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PREFACE & ACKNOWLEDGEMENTS

The research discussed in this volume is intended to demonstrate how models can contribute to an understanding of the development of the ancient Mesopotamian social landscape and human-environment interactions. Although initially intended as a very specific investigation of how small-scale processes contribute to the growth of ancient cities using agent-based models, this volume represents a much more broad-brush approach. It now includes a range of 'bottom-up' as well as 'top-down' approaches as well as qualitative models developed from the more empirical work of the Oriental Institute's CAMEL Lab during the late 1990s and early 2000s. There is therefore no single 'house-style', nor do the investigations follow any particular theoretical path. The main intention, in addition to simply presenting the results the modeling, is to demonstrate how multi-disciplinary teams can come together to produce fruitful research which (we hope) is more illuminating than simply engaging in our own disciplines.

The results presented are based on research conducted by a joint team largely based at the University of Chicago's (Oriental Institute), Argonne National Laboratory (Illinois), and, more recently, at the Universities of Edinburgh and Durham, in the United Kingdom. Subsequently the team members, all of whom started at either the Oriental Institute or Argonne National Laboratory, have become ever more far-flung (see list of contributors).
We are particularly grateful to the *National Science Foundation* which supplied funding in the form of a five-year award (2002-2006) from the *Dynamics of Coupled Natural and Human Systems* program (Biocomplexity in the Environment), NSF Grant # 0216548; $1,200,000) to support a research project entitled 'Settlement Systems within a Dynamic Environment and Economy: Contrasting Northern and Southern Mesopotamian City Regions.' The original MASS Group investigators were T.J. Wilkinson (PI), McGuire Gibson (coPI) and John Christiansen (coPI)]. This collaboration in computational archaeology began in 1998 through an interdisciplinary pilot project funded by the University of Chicago– Argonne National Laboratory Collaborative Grants Program (1998-1999), as well as by the University of Chicago, Advanced Technology Initiative (2000). Earlier versions of the research for Chapter 13 were supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (Project No.23310190, 'Ecohistory of Salinisation and Aridification in Iraq' to Chikako E. Watanabe and Mark Altaweel. We also thank the Institute of Advanced Study at Durham University, for sponsoring a *Workshop on Modelling Behaviour* (November, 2007) which led to a number of insights discussed in this book. Inevitably, much of the discussions and questions raised here reflect the major contribution of Robert McCormick Adams to the understanding Mesopotamian civilization.

We are particularly grateful to our colleagues on the MASS team. In addition to the authors of this volume, MASS team members included: Nick Kouchoukos (University of Chicago, Department of Anthropology) and Christopher Woods (The Oriental Institute and NELC, University of Chicago); Jayne Dolph and Kathy-Lee Simunich (Argonne National Laboratory modeling and GIS specialists); and David Schloen, whose social models provided a major contribution to the theoretical underpinning of both the project and this volume. All played a major role in the development of ideas, data and the computational framework. We also wish to thank our consultants during the early stages of the research, namely Steve Cole, Galina Morozova, as well as Ben Richerson (St Cloud State University, Minnesota), Jesse Casana (University of Arkansas), and Timothy A. Kohler (Washington State University), all of whom provided a forum for discussion during various stages of the Project. Special thanks go to the Oriental Institute's Systems Manager John Sanders, who provide wise counsel throughout the project and helped maintain the computer infrastructure at the Oriental Institute during all stages of the modeling. Moreover, the research could not have been conducted without the enthusiastic and helpful support of the directors of the Oriental Institute: William Sumner, Gene Gragg and Gil Stein, during the earlier collaborations of the late 1990s as well as the MASS research. The role of the Oriental Institute was crucial to the success of the project, not only because it supplied the ideal ground for the growth and development of the research presented, but also because its archaeologists and epigraphers provided a foundation of knowledge for the research. Specifically this was effected through the Institute's Center for the Archaeology of the Middle East

Landscape (CAMEL),[1] which was a major fulcrum of research and discussion. Finally, we must thank Allison Siegenthaler for editing the manuscript prior to its going to press; her skills made a noteworthy improvement to the final product; and to Colleen Coyle, Kristen Hopper and Louise Rayne for processing much of the statistical data presented.

Thanks also go to the various field projects in Syria and Iraq which provided field grounding for the modeling: these include the Hamoukar Project (directors McGuire Gibson & Clemens Reichel), the Syrian European team at Tell Beydar and its director (Dr. Marc Lebeau, Dr. Karel Van Lerberghe, and Antoine Suleiman); also to the British School of Archaeology in Iraq which sponsored the North Jazira Project in NW Iraq. Thanks must also be extended to Professor Sultan Muhesen, Syrian Directorate General of Antiquities, for granting permission for the original fieldwork at Hamoukar and Beydar; and to Dr Michel Maqdisi for help and advice in Damascus during subsequent field research in Syria; to Professor Mu' ayyad Sa'id Damerji, Director General of the State Board of Antiquities and Museums in Baghdad as well as to Manhal Jabr and Salam Yunis of the Mosul offices of the Directorate General of Antiquities. The models presented draw from an amalgam of field results from all three survey areas, as well as beyond.

