A Brief Outline of Causality-Based Cognitive Archaeological Probabilistic Modeling

by

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Abstract

In our effort to identify and manage the significant resources which comprise our cultural heritage, archaeologists have employed a number of methods which have focused on linking "sites" with key spatial factors in a predictive framework. Until recently these efforts have been largely correlative, deterministic, and devoid of social or interpretative theory. This has evolved into practical methods which lack an explication of causality, conflict with the intended economic or interpretative purposes of the undertaking, and relegate human cognition (both in the past and today) to being vaguely represented by a "black box" of uncertainty. In contrast, causality-based methods of cognitive modeling have the potential to produce ways of managing archaeological heritage, explaining patterns of cognition and behavior, and introducing agency and complexity into theories of human-spatial interaction. If the underlying causal relationships between conditions, events and decisions related to site selection are outlined in a mechanistic and probabilistic fashion, we may begin to understand why certain areas are selected for different kinds of behaviors, how that is transformed into what we consider to be "sites," and how we could use our knowledge to identify and protect significant archaeological resources. The methods presented here will be outlined on a theoretical basis, presented in a practical framework, and summarized as the intersection of three quite distinct kinds of models; past site selection, management priority, and disturbances.

Introduction

It is pretty clear that after years of diverse applications (mainly in North America) there is still a feeling on the part of many archaeologists that predictive modeling, as it is currently practiced, is not all that it is cracked up to be (e.g. Church et al. 2000; Ebert 2000; van Leusen et al. 2002; Kamermans et al. 2003). Why should this be so? What is it that seems to be missing?

In the *Phase I: Baseline Report* of the NWO (Humanities Section) within the BBO research program (Stimuleringsprogramma Bodemarchief in Behoud en Ontwikkeling) several classifications were made regarding the state of predictive modeling in archaeology (van Leusen et al. 2002). These classes were expressed as a series of dichotomies between theoretical aims and practical approaches, including; *management* vs. *research*, *inductive* vs. *deductive*, and *ecological determinism* vs. *post-modernist* (van Leusen et al. 2002:3-6). Two additional dichotomies were suggested as well; *correlative* vs. *explanatory*, and *possibilistic* vs. *probabilistic* (van Leusen et al. 2002:6-7).

Each of these dichotomies indicates a concern for why and how quantitative predictive modeling should be, or is, carried out. Although management and research goals are equivalent aims, in practice, applications of quantitative predictive modeling are typically used only in management situations; due largely to their expense. The inductive/deductive dichotomy has long been a misnomer for two different practical approaches to modeling, rather than the theoretical explanatory opposition the terms would imply (Whitley 2003:4-6). Likewise, the distinction between ecological deterministic and post-modernist approaches, is in itself, not fully illustrative. The scientific model of explanation used by correlative approaches mandates a deterministic perspective on theoretical grounds (Salmon 1998:142-163), which in practice becomes dependent on ecological variables (Whitley 2003). Post-modernist approaches are also not the only perspectives to be in opposition to a deterministic one (cf. Salmon 1998:25-49).

The counterpoints of correlative vs. explanatory, and possibilistic vs. probabilistic are more applicable to this discussion. Correlative approaches have also been placed in opposition to *cognitive* ones (cf. Whitley 2003:6), but in the end, the missing element in correlative models is *causal explanation*. In short, correlative models require the existence of causal relationships between sites and initial conditions, but do nothing to illustrate or explain them. They take the perspective of deductive chauvinism (in which the failure of any aspect of a model is an expression only of missing data - cf. Salmon 1998:142-145) and imply the absence of human free will (cf. Salmon 1998:46-47). Causal explanatory models, on the other hand, require a mechanistic understanding of cause and effect and one which embraces the possibility of indeterminism (cf. Salmon 1998:46-47).

In addition, correlative models are overwhelmingly reliant on a few simple limiting factors (and various permutations of them) and the most common or abundant sites. Thus, they are reductionist, dependent on fixed point or highly predictable variables, and leave no room for highly complex contributing factors. They have never been shown to have great *accuracy* or *precision* (known as *specificity* in van Leusen et al. 2002:9-10) in environmentally homogenous regions, and typically only work in heterogenous ones after a great deal of time and money is expended "cleaning up" the existing dataset (see, for example, the results of the Minnesota Model [Hudak et al. 2002], and the stated goals of the North Carolina GIS Archaeological Predictive Model Project [NCDOT n.d.]).

