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Are we the tools of our tools? Understanding impacts of GIS approaches on archaeological research

"Men have become the tools of their tools." Ralph Waldo Emerson

Spatial technologies including geographic information systems (GIS) have come a long way in the last 30 years and archaeology, like other social sciences, has worked hard to create relevant rationalities for and applications of the new technology. For all of our work in defining a space for GIS in our research pursuits, it can be difficult to identify just how much these new approaches have changed us. Though some would argue that these new technical pursuits have simplified certain aspects of our work (e.g. visualization) the current state of affairs between GIS and archaeology is much more complex. In a way, some of the work done by archaeologists in GIS appears to be "keeping up with the Joneses", a necessary participation in the evolution of technology in modern academic and applied social sciences. The necessary tailoring and defining of a place for the technology is an important first step in integrating GIS into our discipline. However, too long in the "keeping up with the Joneses" phase can become counterproductive. And, more importantly, failure to take the time to understand why certain aspects of a technology work and others do not can lead to a stagnant pool of repetitive work and trivial advances in methods, conceptual designs, and theoretical linkages.

It is difficult to cleanly evaluate the current integration of GIS in archaeology for three basic reasons: first off, while technical literature and writing is still conducted, it is increasingly specialized and difficult to apply outside its original design or intent. Secondly, the body of literature that critiques GIS approaches in archaeology tends to point out the obvious and supply

no real solutions. And thirdly, there is not ONE problem with GIS approaches in archaeology – there are, in fact, several. While most of the archaeological work conducted in GIS seems to play on well-established approaches and techniques that are proven, time and time again, to have value in our discipline (e.g. visualization, spatial databases, and basic conversion processes such as *cost surface analysis*), this body of literature as a whole is, in my opinion, remarkably incomplete. The fact that archaeologists are only in part addressing important concepts and underpinnings of GIS is reflected in even our training – or the classical "Introduction to GIS for Archaeology" classes which cover everything and nothing all at the same time. I argue, in this paper, that some of the core issues with the stable implementation of GIS in archaeological research lie in the fact that there are several categories and topics that must be addressed by the discipline at large. And they cannot be constructively addressed with the presentation of a new approach or a new comprehensive-type text (e.g. Conolly and Lake 2006; Wheatley and Gillings 2001). These discussions need to originate in the discipline's population-at-large and should include topics important to both the user and non-user. Setting data standards, discussing parameters for particular processes within the program, and proper GIS research design will all benefit from an open dialogue.

This paper is an attempt to begin such a dialogue. Like most users, my training in GIS is a mesh of ad hoc self-training and constructed generalized training resulting in a kind of "sure, I know the program, but no, I am not sure how to answer that question" kind of existence. My experience in GIS work in archaeological contexts has led me to identify five different areas where clear explanation can be either difficult to glean or sparsely populated with constructive arguments that help me in my attempt to be a grounded user: 1) technical aspects; 2) conceptual understanding and issues; 3) project design and execution; 4) theoretical and methodological

approaches and understanding; and 5) our existing knowledge base. It is my goal, and indeed hope, that this categorization will make sense to other users and non-users and that by focusing on the smaller details via interaction and working together we, as a discipline and a community, can better define the strengths and weaknesses of current uses and set up a foundation for a future where new technologies or extensions of GIS can be more simply assimilated and readily used.

Archaeology and GIS

There are many well-written descriptions and definitions of GIS in general (Aronoff 1989; Dickinson and Calkins 1988; Gillings 1999; Goodchild 1996; Zoran and Stančič 1995; Star and Estes 1990; and Wheatley and Gillings 2001). Fundamentally, GIS has two very important components. First, it is a spatial database designed to easily manipulate, organize, display, and query large quantities of spatial information. Secondly, it is capable of taking said organized spatial information and creating new datasets that were not part of the original data structure. The processes that underlie the second component are based in a varied background which includes concepts in cartography, geography, environmental science, and information science. A "GIS user" is very rarely an expert in all important components of this varied background and seeking answers from outside-discipline GIS literature searches can overwhelm with a depressing quantity of new jargon, concepts, theory, and applications as well as add to existing confusion on what things and ideas should be considered prior to creating an archaeological GIS product.