Although this publication started out as a report on the MASS project and the agent-based modeling framework, ENKIMDU, it has grown in scope to include a wider range of approaches. Nevertheless, we hope that what knits this volume together is that it is not simply about data or computer simulations, it includes ideas and generalizations which can be tested in future, either by field work or additional modeling.

Finally, T.J. Wilkinson wishes to thank Durham University's Department of Archaeology and colleagues on the AHRC-funded Fragile Crescent Project for providing a stimulating atmosphere for the completion of this volume.

T.J. Wilkinson (Durham University), McGuire Gibson (Oriental Institute, Chicago) and Magnus Widell (University of Liverpool).
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[1] Now the *Center for the Ancient Middle East Landscape*, director, Scott Branting.

FOREWORD

McGuire Gibson

In the 1960s and 1970s, many archaeologists presented 'models' that attempted to encapsulate complex processes in graphic form. Most of those 'models' were flow charts or indicators of action, but were still essentially static. Only with the development of readily available, inexpensive, and (most importantly) portable computer technology has it become possible to attempt to create real models of complexity that can adapt to new circumstances, evolve, and even collapse.

In the late 1990s, Tony Wilkinson and McGuire Gibson were invited to a meeting at Argonne National Laboratory, a major high-energy nuclear research establishment connected to the University of Chicago. The aim of the meeting was to explore in what ways we, at the Oriental Institute, and the Argonne scientists might collaborate on projects. The Argonne scientists had been using agent-based models on a number of topics including the assessment of the health system of California and the interdiction of drug traffic in the Caribbean, and agricultural projections for countries around the world. These modeling systems had already incorporated well-developed programs for geology, geography, ground cover, identification of and predicted yield of crops, climate change, and other ecological inputs. One specific collaboration emerged: their information technology specialists, especially their complex modeling staff, were eager to gain archaeology's unique ability to project human activity back in time and the Oriental Institute archaeologists were keen to build upon Argonne's unusual capability of computer simulations of social systems. Oriental Institute participation provided a way of gaining at least proxy data for climate, environment, and demography for thousands of years, not just from excavated sites and landscape studies, but also from the written record. This meeting led to a successful proposal to the National Science Foundation for a five-year program to build a model for ancient Mesopotamia, focusing on the Bronze Age, a period for which we have ample written records, archaeological excavations, and ground surveys.

The MASS Project (*Modeling Ancient Settlement Systems* [in Mesopotamia]) is a true collaboration of archaeologists, epigraphers, environmental specialists, and information scientists located not only at the Oriental Institute and Argonne, but now also at the University of Durham. We have made considerable progress in creating a dynamic model of the development of complex society in Mesopotamia, but particular conditions of the rainfed north and the irrigated south mean that we are actually developing two complementary but contrasting models. It has long been known that there are major contrasts in the trajectories of settlement growth in the rainfed farming zone of northern Iraq and northern Syria as compared to irrigated southern Mesopotamia.

Much of the archaeological data for the project has been drawn from surveys carried out in the south as early as the 1930s by Thorkild Jacobsen, followed by Robert McCormick Adams, Hans Nissen, Henry Wright, Tony Wilkinson and McGuire Gibson. In the north, the fine-grained surveys of Tony Wilkinson and Jason Ur, built on earlier surveys by numerous scholars, have allowed us to view a broad range of territory across northern Syria and the North Jazira of Iraq. It is the southernmost fluctuation of the settlement boundary across that territory through time, combined with excavated evidence of settlement disruption and re-occupation, that provides us with possible proxy data for a shift in rainfall patterns. In the south, local changes in rainfall, though important for increased yields, may be mitigated or play little role as long as the Tigris and Euphrates bring water to the canals. Climatic conditions, landscape, and other natural differences influence the kinds of crops or animals that can be exploited in the two areas, and here cuneiform and other records can serve to give detailed information to supplement archaeologically and scientifically derived data. The existence of radiating roads (hollow ways) around settlements in the north, displaying a pattern of nucleated settlements surrounded by their fields, contrasts with southern Mesopotamia's network of interlinking watercourses along which major and minor sites must be located. In southern Mesopotamia it is unlikely, in our opinion, that most farmers walked out from towns; rather they were located in villages and hamlets scattered over the landscape, adjacent to their fields. The landscape differences also entailed different techniques of cultivation and much different labor patterns. The south had to work harder, in a very different way, to gain a greater yield. But it had the advantage of more reliable water and water transport.