The distinction between possibilistic and probabilistic can be conveyed as the difference between areas *suitable* for use and those which were *likely* to have been used (van Leusen et al. 2002:6-7). Non-causal correlative models are possibilistic because they are not *focused*. In other words, since they do not take an agent-based perspective (i.e. someone making a cognitive decision about site selection) they assume equal representation across the study area, hence they can only elaborate areas suitable for site selection. By *site selection* I mean the choosing of a spatial locality for a particular behavior based on characteristics associated with that locality. Probabilistic approaches model not only areas suitable for selection, but areas which were more likely to have been selected due to reasons of temporal or spatial constraint and perception.

Once again, in practice quantitative predictive models are almost always:

- management-oriented
- non-causal
- non-explanatory
- correlative
- determinisitic
- possibilistic

Social Theory and the Landscape

Clearly archaeologists have strong intuitive ideas about how people interact with their surroundings (the whole notion of landscape archaeology is founded on it). They recognize the great effect that social relationships and cognitive processes have on human behavior (today and presumably in the past), which often transcends what we find in the archaeological record. An artifact obviously might have been used as a tool, but it also carries with it symbolic and cultural traits which can be recognized only in the context of it's social setting. The same can be said for features, sites, and landscapes in general.

To argue that the potential for encountering archaeological sites can be systematically and statistically assessed by evaluating a set of strictly environmental variables has a practical attraction to it, yet is on par with suggesting that our personalities are determined simply by our genetic makeup. It is an unsettling idea, and one which cannot be justified by applying ever-increasingly complicated mathematical processes. It is the social theory behind correlative predictive modeling (or the lack thereof) which unsettles the interpretative archaeologist.

What are the alternatives? How can we use what we know about settlement and the causality of site selection decision-making to inform us about where significant yet undiscovered resources might be located? To this point the practical alternate approach has been to discard quantitative methods altogether and adopt an intuitive model; where we rely on our field experience and professional "common sense" to devise areas of high and low site potential. Intuitive models are actively employed throughout the US as well as the Netherlands (Kamermans et al. 2003) in both management and research contexts. In fact, they are the guiding principles behind survey standards employed in most states for CRM purposes.

Intuitive models (though much less expensive to implement) are about as accurate and precise as correlative models, or probably typically slightly less so depending on the region. They are, as well, without any explication of causality and usually are not replicable, or even definable. Thus they tend to lack the strong sense of validation provided by applying at least *some* statistical technique.

But why do we feel that we have to toss out the quantitative aspects of predictive modeling altogether just because we recognize the limitations of correlative approaches? In fact, if we understand the true advantages of Geographic Information Systems (GIS) to add infinite levels of interpretative ability in a conceptual, yet quantitative fashion, we could see that, far from being a deterministic, limiting tool with an absence of causality, site selection modeling can focus on causal explanations and interactions which have implications well beyond just managing the resources. It can actually have major consequences for how we deal with past human cognition as a topic of inquiry entirely on its own. The first step to building a framework within which to visualize these ideas is to fully elaborate the nature of site selection decision-making in a causal and explanatory way (cf. Salmon 1998).

The "Black Box" of Cognition

All predictive models have one thing in common; they are expressions of a probabilistic relationship between human behavior and prior existing spatial conditions. It is there that, in practice, the similarity evaporates. Correlative models assume that the current distribution of archaeological sites is a direct reflection of once observable characteristics consciously, and/or subconsciously, selected as locations for human behavior. Statistically assessing the relationships between known sites and such characteristics leads to a predictive formula. The key elements of that formula are the currently measurable variables which represent the *initial conditions* of the past, and the actual products of behavior. Hence, any one point in space has the probability (based on an expression of the initial conditions) to be either a *site* or a *non-site*.

A predictive formula, as constructed in a correlative model, though, lacks two key elements; causality and cognition. Obviously, correlative modelers are not assuming that there is no human agency or decision-making in site selection. Yet, the nature of the reductionist statistical analysis used in such models precludes any attempt to understand what cognitive steps are actually present in the process.