Facing GIS as a whole head-on is exhausting and depressing, if I may pull upon my personal experience. Yet, it is not completely impossible to understand. Acknowledging the

complexity of the program, the array of uses, and the future the technology has in the discipline are all positive steps towards understanding what great things GIS can provide. The discussion of the five categories of GIS problems is a useful beginning point that will hopefully provide users and non-users alike with an understanding of the complexity of the issues and where we, as individuals, can best impact and improve our work, our GIS community, and our discipline.

Technical

The technical aspects of GIS can be difficult to grasp for the casual user. The learning curve for the program and the underlying components can be intimidating, difficult to navigate, and even harder to apply. The typical GIS user may have had the fortuitous experience of taking a class or two (or getting their hands on a really great manual), but most of these classes focus on procedural approaches using already constructed datasets and rarely touch on issues with creating data from scratch. Conceptually speaking, GIS performs four different tasks: cartographic design (creating useful maps), organizing and storing spatial data (geodatabases), varying levels of spatial analysis, and new data creation. Expectedly, most users start out learning to manipulate the extremely broad applications in mapping alone. But, as any GIS user who has gone to work for someone else knows, there is a point in time where what one has learned is insufficient for what someone requests. There are few books or literature sources which cover detailed GIS approaches in archaeological contexts. A few of these books are treated as manuals (e.g. Lake and Conolly 2006; Wheatley and Gillings 2001) while others, particularly edited volumes, tend to be themed-based (e.g. predictive modeling: Mehrer and Wescott 2006; Wescott and Brandon 2000).

The reality is that as a software program GIS is very complex. The most common software in the United States – ESRI's ArcGIS software – is technically three or more different programs, each designed to work together but all having their own tasks that make them unique. It never ceases to amaze me how much new students, even those with extensive computer experience, struggle through understanding the how's and why's of the program – strictly in the point and click context. To complicate matters further, students cannot succeed in using the program without understanding how vector and raster data are handled, which data model is most appropriate to use in different situations, and which geoprocessing tools can be used with different datasets. Further, absolute failure can result when information is not properly projected, coordinate systems vary, or incorrect information is used as foundational data.

Correcting the issues with technical problems lies greatly with the user. Although it would be nice to have a comprehensive manual written strictly for archaeologists, the reality is that those interested in using GIS simply have to sit down with the program and work to understand it. As each user has a different background, patience and smart time-management can help in this arena. Technical issues can also be rectified by making procedural and technical information regarding work done in GIS available in our publications, presentations, and interaction. Providing information about our work, even if we are slightly worried about being critiqued, can help future generations understand their routes and improve the quality of the technical work in the future.

Conceptual

The concept of "spatial is special" is a fundamental component in most introductory GIS courses (Anselin 1989; Goodchild 2001; Longley et al. 2001). Although the acknowledgment of

spatial being special is useful to keep in mind when applying GIS, it can also be a bit counter-productive. The separation of GIS and its underlying method and theory gives the illusion that work conducted in GIS is some how special unto itself – or more importantly it hides the reality that the 'spatial' aspect of any work done in GIS is really not any different than any other type of analysis. From a conceptual perspective, there is a lot to learn in GIS. Any GIS program (ESRI, GRASS, Geoda) are all constructed to perform very specific functions for the user. These functions, such as interpolation, clipping, merging, and map algebra, are becoming easier and easier to access and apply, but are still steeped in confusion for many users. Most of the functions and tools contained in a GIS program will create and respond to anything than the user is interested in doing – regardless as to whether that particular function logically works with the data or whether the data set is complete enough to warrant using the function in the first place. In other words, GIS pretty much lets you do anything. And the user friendly GUIs (graphic user interfaces) and easy access do not solve the biggest problem for many users – when is it appropriate to use certain functions, how do you choose the particular functions, and what happens to your product when you apply a function.

This 'conceptual' category can be divided into two different areas: understanding the concepts within GIS for the various functions AND applying those concepts to projects in archaeology. There is a rationality for why a function exists and ideal situations where those functions and tools can be applied. There are also underlying needs for each archaeological project. For successful GIS product manufacture it is not just a matter of learning the functions and flow of a GIS program; it is a matter of finding valid applications of the tools/functions in specific archaeological cases.