The main techniques employed in the project are methods of agent-based computer modeling that are capable of incorporating a much wider range of information (social, economic, environmental, archaeological, and textual) than is normally the case in archaeological research. Moreover, and of interest to both archaeologists and philologists, is that by treating the individual and the household as 'agents,' it is possible to simulate human behavior in some degree of detail. In order to produce those simulations, we must input large amounts of data and make some basic decisions about the makeup of Mesopotamian families and society in general. We have some help from texts, but we cannot rely on just what is written, because those documents were not made for posterity, nor were they meant to be an encyclopedia. In cases where legal matters involving families, such as marriage and divorce, are concerned, we have to assume that we are looking at the exceptions to the rule. Among the hundreds of thousands of known cuneiform texts, there are fewer than 200 documents related to marriage, a ratio so small that it cannot reflect normal practice. As in most pre-modern societies, marriage and divorce in ancient Mesopotamia were handled through custom and normally would not need a written document. Only in alliances between rich and powerful families, or when the marriage goes against usual custom, would they have needed a legal contract. There are enough hints in cuneiform, although not expressly stated, that ancient Mesopotamia both north and south was essentially a patrilineal, patrilocal society, and there was even preference for father's brother's daughter marriage. The system was, then, similar to that in the Near East today. This does not mean that there were not marriages with kin on the mother's side, and it does not mean that in many times and places there was much less or even very little father's brother's daughter marriage. But as it was the ideal. In much the same way, we must assume that larger kinship structures of patrilineal lineages, clans and tribes were also the accepted pattern, even if there were many fictive linkages and even made-up tribes. These structures evolved and changed in part by becoming state structures, but also remaining within those states, operating at a reduced level of importance or corporateness but there to be reconstituted when that central authority collapsed. Kinship patterns may well have shifted into a bilateral mode in times of strong central control, in particular places like cities or in certain strata of society, e.g. merchants or administrative or religious elites, but from all that I can see, the dominant pattern was patrilineal. The model can accommodate variations once the dominant pattern exists.

In developing this model, we have entered much real data from cuneiform and other ancient records to give agricultural data, such as rates of seeding and yields. We have estimated labor needs for specific tasks, figures for amounts of goods transported by animals, carts, and boats of different sizes. The simulation also incorporates herds and their products. In order to have estimate the size of households our model has adapted demographic tables from studies in other ancient contexts. Such data were already incorporated in programs that the modelers have developed, as are already existing models of global climate change, crop failures, droughts, flood cycles, and other natural or humanly-influenced disasters. Our models also introduce aspects of human differences, for example special skills such as craft production or aptitude for trade or farming and husbandry, as well as special allocated roles such as ritual functionary or intermediary or war leader. These differences should create inequalities that lead to conflict, conflict resolution mechanisms, and to greater societal complexity. One expectation is that the simulation itself will create such complexity, and maybe even reversions to less complexity. To help this process along, we introduce problems like drought, flood, disease, inter-communal conflict, over-population, migration and warfare to see how the modeled communities respond. We already have some indications of how our modeled society reacts to stimuli on a relatively simple level, and we hope that this book will encourage others to build upon the first steps outlined here to build more sophisticated and effective models in future.

CHAPTER 1

BACKGROUND, RESEARCH DESIGN AND STRUCTURE OF THE MODELING PROGRAM

AIMS OF THE MASS PROJECT

The Near East is well known as the birthplace of agriculture, and Mesopotamia is renowned as the hearth of what Childe dubbed 'the urban revolution.' It is the initial development and growth of cities that we wish to explore in this book. Overall, southern Mesopotamia is considered to have witnessed the growth of cities, as well as the paraphernalia of civilization, before any other area on Earth. Although some form of symbolic script appears to have been in use in China as early as 6500 BC, and large urban areas incorporating palaces and the trappings of elite life existed at Erlitou and Zhenghzou in China during the second millennium BC (Higham 2006: 557-561), there appears to have been nothing to have rivaled the literature and cities of Mesopotamia during the fourth and third millenniums BC. It has been suggested that it may have been the unprecedented size of these Mesopotamian cities alone that led to the process resulting in the development of literate states in the fourth millennium BC (Adams 2001; Marcus 1998). Such was the rapidity of urban growth that it appears to have been greater than could have resulted from the natural excess of births over deaths, and instead some form of positive feedback process is likely to have contributed to urban development. In other words, there was an upward-spiraling growth in which large settlements attracted an increasing population from their surroundings, and in which was a commensurate increase in power and institutions. As a result, there was a process of positive feedback, with the rich getting richer and the successful getting more so (Adams 2001: 353-54).

The development of cities is a vast academic field that is the domain of numerous disciplines, and because most cities are fairly long-lived entities, anyone who wishes to understand the developments of cities needs to be aware of the history of their ancient predecessors. The ancient city itself has been the objective of numerous conferences and seminars, some of the more prominent being the University of Chicago symposium 'City Invincible' (Kraeling and Adams 1960), and the Institute of Archaeology conference that resulted in the volume 'Man Settlement and Urbanism' (Ucko *et al*. 1972). Van de Mieroop (1999: 24-27) has distilled existing approaches to the origins of Mesopotamian cities into three broad categories, namely:

1) cities as ceremonial and religious centers (exemplified by the studies of Wheatley 1971 and 2001)
2) the role of cities in long-distance trade (e.g. Pirenne 1925, Jacobs 1969)
3) the role of cities as centers of redistribution based upon the development of cities as stable centers for social development, in which earlier kin-based societies were transformed into more stratified societies in which the elites played a major role in the redistribution of goods (Adams 1966).