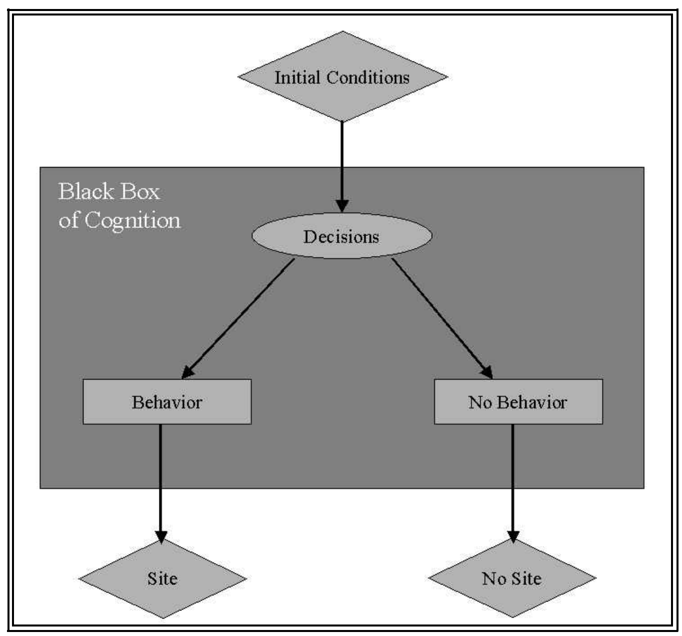

Figure 1. Site selection in a correlative model.

If we graphically represent the nature of site selection as envisioned in a correlative model we see several primary constituents (Figure 1). First, the initial conditions at one point in the landscape; meaning those variables which had some role in determining spatial behavior (not just environmental ones). And second, the products of that behavior; either a site or no site. In between there is an assumption that some cognitive process took place which led either to the behavior which caused the deposition of the site, or to the absence of behavior. Absence of a site in a correlative model implies the absence of behavior, or at least lesser importance to us as archaeologists. This makes the assumption that we are concerned *only* with the physical products of the archaeological record itself.

The intermediary steps, though, are not the object of concern for correlative models. By empirically showing the correlations between sites (or non-site localities) and the modern proxies for past initial conditions there is presumed to be no need for understanding the in between step of cognition at all. Thus, correlative models place this process in what is essentially a "black box." Cognition is implied, but is of no direct consequence for identifying correlations. In addition there has been no attempt at understanding the relationship between behavior and the deposition of artifacts or features; it is assumed that there is a direct correlation.

If we recognize the black box of cognition for what it is (namely a causal Bayesian network; cf. Pearl 2000:21-26), we can begin to fill in the various elements which describe its mechanisms. These mechanisms can be expressed as units which are causally related to each other; conceptually presented in Figure 2.

Each of the components in this network can be classified as belonging to one of three different categories:

- *Conditions* - those characteristics which can be (or were at one time) observed in the landscape (or more properly the land unit under evaluation).
- *Events* - a behavior, or action, bounded in space-time which is typically not directly observable today, but which may have physical consequences (conditions) that are at least partially observable.
- *Decisions* - cognitive choices which took place at one time in the past (or are made today) which bridge the gap between observations of conditions and the activity of events.

Contrary to the simplistic conceptualization used by correlative models, the causal network of site selection decision-making involves numerous interactions of conditions, events and decisions. It becomes quite easy to see how limited the ideas of correlating sites and environmental conditions are when a causal explanatory examination of the process is employed.

The Causal Network of Site Selection

The first event in the process is the *interface*. All conscious and subconscious spatial decision-making is a factor of the interface between the actors (those making the decisions) and the initial conditions under observation. This interface represents the acquisition of information. It can be either *direct* (as in something perceived with the immediate senses; vision, hearing, taste, touch, and smell) or *indirect* (information gained from other sources; second hand description, previous experience, or pure speculation). All of the direct and indirect interfaces together represent the cognitive process of *perception* (or acquiring knowledge).

After perception, each initial condition is classified (either consciously or subconsciously) with regard to its beneficial or adverse effects on site selection. These categories would include; those conditions having a *direct benefit* or *direct cost* for the behavior, those having *indirect benefit* or *indirect cost*, and those that have *no cost or benefit*. A direct cost or benefit would include variables which have immediately perceived advantages or disadvantages. These might include the presence of a prime resource, close proximity to trade routes, or good visibility of the surrounding region for defensive purposes.

Those variables which have no benefit or cost immediately obvious to the actors involved, but are distinctly related to variables which do, would have an indirect bearing on the behavior. Such variables might include a soil type (in which the soil is not a selected resource, yet certain soil types are auto-correlated with the high potential for gathered plants, crops, or other kinds of resources), or a high mountain range (which may help provide a level of predictability useful for avoiding encounters with neighboring groups). Of course, any one initial condition may have both direct and indirect bearings on site selection.