Conceptual understanding belongs to the discipline at large. GIS users, the people they might work for, and the audience should all have some understanding of what the broad set of functions in GIS accomplish – or don't. I cannot specifically recall the number of times I have sat in on a presentation where a GIS density map was used to discuss 'intra-site' variability across a site and wondered exactly what the GIS user did to create the surface. There are multiple avenues that exist for creating such surfaces and when the creators of such surfaces do not explicitly describe their processes the surface may not only be incorrect, but additional information or interpretation based on it can be potentially incorrect as well.

Project design and execution

Introductory texts in GIS state that one of the important tenets of creating a working GIS is to start by envisioning the output (Longley et al. 2001). This product-driven approach appears easier than it actually is. In actuality, project design and execution is contingent on a wide-range of variables that the GIS user may or may not control. This can create very real problems including incorrectly applied processes, incorrect outputs, unclear presentation, and poor rationalities for the project. Archaeologists, who are used to locating a site, planning their strategy, and then collecting their data tend to take this approach with the majority of their work. Though this front-end/inductive approach is necessary, it does not and should not necessarily extend into the realm of GIS-work. If a project director is interested in density at half-meter intervals, they MUST collect the data at the correct spatial resolution in order for the output density surface to be correct. If the project director hands artifact density information for 1x1m units and asks for a density surface at half-meter intervals, the GIS user should immediately explain why this is not possible. However, if, prior to excavating, the GIS user recognizes the

project director's interest, suggestions for data collection can be proffered and future problems avoided.

Most of the time GIS users are not necessarily involved with a project that collects data from scratch. A great deal of our work is based on existing datasets – foundational information such as DEMs, environmental variables, and regional archaeological site information. Oftentimes, when beginning a project, the datasets have not even been identified. Depending on where you are working around the world, access to foundational datasets can range from easily accessible to non-existent. Familiarity with the available data can help in determining exactly what information is necessary to create a particular output or product and aid in understanding what products can be produced from these datasets. Varying scale and resolution in datasets, temporal and static issues, as well as continuity of datasets all play a role in whether an envisioned product can be realized or whether the user (and whoever they are working for) will have to settle for something else.

Advances in this particular arena fall on all archaeologists. Spatial visualizations and analyses are important in most archaeological research and understanding the limits of GIS and the accompanying datasets is key to producing a meaningful and correct product. Further, this is an area where non-users need to be informed as GIS products used in articles or presentations should be considered in whole – meaning the viewer should be aware of the data scales, attribute information (e.g. elevation, etc), and the basic processes used to render such products. Again, taking time in articles or presentations to briefly outline GIS product design and/or its place in the larger project can help clarify its use and highlight successes and problems which need to be addressed.

Theoretical and methodological issues

By far, this is the broadest, most problematic, and most sporadic category of GIS problems. This category contains topics ranging from acceptable knowledge formation, uncertainity, and ontology to proper formation of surfaces, realistic uses of GIS products, and issues in the emerging technology-driven paradigms. It is in discussing the varying aspects of this category where we should truly be questioning whether we are becoming the "tools of our tools". From a methodological perspective, archaeologists have a lot of work to do. One of the most complex GIS applications in GIS is the predictive model which is, ironically, the perfect combination of the core issues and problems recognized within this category. To create a predictive model is to face problems in the following arenas:

- ***Method*** – what variables were included in the predictive model? What were the different scales of the datasets and how were they corrected (or were they corrected at all)? Which statistical tests were applied to determine the weight of the different datasets (e.g. logistic regression) and what GIS process was used to assign the weights? How was the area for the predictive model determined and is it a 'best-fit' for the goal of the product?
- ***Theory*** – do the chosen variables and output reflect the real world or a process/event in the past? What measures are used to test the model and is the testing conducted on the model sufficient enough to provide sure measure that the output surface was accurate or not? Why bother with a predictive model in the first place and is it the best solution to the particular archaeological question? Is the model reflective of human behavior or is it too environmentally deterministic? Does creating a predictive model damage the archaeological knowledge foundation for the area or does it help bolster one particular idea? Does a predictive model that fails really fail or is it because not enough variables were included? Does a predictive model that succeeds really reflect anything?
- ***Technical*** – If the predictive model is built in an area, how does the user handle combining edges? If creating a set of random points, how does the user ensure that these points are indeed random in space? If known points are spatially autocorrelated, what additional tests or considerations should be used to ensure that the variables outside the clustered areas are properly considered in the predictive model? What clusters may be more a reflection of survey? Are the raster themes overlaid properly?