Alternatively one can characterize cities as being defined by 10 basic criteria, as was suggested by Childe in his famous essay in the *Town Planning Review* (1950).

Although cities can be newly established and built by individual kings, or can be traced back to founding fathers, in recent years there has been increased interest in developing models of urban growth that emerge from 'the bottom up': that is, from the daily activities of individuals and households, rather being imposed from above (Batty 2005: 6). Growth is then fueled by processes of positive feedback, during which cities well endowed with advantages or attractiveness grow at the expense of others (see Chapter 14). In the case of ancient cities, this could include centers of power or religion; for the modern city such advantages would include centers of innovation or the fact that the city is located so that it can take full advantage of its location within networks of trade, movement and innovation (Rosewell 2008). As discussed in Chapter 9, networks of communication must also have played a fundamental role in the ancient city. Such networks not only entail transportation systems, but also include the rapid innovations of communications that took place at the end of the fourth millennium BC, and which are explicitly related to the increased complexity of economic transactions that were required when cities started to grow in excess of 10,000 people (see Nissen, Damerow & Englund 1993). Although the role of networks in the growth of cities extend back until at least the models of Wilson (1970) and Haggett and Chorley (1969), the simulations of the MASS Project were able to tackle these questions at both community and city levels (Chapters 11 and 14).

In Mesopotamia, although cities grew to a larger size and were somewhat earlier in date in southern Iraq than in the rain-fed zone of Upper Mesopotamia, careful examination of the archaeological record suggests that the trajectory of urban development is not quite that straightforward (Gibson *et al.* 2002; Ur *et al.* 2007; Oates *et al.* 2007; see Chapter 3). Nevertheless, it is possible to recognize that there was a so-called 'Mesopotamian advantage', which sees southern Mesopotamia as being specifically endowed with advantages so that cities grew rapidly and civilization flourished in ways that were not possible in less propitious locations (see Algaze 2001: 204; also Stein 2004). Such advantages can be modeled for specific cities, as is discussed in Chapter 14.

In this vein, the following quote from the original MASS NSF proposal sets out the main, and perhaps unrealistically ambitious, aims of the project:

> 'Here we propose that early urban settlements in the Near East provide an ideal laboratory for the study of human-environmental interactions because they offer an enormous array of data drawn from archaeological and textual studies that can be incorporated into an overall social, economic and environmental analytical framework stretching over several millennia. Based on nearly four years of collaboration between the Oriental Institute and the social modeling group at Argonne National Laboratory (ANL), we propose to model and explain trajectories of development and demise of Bronze Age settlement systems for both the rain-fed and irrigated zones of Syria and Iraq. Climatic, hydrological, agricultural, demographic and active agent social models will be combined using ANL's DIAS simulation framework to provide a new holistic dynamic object model. The goal is to determine under what conditions urbanization or its opposite, ruralization or even collapse, might have taken place.'

This continued with a rather undisguised agenda to follow a bottom up process of simulation:

> 'We now propose to apply concepts of complex adaptive systems to demonstrate that systems of early cities co-evolved in an intimate relationship with their environment, primarily by means of the aggregation through time of smaller fundamental units (households). In other words the local rules that determined the subsistence practices of the peasant householder were able to develop into much more complex land-use strategies and social mechanisms which in turn culminated in the emergence of complex settlement hierarchies, the patterns of which show little resemblance to the patterning of the original households or small-scale communities. As larger systems of settlements and more complex systems of exchange and administration developed within the capricious semi-arid environment of Syria and Iraq, components of the agricultural systems became less sustainable through time.'

In other words, we intended to take settlement communities in the northern rain-fed zone of Mesopotamia and compare their long-term trajectories of development with those in the irrigated south. The fundamental 'agent' was the household or individuals within such households, and by using these (and the interactions between them) as the basis for the models, we hoped to see how villages would develop into towns and perhaps cities, and how the component communities would interact together.

Using the ancient Near Eastern city as a particularly well-documented example of long-term settlement, the MASS project aimed to address specifically how and why in the third and fourth millennium BC cities in the irrigated zone of southern Mesopotamia grew to a greater size and complexity than those in the rain-fed north.

In addition, we hoped to demonstrate how such settlements and their inhabitants might have responded to a capricious natural environment and were able to grow, survive or decline under various social, environmental, and economic stresses. We placed land-use practices at the core of the analysis because they had the capacity to mediate between social groups and the environment. In other words, crop productivity is not simply a function of environmental factors, but is also dependent upon human decisions such as the frequency of cropping and the availability of crop amendments derived from pastoral flocks and settlement wastes.

At the time of writing the proposal, we fully acknowledged that climatic fluctuations must have had an impact on human communities by inflicting crop failures and sometimes famines. In addition, our field work had shown that the massive scale of cities in both the north and the south must have contributed significantly to the degradation of the environment, including salinization and the depletion of nutrient supplies, so that soil resources must have been stressed to the point of diminishing returns – a point taken up more recently in the book *Dirt* (Montgomery, 2006). However, our approach was, and continues to be, that a wide range of factors influenced ancient communities, and that it is overly simplistic to see cities developing or collapsing simply as the result of a single dominant variable such as a favorable environment, trade, warfare or any other.