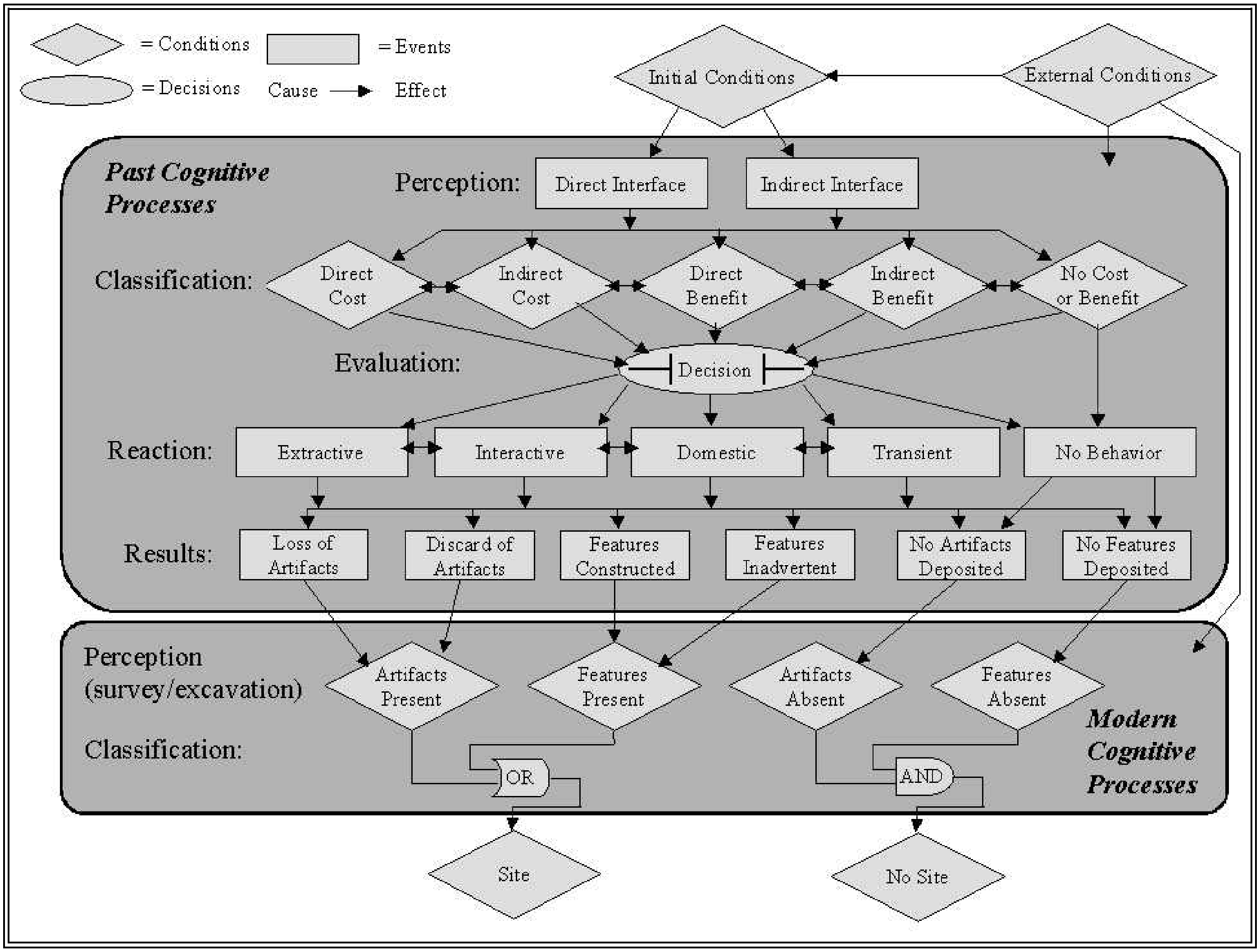

Figure 2. Site selection in a cognitive model.

Those variables with no direct or indirect cost or benefit to the behavior may be typically ignored, but a key factor of the cognitive process of *classification*, is that some conditions might also affect the costs or benefits of other conditions. Thus, even though something may have no bearing on the behavior, it may affect how other direct or indirect variables are perceived and classified. For example, extracting lithic resources in a given area may have no visibility limitations, but atmospheric haze on a single day could prevent full direct perception of a beneficial or costly spatial variable and the extractive behavior could be altered. Similarly, social relationships may increase or decrease access to spatial information, or change its accuracy.