This category also contains fundamental issues related to the application of 'space', the organization of spatial data, what patterns may or may not indicate, and the ongoing struggle

between the quantification of spatial information (e.g. the usefulness of spatial analysis) and the realization that humans construct space and humans are not always rational and patterned. Temporal considerations, 3rd and 4th dimensions, artificial intelligence and decision matrices and their application to archaeological landscapes, and theory-based modeling also fall within this category.

Unfortunately, problems in this category are complex and not easily addressed. More importantly, literature related to themes in this category tend to gravitate towards a best-fit solution or approach by an individual (e.g. statistics are good or statistics are bad). They can be heavily biased, limited by paradigmatic restrictions, or based on limited personal experience. Though these are all warranted aspects, the dearth of literature that addresses the variety in this category can lead to everyone knowing the same thing and stump progress that open discussion would most likely aid. This category is the true reflection of ourselves – how comfortable we are with increasingly complex technology, the impacts it is having on our research approaches and analyses, and what issues we are ignoring, despite them looming over our heads.

Existing knowledge base

Outside of theory lies a more philosophical realm where we define ourselves, our ideals and goals, and define the relationship between ourselves and our data. Archaeologists seek understanding of past human relationships, behavior, and patterns and additionally work to provide this information to humanity at large, for knowing our roots is important. To archaeologists who have, in some ways, a very tenuous hold on these past processes, fully exploiting the archaeological assemblage and derived datasets (lithic measurements, etc) are key to ensuring as robust an interpretation as possible. In a GIS context, recognizing the varying

components of our knowledge foundation and how all the issues mentioned above fit into our understanding of ourselves is important to being successful. However, despite the knowledge base clearly existing, it is often difficult to grasp and sometimes very difficult to apply. The answer to a spatial arrangement is not just the arrangement itself, but what it may mean, what components of the arrangement make it reflective of a process or behavior, and necessary underlying and identifiable links between the pattern, our theory, respective paradigms, and what is considered necessary to define the phenomenon in the first place.

The problems experienced by GIS users are rooted in the broader foundation of archaeological knowledge and practices including, but hardly limited to, our knowledge formation, our application of spatial statistics and the theoretical role that space plays in our discipline. Our ability to use GIS is based in our understanding and application of the spatial concepts that underlie the construction of the applications that comprise the program and how those concepts can potentially aid us in understanding the past. There is, in part, a gap in understanding between "spatial" as it is used in the context of GIS and "spatial" in archaeology. Aside from creating a situation where it is difficult to find uses for the program beyond mapping, this gap in understanding is widened by the use and subsequent summation of results and methods of GIS that are currently being used in archaeological research. The question for existing and future researchers interested in making GIS and related technology relevant to their research is: how can we better prepare ourselves and our research for a technology such as GIS?

There is a long history in archaeology concerning knowledge or more appropriately "knowability", specifically the need to distinguish between knowledge based on the facts of the archaeological record (data) and knowledge based upon our own preconceptions regarding the workings of the past (interpretation) (Kosso 2001). Despite being frequently addressed (e.g.,

Clarke 1972; 1973; Hodder 1985; Kosso 2001; Renfrew 1983), there is no clear solution to this dilemma due to the archaeological record being comprised of artifacts vaguely tied to past human behavior (Waters and Kuehn 1996). In other words, in terms of representing human behavior and culture in the past, it is remarkably incomplete. Our knowledge foundation is populated, at least partially, with the actual material retrieved from the ground. However, the majority of understanding and academic knowledge comes from approaches archaeologists have developed to expand their datasets and join them with theoretical underpinnings to produce multi-scalar information about who, what, when, where, why and how. These approaches are constantly being overhauled by researchers in an attempt to make the interpretations as accurate and precise as possible. But what exactly is an accurate or correct interpretation? How do we protect our knowledge foundation from incorrect or fixed assumptions? How do we deal with an increasingly large and complex set of data, making it as constructive for our discipline as possible? All of these questions, and more, subtly rooted in our approaches to investigation, can be boiled down to one question: how exactly do we *know* what we know?

Our knowledge base is comprised of data from the archaeological record, interpretations related to that data, theoretical underpinning representing our interpretations, ideas related to human behavior and action and philosophical components that help make the theory applicable in a larger context. This knowledge is constructed in a wide variety of ways. Some knowledge is based on direct and observable information. For example, we know that people of the past made pottery because pottery can be removed and analyzed from the archaeological record (Bryan 1964; Camilli and Ebert 1992; Katalin 1998; Parsons 1972; Read 1986). Some knowledge is based on well supported scientific suppositions such as the law of superposition, the law of inclusion, the law of association, and the law of cross-butting relationships (Schiffer 1987).