One of the great advantages of the collaboration between academics at the University of Chicago and the Argonne National Laboratory was that the agent-based techniques enabled settlement/land-use systems to be modeled from the ground up – that is, from the smallest social element (the household) to much larger entities such as networks of interacting cities. The outcome of the modeling would then be tested and validated by a broad framework of data established by combining the results from archaeological excavations, regional archaeological surveys, satellite remote sensing, and regional-scale environmental studies. Here caution is necessary, because we were aware from our earliest attempts at modeling during the late 1990s that there was a danger of in computer simulations of using input data derived from field work and then using field results to compare with the output from the modeling: this process led to a tendency for the input to influence the output in a self-fulfilling manner. As much as possible in this volume, as in our modeling in general, we try to maintain a separation between the data sources, so that output is not used as a measure against the same type of output.

WHY MODEL? SOME PRINCIPLES OF MODELING SOCIAL / COMPLEX SYSTEMS

Ancient urbanization has often been viewed from a perspective that sees ancient societies as systems in which human behaviors can be explained as a result of relatively straightforward processes such as migration, war, the operation of kingly power, environmental change, irrigation, and so on. As our data sources for ancient societies become ever more complex and the relationship between cause and effect becomes more ambiguous and subject to qualification, it has become apparent that if we are to understand how ancient civilizations developed we need to be able to analyze such complex data sets together within the same framework. Unfortunately, this is difficult because of the disparate range of sources available to us. For example, the main sources of information for the ancient Near East are:

- archaeological excavations,
- archaeological surveys and landscape studies,
- cuneiform texts (historical, economic, literary and diplomatic texts),
- ethnoarchaeology.

Unfortunately, it is not always possible to relate one data set to the others, since not only are the data classes very different, they also differ in the time scales they cover. Thus archaeological excavations provide excellent information for households, individual buildings or clusters of them over decades and generations, whereas settlement surveys contribute much coarser-grained information for large areas of landscape and for longer durations. Texts, by contrast, are highly specific and often relate to the activities of a single individual and moment in time. Although the presence of cuneiform texts on a site provide an invaluable source of information, their presence also suggests that the administrative system extended well beyond the site itself, perhaps to neighboring polities or centers of power. Even though such a site might be of modest size, in terms of modeling it is necessary to incorporate a wide range of sites into the analysis. In other words, if their are more information sources at a site this can lead to an increase in the scale of the model framework and complexity, showing that that modeling does not become easier with more information.

Where long-term records are evident, as is the case with some economic texts, it is difficult to relate them precisely to a specific excavated building or context. Although excellent examples of texts within specific building contexts have been analyzed (Stone 1987; Van de Mieroop 1999), the three fields of survey, excavation and text-based studies often proceed in parallel. The simulations of the MASS Project attempt to bring these three fields together within the same analytical framework so that they can be analyzed within a single interactive environment.

A key feature of the debate surrounding the development of past human societies is the role of human agency, namely that the 'archaeological record is created by the action of individuals' (Johnson 2007: 142). This seemingly rather obvious point deserves emphasis because many archaeological data sources deal with aggregate phenomena that treat society as large units such as settlement or even systems of settlements There is then a tendency to assume that such entities actually adapt to or interact with their environment. Hence one might talk of the collapse of an ancient city as a result of drought-induced famine, which gives the impression that the city itself interacts with the environment. The city itself, however, interacts with nothing; rather it is the individuals or heads of the households within the ancient city who take the decisions to grow crops and thereby suffer from the result of, for example, a crop failure. In other words:

> '... a society cannot adapt to the environment. Rather individuals make local choices about how they will obtain their food (based on their subscription to social concepts regarding appropriate food, activities to get food etc.) that result in aggregate patterns at the level of the society, creating the illusion that society has "done" something.'
> (Beekman 2005: 54)

At another analytical level, practice is the notion of what humans (or agents) actually did and how the 'abstract structures and norms of "culture" are translated into actions on the ground.' As discussed by Johnson in his book *Ideas of Landscape* this practice relates to the actions of everyday life, namely:

> '...the patterns of moving to and from the fields, the actions of ploughing and harrowing the soil, the everyday rhythms of individual, household and community life.'
> (Johnson 2007: 142)

Johnson also outlines examples of practice for the landscapes of medieval Britain, which include:

> 'The way "hollow ways" were excavated and sunk into the ground, the construction of the banks that define tofts and crofts, the manuring of the soil as a transformation in its texture. And it should go on to delineate the everyday movements around that landscape – movements to and from fields, the ceaseless up and down of the heavy plow, its oxen and their driver, activities around the house and in the yard.'
> (Johnson 2007: 150)

Throughout the 1990s the Oriental Institute followed such an approach to the landscape, and this resulted in a series of workshops that attempted to identify the way that agriculture, economy and everyday life operated. These workshops resulted in a prototype project that explored the possibility of simulating ancient Near Eastern agricultural economies, which eventually led to the MASS Project[2].