The next cognitive process is that of *evaluation*. Once conditions are classified a decision is made regarding whether to carry out some behavior in the land unit under evaluation. That determination is not based on one cause and effect relationship with a single variable. But, in effect, it is a decision which is triggered only when sufficient information has been processed through evaluating a number of influential variables; presumably all of those which have a direct or indirect cost or benefit for the behavior. In actuality, it is likely that many behavioral decisions were made on the basis of partial or incomplete information. Thus, the process of evaluation may be considered a “fuzzy” decision; in which behavior is indeterministic on yet another level.

In the final probability assessment, it is this very decision which is being modeled. A probability formula should, then, be as explanatory and expansive as possible, and not a reductionist *lowest common denominator* of suitability. In a conceptual framework, this function can be represented symbolically as a capacitor (an electrical device which stores a charge, or cumulative charges, until it is intentionally released). A capacitor typifies the kind of additive, or cumulative, cognitive process of behavioral decision-making.

Evaluation results in a behavior (or set of behaviors) shown here as the *reaction* part of the cognitive process. With regard to site selection there are at least five different kinds of *intentional* behaviors which can be produced. Distinguishing between these kinds of behaviors is critical to understanding the nature of such decision-making and probabilistically assessing where suitable and likely areas for each kind of behavior might lie.

- The first kind of behavior is *extractive*; meaning that the choice of that land unit is due to the presence of some resource or resources (e.g. lithic raw materials, water, fauna, etc.) which provide a clear benefit of some kind.

- The second type of behavior is *interactive*; meaning that the land unit itself may not provide a material benefit, rather it's location is conducive (or detrimental) to interacting with other people (e.g. trade routes, defensive viewsheds, predictions regarding the presence of neighbors, etc.), which is a cost or benefit of an entirely different kind.

- The third type of behavior is *domestic*; meaning the land unit provides conditions suitable (or detrimental) for dwelling, or day to day activities (food production, consumption, discard, etc.). Benefits are largely internal ones (e.g. comfort, internal social structure) and may be highly dependent on temporal constraints.

- The fourth type of behavior is classed here as *transient*; meaning there is no benefit designated by that land unit, but it is assessed as a cost which may be exchanged for benefits which lie in other areas. In other words, the cost of travel to reach beneficial areas.

- The fifth type of behavior is none at all, or more appropriately, *avoidance*. Keeping in mind that site selection decisions are based on processing the spatial costs and benefits of a landscape, some areas may be highly significant precisely because they were avoided. For example, it may be important to understand where sites are absent if we want to envision territorial boundaries.

Armed with an understanding of these behaviors and how they are placed into a matrix of cause and effect, we can see that, in fact, archaeological sites themselves are the product of yet another process; *results*. This is the process which allows us to perceive and categorize the previous occurrence of behavior. In the case of different behaviors, different potentials exist for the placement of what we might recognize as an archaeological site. The two primary components of archaeological sites are *artifacts* and *features*. Certain kinds of behavioral events are more likely to produce the intentional discard of artifacts, the unintentional loss of them, and/or the intentional, or unintentional, creation of features. Once again, they have effects on each other as well.

But artifacts and features are not uniformly representative of past behaviors. In fact, some highly significant spatial behaviors result in the deposition of no artifacts or features whatsoever. Likewise, preservation of certain kinds of materials strongly affect how we see archaeological sites as representative of behaviors. One of the key elements of understanding this causal network is the recognition that interesting and important cognitive processes may result in the use of land units, or vast landscapes, without any archaeological component being deposited. This must also be distinguished from the avoidance of areas for entirely different reasons.

This brings us to the second layer of cognition within the site selection framework; that series of cognitive processes carried out by us as archaeologists. Past cognition does not result in "sites" per se, rather in spatially dispersed material results which unevenly represent many incidences and several broad categories of past human behavior. Our modern cognitive process of perceiving these material byproducts (through survey and excavation) and classifying them into meaningful clusters (i.e. sites) completes the causal chain from the initial conditions to our typical units of study. The classification of sites is symbolized in Figure 2 by the use of logic gates. A site is classified by the presence of artifacts OR features (or both), while the absence of a site must be signified by the absence of artifacts AND the absence of features.

Of course, the chain of cause and effect can be carried out to include our evaluating archaeological sites for their significance to heritage management, our reactions with different kinds of preservation or management behaviors, and the results of our efforts on understanding specific cultural landscapes and the archaeological record in general. Thus, we see a perpetuation of the same overall cognitive processes of perception, classification, evaluation, reaction, and results, using the same categories of conditions, events and decisions.

