Agent-based modelling is used to simulate the emergence and functioning of complex systems through the actions and interactions of autonomous agents, who are programmed to behave according to certain defined rules. These agents can either be individuals, or can represent collective entities such as organizations or groups. While it has been more consistently used in other fields such as computational sociology and ecology, it has not been frequently applied to archaeological questions. The ways in which the results of agent-based modelling in archaeology have been interpreted in the past have been problematic, sometimes leading its value to the discipline to be misconstrued. The outcomes and goals of simulation modeling have often been conceptualized in terms of the idea that the ultimate goal of an agent-based model is simply to run it and have it approximate reality as closely as possible, and therefore that its ability to do so represents its ultimate value to archaeology. When the endeavour is viewed this way, the criticisms are obvious; it is impossible to account for every single possible factor that could affect the outcomes of processes in complex systems like ancient societies, and the idea that we can adequately account for random variation is also problematic.

The outputs of computer-based simulations can be compared to the archaeological record, but this is generally best done as a means of testing specific hypotheses about explanations for the appearance or behaviour of certain phenomena and the investigation of new research avenues (for a recent attempt in biomedicine, see Kammash, 2008). ENKIMDU is a modeling framework with the capability to create a virtual world in which to run simulations based on various environmental and social parameters (Christiansen, 2005; Christiansen and Altaweel 2006a; Christiansen and Altaweel, 2006b). ENKIMDU's approach is holistic and agent-based, and represents a "bottom up" method of modeling. This means that its simulated historical trajectories appear as the cumulative outcomes of a host of small-scale activities and interactions, for instance as a result of actions by individual persons, households, crop fields, and domesticated animals. ENKIMDU was developed with the intention of testing the idea that the appearance of urban centres in Mesopotamia was an emergent phenomenon that was ultimately regulated by positive feedback loops that encouraged population agglomeration and settlement growth, and negative feedback loops that constrained growth and kept it within certain limits.

For much of its environmental modelling, ENKIMDU relies on communicating with third-party software called SWAT, the Soil and Water Assessment Tool, developed jointly by the USDA Agricultural Research Service and Texas A&M University (Neitsch et al., 2002; Arnold and Fohrer, 2005). This software was developed to model a variety of natural processes, such as basic weather patterns, hydrology (including surface runoff and water table dynamics), soil evolution and erosion, plant nutrient cycling, and vegetation growth (including both the natural environment and human-managed crop growth). SWAT's internal weather generation abilities are augmented by using ClimGen, a Markov-chain weather generator (Stöckle et al., 1999). This SWAT-based environmental model is then positioned in a larger social model, whose original focus was on subsistence economy, agricultural processes and sustainability in relation to