[2] The workshops were Gibson's seminars on the Structures of Everyday Life, and Wilkinson's course on Archaeological Landscapes of the Near East. See also Lehner 2000 and Schloen 2001.

The above notions of 'agency' and 'practice' have been discussed extensively in the literature of social science (Giddens 1979; 1984; Bourdieu 1977). We emphasize, however, that these concepts are not simply abstract: agent-based models enable us to simulate ancient societies, employing action that is rooted in the individual or household, with those individuals going about their daily agricultural and social activities, not in real time, but within a simulation environment. The accumulated results of all these actions can then be seen at the levels of both single and multiple communities. Not only are individuals and household agents reacting to their natural environment within a social environment in response to their needs, but such actions can be also scaled up within the model to show an emergent aggregate behavior which can then be compared with broad-scale results of archaeological surveys and landscape analyses, thereby bridging the gap between the individual, the household and the local region.

Specific advantages of modeling include:

- agent-based models allow the activities of individuals, households, sedentary communities and mobile groups to be represented within one simulation universe
- it is possible to encompass significant differences of scale within the same modeling framework. These range from an individual household to an entire region consisting of numerous settlements within diverse landscapes
- different ways of life – sedentary and nomadic – can be accommodated
- individual persons can be accommodated within the simulations, which specifically allows for human agency and individual actions to operate and be accounted for. This answers one of the criticisms against processual models of ancient societies, in which most behaviors are averaged and the outcome of models tends to be aggregate behavior rather than the idiosyncratic unfolding of scenarios that are more characteristic of the real world.

We emphasize that modeling is not new, only different, since the availability of computer systems and software now enable much more complex simulations to be run than was formerly the case. In the context of irrigation in ancient Mesopotamia, in the 1980s *The Irrigation Management Game* provided a way of modeling irrigation systems, which required a group of individuals to participate rather than using computer simulations. The game, devised in 1982 by Sir M. MacDonald and Partners, originally used MSc students at Wye College, University of London (MacDonald, 1987). Later it was introduced at other UK universities and for a training course. This simulation is an example of a role-playing exercise which can be used to show the relationship between crop growth and water supply, the relationship between the location of a farm within an irrigation network and its water supply, as well as the work performed by the irrigation administrators and the strategies of the farmers who receive water. When this game is played, it rapidly becomes evident that different users interpret the available resources in very different ways, with the result that crop yields vary depending upon the combination of crop choices, the amount of water availability, the location of farmers along the canal (that is, upstream or downstream) and the individual planting strategies of the farmers. The outcomes of such games are very similar to more recent computer simulations by, for example, Stephen Lansing (1991), which demonstrate the complex and frequently non-linear outcomes when social and other factors are incorporated into processes of agricultural decision-making.

Building on this need to model complex systems such as irrigation networks, in recent years there has been an upsurge in the use of agent-based models by social scientists, anthropologists and geographers because of their apparent ability to incorporate a wide range of behaviors and data; typical of these approaches is a recent volume to which the MASS team has contributed (Kohler & van der Leeuw 2007).

Kohler & van der Leeuw offer the term 'model-based archaeology' to describe the way that models can be built up using mathematics, computer code or other symbolic media in order to fit a portion of the 'real world' and represent it for a specific purpose (Burch 2006; Giere 1999: 5-6, 73).

Kohler & van der Leeuw also state that 'A good model is not a universal scientific truth but fits some portion of the real world reasonably well, in certain respects and for some specific purpose. Degree of fit is determined through empirical research, but a model that does not fit one case may be useful for another – as opposed to a candidate generalization or covering law that can be fully discredited by one contrary observation' (Kohler & van der Leeuw 2007: 3).

Models necessarily represent a simplification or idealization of reality, and the agent-based models that we describe here are a useful way of running 'experiments' in ancient social systems. Consequently we might ask under what circumstances will a given community respond to a certain event or stress, such as overpopulation, an increase in taxation or a run of exceptionally dry years. Alternatively, how might slightly different communities located in different environmental zones respond to such events?

As pointed out by Kohler and van der Leeuw (2007: 5), the complex systems approach acknowledges that all systems, including social ones, are in open interaction with their environment, exchanging matter and energy with it. This is not as dry and abstract as it sounds, and Algaze has described the conditions for the development of the precocious civilizations of ancient Mesopotamia as a 'synergistic cauldron'. In other words, when we view a community that is growing into a large city, it cannot be seen as a subsistence society drawing all of its resources from a limited area. Instead, even though perhaps a majority of its food supply might be brought in from its nearby territory, trade, other sources such as exchange, marriage partners, wars, diplomacy and other relations, all result in influences and supplies being introduced from elsewhere. The presence of such externalities and open systems (which occur to some degree in even the simplest societies) necessarily introduces many more complexities into the analysis and make it more difficult to relate cause to effect. If people can respond in many different ways to any one cause or event, then it is difficult to state what event caused any specific response.