Throughout, the process we can also recognize that every condition, event or decision, is affected by external conditions, and presumably external events or decisions as well. This representation of the processes of site selection is a mere simplification of one aspect of a very large dynamical system (i.e. culture). Other processes (including non-spatial ones) may be framed in quite different ways, with very different kinds of behaviors resulting from evaluating different initial conditions. What we consider here as "initial" conditions, are in themselves the results of other processes, including large scale geological and environmental processes, but also previous cognitive processes (not the least of which are earlier incidences of site selection). Ultimately, though, how do we turn this into a practical causal explanatory probabilistic model?

Modeling Site Selection

Let us consider what we are modeling to begin with. Based on the discussion above, it is clear that we have a causal framework for site selection laid out. To this point it is entirely conceptual and no actual probability values are entailed. A key point is that the central decision (symbolized by the capacitor) may be an accumulation of the causes and effects of a series of conditions, decisions, and events but the output is a single behavior, not an archaeological site. That behavior, not the presence or absence of a site, is the product in the probabilistic formula. Therefore, the starting point for determining the operators, constants, and variables in the decision is to understand what behavior is being modeled.

Most regions (especially in Europe) have had long periods of human occupation which have resulted in complex sequences of diverse archaeological deposits. These deposits are the byproducts of the kinds of behaviors outlined above. Researchers who work extensively in specific areas are well versed in the nature of the archaeological and historical records from their region. They are in the position to build explanatory arguments about site selection based on their experience and knowledge of regional settlement patterns, socioeconomic models, research topics, and ideas about human-spatial interaction. This "expert system" is largely in place and merely needs to be expressed in specific quantitative terms to be useful in a probabilistic model.

But how do you quantify these systems, especially strictly social or cognitive variables? The theoretical basis for modeling cognitive processes is dependent on the use of spatial proxies (Whitley 2002). All variables used in GIS analysis are in effect proxies, or mathematical representations of physical data. Digital Elevation Models are exactly that; *models* for elevation, not actual measurements of it. Elevation values are calculated, in a variety of ways (e.g. kriging, inverse distance, etc.), based on samples of measured points. Elevation as a concept, is itself, based on an arbitrary baseline (mean sea level). Similarly, every environmental variable currently in use is the result of modeling spatial information based on sampled locations.

Any GIS surface is an expression of information for every spatial location in the dataset. For points, lines and polygons, that information is linked to discrete objects. For raster data, it is expressed as a value for every point on a regular grid. On a raster plain, we might have one location which represents the actor in a cognitive process (perhaps an individual making a spatial decision of some kind). His or her ability to make that decision is a factor of their perception of that plain (i.e. the interface with initial conditions). What can they perceive directly about their surroundings? What indirect information do they have?

Direct perception can be modeled using existing GIS tools, like viewsheds and proximity analyses. Depending on how you use such models, they can be proxy representations for any number of cognitive perceptions (including the five senses). In addition, direct perception is a factor of time spent in proximity to the condition under observation. Therefore, we must assume that, in general, the level of detailed direct knowledge of a spatial area (and its conditions) is inversely proportional to the distance from the source and the amount of time spent in the manifold. In other words, we know first hand a lot more about those spatial areas which are close at hand, and within which we spend the majority of our time. In a real topographic situation distance can be replaced by cost-distance, since ease of travel plays a major role in determining spatial access.

Indirect perception (such as spatial knowledge gained from secondary sources) may be unevenly distributed (depending on what those secondary sources are) or assumed heuristically based on previous experience. The primary difference between direct and indirect perception, though, is degree of certainty. How sure are we that the information is accurate? We are always more confident of that information we perceive first hand, and much less so for that which we gather from other sources.

Interaction with neighboring groups, territorial boundaries, and many other aspects of indirect perception are the kinds of attractors which can be spatially modeled on the basis of expert systems knowledge applied to spatial statistical tools. Proxies for territorial boundaries, for example, can be expressed as the interface between two cost-distance evaluations (Whitley 2000). Social classification of landscapes can also be modeled on different linguistic or conceptual ideas, such as point-fields or polygons (e.g. Lehman and Herdich 2002). Similarly, least-cost paths, hydrological analysis, elevation, density and surface analyses can all be applied to conceptual data to produce proxies for perception.