Other knowledge is based on identifying and organizing patterns found within the archaeological record (e.g., intra-site [Binford 1983; Brooks and Yellen 1987; Brown 1985; Bryan 1964; Dancey 1988; Emerson, McElrath and Fortier 1998; Enloe and Hare 1994; Hoffman 1993; Hull 1987; Kent 1984; Marean and Bertino 1994; Oetelaar 1993; Rapoport 1990]). Finally, archaeologists construct knowledge indirectly, or infer information and events in the past that are no longer available for direct observation (Kosso 2001).

Archaeological inferences frequently utilize knowledge obtained through observation based in current social and behavioral sciences such as geography, psychology, sociology and biology. For example, Human Behavioral Ecology's (HBE) 'prey-choice' model is based largely on what researchers can assess about modern hunting and gathering groups (Winterhalder and Smith 2000). Information adopted from other disciplines and used as foundational material for archaeological interpretation can form the basis of archaeological inference and thus, archaeological knowledge. In other words, the unseen becomes "knowable" in the context of the seen. (Kosso 2001:18)

But what is considered tangible interpretation and knowledge is highly variable within the discipline at large. Divergence in acceptance of a particular interpretation can depend upon what area of the world work is conducted, the institution responsible for training an individual, differential exposure to archaeological material, accrued experience, academic versus public associations, specific research interests within the discipline (e.g. complex societies (Paleoindian, etc) and paradigmatic affiliations. Each concept, each artifact and each feature is filtered through an academic process designed to tailor an output or interpretation. These interpretations are combined, modified, rejected or recreated as new information is added or modified and, if

deserving, translated into knowledge or the base set of information that represents what we know about the past.

Using a tool, like GIS, unfortunately highlights areas of our knowledge base that are vague and/or poorly linked to theoretical concepts. We all acknowledge the generalities of a 'complex society' but when looking at a scatter of buildings and accompanying attribute information it is difficult to use GIS to delineate "complex" from "kind of complex". In other words, the assignment of a value to a dataset is oftentimes based on an individual's understanding of theoretical concepts and models. Anyone can use GIS to model complexity in space, but the final interpretation, if you're strictly wishing to use the program to make the delineation, is only as good as what the user provides the GIS. Successful implementation of more advanced uses of GIS or GIS use that "revolutionize(s) our thinking and approaches to the study of archaeological phenomenon" (Kvamme 1999; 155), requires constant attempts to build a series of accepted methods and approaches that link theory with data and the attributes of that data. Constructing models and related testable assumptions can help aid users and the discipline at large in finding appropriate ways to apply GIS in creative ways.

Conclusion

So, in the context of GIS, are archaeologists the "tools of our tools"? It would be counterproductive for my career to single out individuals that might fall under the 'tool' category, so instead I will stick with the following: I have been, am, and inevitably will be a 'tool' of GIS. Though such self-labeling may appear problematic, I argue that the acknowledgement of it is kind of freeing. GIS and related technology is complex and the problems I have personally experienced creating useful products in it is not just related to one

simple and easily corrected issue. Its use in any context forces users to address fundamental concepts and theory embedded in our training and understanding of archaeology at large. Clarity for GIS users will most likely never really be attained, but it can be worked towards. Indeed, if we don't start identifying problem areas of the use in whatever context they appear (technical, conceptual, theoretical, etc), the discipline may lose its grasp on and future with the most interesting part of GIS, specifically that it is a tool with infinite ways to examine, construct relationships between, and assign meaning to a unique dimension of the archaeological record.

For the past 30 years, GIS has slowly worked itself from the peripheral and specialized use of a few to the center of our mapping and visualization toolkits. Original discussions of GIS, including those pushing the importance of the program, accomplished their jobs – we all know what GIS is and some of us could even argue that we know what GIS does. Yet, the development and application of GIS is still in infancy stages in some areas of archaeology and its true relevancy, hinted to since its first use in archaeological contexts, has yet to be fully realized. The true solutions to GIS problems in our discipline will only be solved with communication, careful critique, and meaningful dialogue.

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