Boccara (2004: 3; see also Kohler and van der Leeuw 2007) suggests that complex systems exhibit the following characteristics:

- they consist of large numbers of interacting agents
- they exhibit 'emergence', which can be described as a self-organizing, collective behavior that is difficult to anticipate from knowledge of the agents' behavior
- their emergent behavior does not result from the existence of a central controller.

Hence, many recent approaches to modeling communities speak of 'bottom-up' behaviors rather than the imposition of order and structure by 'top-down' mechanisms. In the models described in this volume, many of the outcomes are the result of such behaviors, although we must point out that this does not mean that we exclude the operation of top-down processes. For example, in the analysis of ancient empires we see the operation of imposed order and coercion in the forging of ancient societies. Nevertheless, even in such autocratic societies, it is possible to suggest that empires developed out of smaller, more elemental social structures, sometimes as a result of the exercising of the raw power of ambitious kings. We will not belabor this contrast, but simply point out that ancient Mesopotamian society probably developed out of the tension between both bottom-up and top-down processes.

As has already been noted for early modeling efforts, most models described in the Santa Fe volume (Kohler & van der Leeuw 2007) make an effort towards realism and precision, with the result that generality is sacrificed to achieve a 'goodness-of-fit' to the particular archaeological or historical reality. Certainly, this would seem to be the case with the MASS model.

Finally, we emphasize that we are not simply approaching the development of ancient civilizations from the perspective of behavioral models and the social sciences. One of the most pragmatic and worthwhile outcomes of the MASS project is that it has resulted in scholars from a wide range of sub-disciplines working together on the same problem, and doing so on a regular basis, to produce results that no one individual could produce in isolation and without cooperation. Thus our seminars and workshops at the Oriental Institute witnessed epigraphers, archaeologists, anthropologists, modelers, and geo-archaeologists working (and arguing) together to weave a combined perception of how ancient society functioned in order to supply the input data for the model. In this increasingly specialized world which usually only pays lip-service to cross-disciplinary studies, the discussions in these seminars were a major reward.

CHALLENGES ASSOCIATED WITH AGENT-BASED MODELING (ABM)

At the outset it must be acknowledged that some members of the archaeological community have voiced concerns about the use of agent-based techniques to model ancient communities. Some regard ABM as dressed-up systems theory, whereas other see complex systems approaches as insufficiently complex to accommodate the true complexity of ancient society. It is therefore necessary to recognize some of these points[3].

One argument that explains the increased interest in ABM is that many archaeologists approach the recreation of social systems from the ethnographic scale of analysis (Mark Lake, pers. comm. 23 July 2007). This provides a basic interest in the behavior of the individual or small groups. However, does agent-based modeling really deal with agency? Some might argue that the agency dealt with in ABM, with either stochastic processes or rule-based behaviors, does not realistically encompass the true range of idiosyncratic human behaviors. Can it really address, for example, the 'big man' view of history, in which one perhaps charismatic individual changes and even directs the course of events?

ABM, with its origins (or one of its large user communities) within the defense modeling and drug-interdiction world, may represent a suspicious linkage between academic methods and a political-military system. It has been argued that the Rand Corporation had a similar influence on an earlier generation of social science analysis. Does one need complexity to explain complexity, or can complex results be produced by simple inputs?

There is also a problem of multiple process pathways. In other words, in complex modeling domains, can a number of outcomes result from one specific set of input data?

The scale of data needs to be aligned with the scale of the question or entity under investigation. It is therefore not simply appropriate to scale up the complexity of the model to suit the complexity of the system being modeled. For example, the economist Paul Ormerod has suggested at a workshop on 'Modeling Behavior' at Durham University[4] that there are two basic classes of social (simulation) models: High Dimensional Models and Low Dimensional Models. The MASS project is an example of the former, and the simple yet elegant models of Balinese irrigation (Lansing 1991) are an example of the latter. The models of city development discussed in Chapter 14 also supply examples of the latter.

From within the ABM community, Batty (2005: 107) has argued: 'As the models become more complex – including more parameters and variables – it becomes more difficult to disentangle the effect of these on the forms generated.'…. '[We] will faithfully follow the principle of Occam's Razor: keep models as simple as possible'.[5]

Advocates of the last points for the use of simple models, rather than 'everything but the kitchen sink,' have provided compelling and informative output such as the remarkable patterns of fractal cities by Batty (2005). Nevertheless, if we are going to analyze the wide variety of data sources that exist from Mesopotamia and at the same time try to understand the complexity of Algaze's 'synergistic cauldron' (Mesopotamia could after all be seen topographically as a giant kitchen sink), then it is necessary to employ models of an appropriate level of complexity. In this volume we attempt to model from both perspectives: the complex, represented by the

[3] Some of these points were discussed at a workshop at the University of Edinburgh e-Science centre in July 2007. We would like to acknowledge Mark Lake, UCL, for pointing out some of the more pertinent political critiques.
[4] Held in 2007 and sponsored by the Institute of Advanced Study, Durham University.
[5] But see Chapter 15, for an alternative perspective.