In addition to the accuracy of first or second hand information, the variables themselves have inherent levels of predictability. Distinction between the dynamical categories of *fixed point*, *periodic* and *strange attractors* is a key to evaluating predictability (cf. Whitley 2000). Fixed point variables (such as lithic sources) are highly predictable, while periodic ones (such as migrating herbivores) are less so. Strange attractors (such as neighboring groups) are typically quite unpredictable.

Predictability also carries with it an inherent assumption of temporal asymmetry; in other words predictability is the diachronic expression of spatial confidence. Ideally, a complete perception surface should consist of knowledge multiplied by spatial confidence multiplied by predictability.

Spatial statistical tools can be used to simulate perception in these ways. However, to employ perception surfaces in a probabilistic framework they need to be standardized. Using map calculator functions it is a minor effort to transform any perception surface into a range of 0 to 1; representing no perception to full and accurate perception. Exponential or other transformations of this data can easily be employed where they might be applicable. Each variable is unique and should be treated in a unique way, but with respect to how we believe they may have been perceived in the past.

In the classification stage of site selection, the actors sort what they perceive into categories that have costs or benefits for the modeled spatial behavior. High benefit does not imply low cost, and vice-versa, rather costs and benefits for behavior are two very different distinctions and should be modeled as such. Every spatial evaluation is the product of a cost-benefit analysis, strongly influenced by the perceptions which preceded it.

For the purposes of modeling site selection, the key is that we would also need to standardize cost-benefit surfaces for use in a probabilistic assessment. This means that every point in the manifold may have an expression of how costly or how beneficial the modeled condition is perceived to be. Most effectively, this can be modeled with a standardized range in values from -1 to 0 for costs (highest possible cost to no cost) and 0 to 1 for benefits (no benefit to highest possible benefit).

The nature of site selection is based on an understanding of costs and benefits for each variable (ranging between -1 and 1) multiplied by the perception of each variable (ranging between 0 and 1). The combined cost benefit/perception surface then represents the cognitive conception of that variable which is presumed for the individual decision-maker (Figure 3).

Modeling a single cognitive variable in a GIS then becomes and issue of determining:

- The focal point - Where is the decision-maker located in the spatial manifold? This may be a