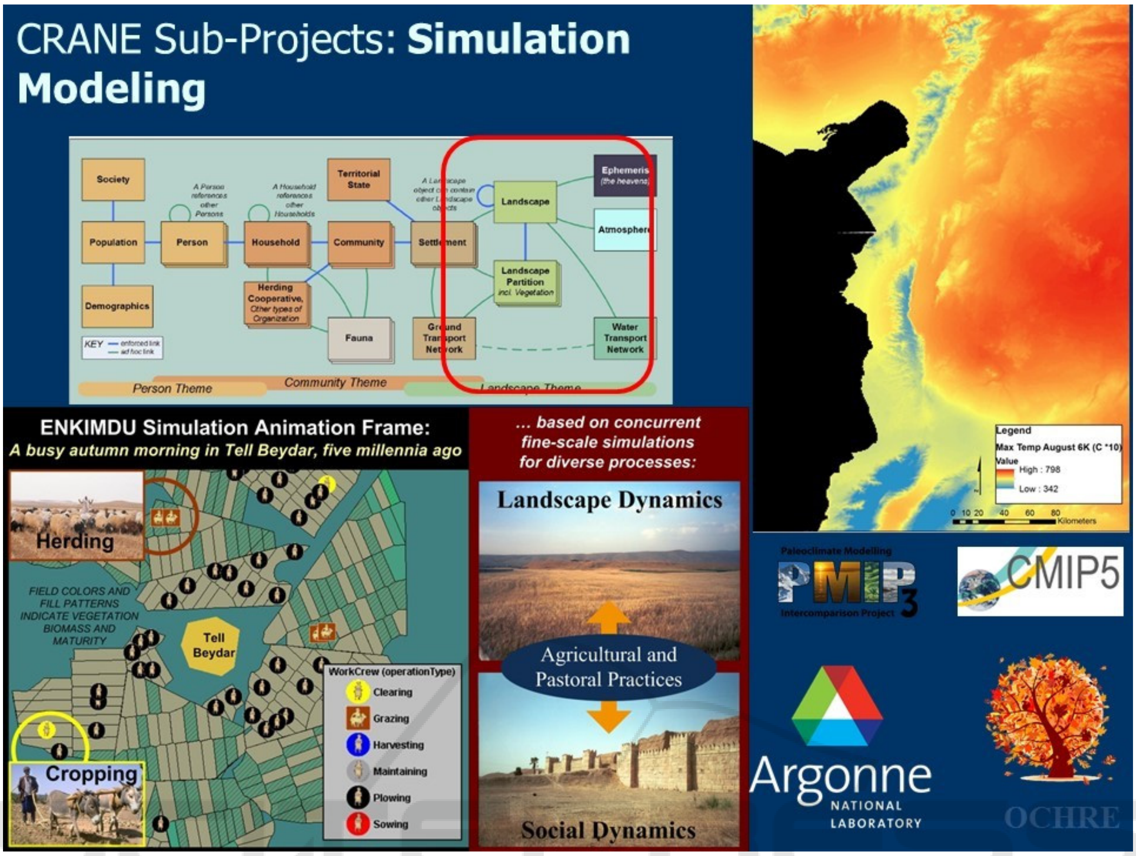

Figure 4: The simulation modelling.

environmental conditions and the demographic structure of the population. The model focused on the performance of detailed aspects of the agricultural cycle, including planting, irrigation, harvesting, crop processing, storage and consumption (Fig. 4). Although the ENKIMDU model creates individual people as agents, the primary decision-making social agent for agricultural processes is the Household. Households can allocate labor and other resources, and plan both short-term and long-term agricultural operations. Households can also identify situations of short-term, medium-term and long-term food stress, and deploy a variety of different coping strategies for dealing with each of these situations**.**

Another important area of CRANE's interest has been in the implementation of paleoclimate modelling using General Circulation Models, in particular, the models of the Coupled Model Intercomparison Project (Taylor et al., 2011) and the Paleoclimate Modelling Intercomparison Project (Argus and Peltier, 2010; Tarasov et al., 2012; Lambeck et al., 2010).

These projects model various climate-related variables both forward and backward in time, including temperature and precipitation, but also a host of other factors relating to issues like ocean currents and temperatures, wind patterns, snow coverage, and vegetation patterns. CMIP5's standard modelling time frames include 6kya (the mid-Holocene, ca. 4000 BC), while PMIP runs experiments for additional time frames including the Early Holocene and the 8.2 kya climatic event (ca. 6200 BC).

2.3 Data Mining

Archaeologists are frequently pursuing new techniques and tools to analyze their data. In an effort to identify relationships for interpretation, they have utilized a number of different approaches. Data analysis and information retrieval is explicitly described in Richards and Ryan, 1985. Statistics is not a new topic for archaeology and is extensively analyzed by Kimball 1997. The differences between qualitative and quantitative analysis is also covered using examples in Drennan, 2008. In another approach it is explained how statistical techniques can clarify ambiguous patterns in an historical application (Kelly-Buccellati and Elster, 1973). It is demonstrated that the application of statistical thinking and techniques can aid the archaeologist in retrieving as much information as possible from artifacts (Bentley and Schneider, 2000).