ENKIMDU models in the rain-fed north (Chapters 10 and 11), and the spatial maximizing models presented by Altaweel in Chapter 14.

A number of critiques have emerged, however, even within our own modeling group; for example (addressing complexity theory and agent-based models), Schloen points out:

> 'More fundamentally, from the point of view of philosophical hermeneutics, the objectifying formalism of a systems approach, as valuable as it may be within carefully circumscribed domains, can never provide an encompassing sociohistorical paradigm,…..That this is true even with respect to complex nonlinear systems is demonstrated by the weaknesses of recent archaeological attempts at "agent-based modeling" by way of computer simulations of complex adaptive systems (see Epstein 1999; Kohler and Gumerman 2000).'
> (Schloen 2001: 59)

One problem, the argument continues, is that the rules determining the behaviors of agents are usually based on 'functionalist or materialist assumptions' of what is rational (such as the principle of least-effort), and what might be described as 'positivist fictions' invented by the researcher. There is no doubt that such critiques point out the absence of, for example, social identity and a wide range of other social behaviors that are fundamental to human social behavior. Since such critiques were initially made, modelers have introduced various protocols for modeling human behavior (Kennedy 2012), although there remains the problem that such behavior may rely too much upon modern or recent ethnographic data. Moreover, within constrained domains of, for example, the modeling of land use and agricultural practice, or specific aspects of everyday life, modeling is capable of some rather illuminating insights that can at least be tested using a wide range of inputs and parameters.

We hope that the above answers at least some of the questions that will emerge in later chapters.

LAYOUT AND STRUCTURE OF THE VOLUME

Part 1: Context to the modeling program

This book does not solely approach Mesopotamian society from the perspective of agent-based models. Rather, the introductory chapters build upon a large body of background research that the MASS team members have conducted over the past decade. Much of this, initially conducted in the Oriental Institute's *CAMEL* Lab, entails the reconstruction of human settlement and environment in both northern and southern Mesopotamia. Following a summary of the environmental context and the role of water in Mesopotamia in Chapter 2, Chapters 3 and 4 describe the patterns of settlement and land use that arose in these contrasting environments. Such settlement systems provide a 'template' for our model communities, and will contribute at least part of the structure of the models discussed in Part 2.

The foundation of our models is based upon the everyday operation and life of household members, and Part 1 includes a sketch of ancient Mesopotamian society and how this will be used in the simulations to follow. Specifically, Chapter 5 summarizes the large body of data relating to the crops and foods used in both northern and southern Mesopotamia. This chapter presents a large amount of material that constitutes the input of the model. They have been culled from cuneiform texts, ethnographic studies and consultants' reports, which enable us to sketch the possible factors of everyday life and food production that allowed Mesopotamian societies to survive and develop. Our aim with these data is to provide information on food production and consumption that contributes to the simulation of these ancient communities from the ground up.

Chapter 6 provides an outline of patterns of consumption and storage, with Chapters 7 and 8 giving perspectives on both household and village within sedentary societies, as well as the broader role of pastoral societies. Chapter 9 introduces a general perspective on the significance of networks in the ancient Near East.

Overall, our simulation will include a ‘cyber community’ of individuals and households, who go about their lives by marrying, having families, cultivating fields, tending flocks, and conducting exchanges to satisfy real or imagined needs. The simulations that follow in Part 2 require a vast amount of input data drawn from a wide range of sources, which include cuneiform texts for information on social groups and their economic transactions, archaeological excavations for household data (the size of houses, food consumed, etc), and surveys for information on the layout of settlements and their fields. Such data sources are clearly insufficient, however, to create a simulated community, and in order to fill in the gaps and provide further information it has been necessary to use data from ethnography, ethnoarchaeology, consultants’ reports and economic histories. Such views of the traditional economy cannot be uncritically projected back in time; nevertheless, when used with care such sources can provide valuable insights into how certain parts of society may have functioned.

Part 2: Model output and discussion

In Chapters 10-15 we deploy the above input data to develop a series of simulations of Mesopotamian society under a wide range of circumstances: ‘normal’ conditions of everyday life, as well as under the duress of a number of selected environmental, social and economic stresses. These results show how agent-based models can be used as a laboratory to simulate a range of circumstances in which human actors behave and either overcome adverse circumstance, adapt to them, or create new conditions that enable them to develop and move forward. In Chapters 10, 11 and 12, which outline the modeling framework and selected outputs, the model communities are usually small-scale settlements of a few hundred individuals living in a single settlement surrounded by their rain-fed fields and attached pastures. In order to inject the appropriate level of realism into the models, the intention was to scale them up to include neighboring communities as well as interactions with mobile pastoralist groups located in the steppe beyond. As discussed in Chapter 12, it has also been possible to include pastoral-sedentary interactions. Finally, the mathematical and generalizing models developed by Altaweel (Chapters 13 and 14) provide a valuable yardstick against which we can compare the highly granulated models of the ENKIMDU framework. The contrasting perspectives offered by these different modeling frameworks will be discussed in Chapter 15.

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