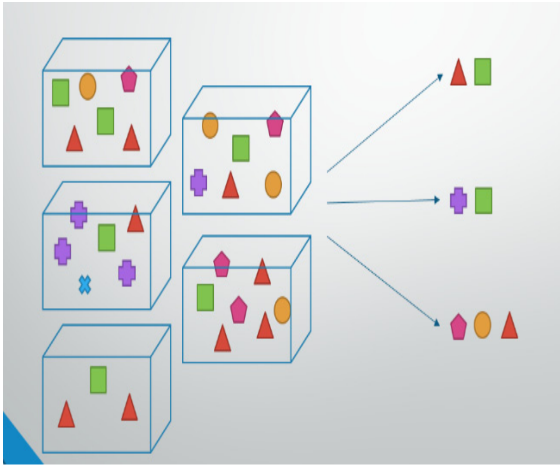

Figure 5: A diagram with association rules.

Data mining is a scientific topic of information technology widely used in many applications. Handling different data types data mining techniques result in automatic knowledge discovery and decision support (Han et al. 2011), (Olson and Delen 2008). The association rules establish relationships between variables in a given data set. Mining association rules were first introduced in Agrawal et al. 1993. Since then they received much attention in academic and industrial applications (Jiao, et al. 2006).

There is an approach deals with data mining techniques on heterogeneous archaeological databases on smaller scales to that of CRANE (Zweig, 2006). Data mining techniques have been also used for historical manuscripts and cultural artifacts (Zhu, 2011). It has been proposed the application of Association Mining algorithms (in particular an updated form of the Apriori algorithm as initially conceived by Agrawal et., 1993), in order to reveal heretofore unrecognized associations between artifacts in archaeological contexts, as itemized in archaeological data warehouse environments, such as OCHRE. The Apriori algorithm is utilized to detect those items (i.e. artifacts) which are frequently associated with one another in context, the relationships between which are indicative of past commonly attested practices within the community under analysis. The output results in a series of association "rules" (lists of the frequency with which items are found together in context), which may be graphed to provide a visual representation of the past organization/structure of a community (Fig. 5). The methodology has been applied to a small Iron Age settlement (ca. 9th century BCE) in northwest Syria, in order to produce a more nuanced characterization of the community, based upon commonly attested practices amongst households at the site.

The archaeological data are described by attributes with their values. A value can be numerical and non-numerical. An attribute is an individual characteristic of an artifact which represents the archaeological finding. In our sample the artifact is an item and can be further subdivided by its attributes. The attributes have non-numerical values describing different traits such as color, texture, form, shape. As an example the attribute form can have as values "Bowl", "Cooking Pot" or "Store Jar". Relationships between variables can be found using logical operations as an expression. The items are discovered in different location of the excavation and the whole excavation area is split into 11 rooms. There is also an attribution based on a spatial relationship representing the location of the items. The location of the item is defined by the value "Room" with its number, e.g. "Room 5". The spatial relationship "included_by" can also be used to identify the location.

3 CONCLUSIONS

The rapid proliferation of digitally generated archaeological data (both new and digitized legacy data) represents a profound opportunity for our discipline to contribute meaningfully to issues of pressing contemporary concern, while providing deeper insight and understanding about the world in which we live. However this can only be achieved through the development and utilization of robust computational tools. Near Eastern Archaeology represents an ideal test case for developing a computational framework capable of integrating the complex, heterogeneous, or "messy", datasets that typify our world, and defy the homogenizing algorithms of machine-driving learning. Thus, the most successful collaborative data-sharing ventures in this effort are likely to be those that accommodate multiple, diverse taxonomic structures and hierarchies of knowledge and meaning. To ensure the full exploitation of these datasets by both archaeologist as well as public stakeholders (such as Cultural Heritage Management Groups), more powerful tools that maximize the potential of the computational tools available to us today.

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