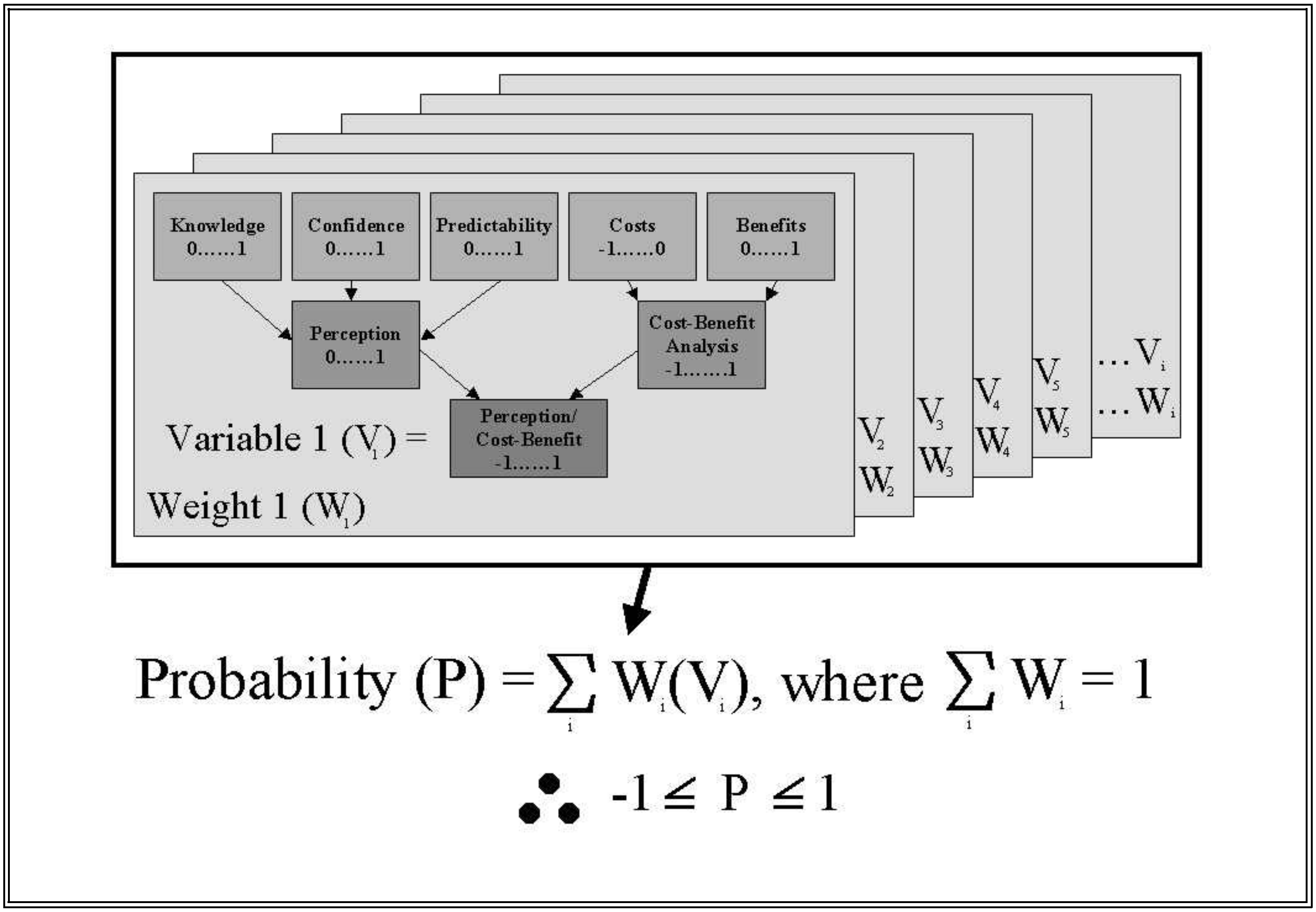

Figure 3. Calculating probability.

point location at one given time, but may involve a series of points, a line, or a polygon over several periods.

- Perception - What is the most appropriate depiction of cumulative direct and indirect knowledge regarding that condition? How does confidence and predictability factor into the equation? The result should be a surface which includes grid values ranging from 0 to 1.

- Cost-Benefit - How does the condition under observation relate to the ability to carry out the modeled behavior? What are the costs involved? What are the benefits? The result will be a surface ranging between -1 and 1.

It should be noted that, in a conceptual cognitive model, it is not merely social variables which are modeled as standardized values in this fashion, but environmental ones as well. Slope and distance to water, for example, are not modeled as values represented by the raw data. Instead, they are also represented as cost-benefits multiplied by perception.

To model the entire process of site selection then becomes a matter of combining the results of all individual modeled variables for that behavior (see Figure 3). This is carried out in the same fashion as any other weighted additive model (cf. Kohler and Parker 1986). Determination of the weights becomes another issue for the expert system, but with all variables standardized it becomes a simple process to produce many variations of individual weights simulating different levels of importance. All of the weights can be most effectively expressed as proportions ranging between 0 and 1, with the sum of all weights equal to 1 (100%). A single formula, then, could be produced by summing each variable (i.e., the cost-benefit/perception surface) multiplied by the projected weight for that variable. The resulting surface would then include probability values for every grid point ranging between -1 and 1 (no potential to very high potential).

Discussion

I would argue that in this fashion there is actually no spatial variable which cannot be modeled, be it environmental in nature or strictly cognized. As long as there is a spatial component, it can be simulated in the GIS. Granted, the accuracy of some cognitive variables may be quite questionable in some contexts, and projections about perceptions and cost-benefits could be misleading. Similarly, weighting of individual variables in the model is subject to interpretative experience. However, it is the purview of regional experts to make these decisions, and interpretations of specific behavioral patterns must be addressed in the context of a causal explanation.

One could rapidly produce hundreds of formulas based on the same variables and test each of them against the dataset of known archaeological sites. With such a mechanistic approach to causal explanation it also becomes possible to use small datasets of known sites. This allows a comparison with other probabilistic formulas, and a great deal of understanding of the nature of human-spatial interaction. With a strictly correlative and deterministic approach we would have been unable to generate a formula at all for such datasets, and would have made the assumption that no significant behavior occurred.

Now, this process is, in fact, quite similar to *land evaluation* (Kamermans 2000), however it differs in two ways. First, by the incorporation and quantification of social or cognitive variables. Land evaluation as discussed by Kamermans (2000) was keyed only to environmental characteristics related to agricultural or pastoral productive capacities (i.e. extractive behaviors). In this model, I believe that each land unit has capacities for many different kinds of behaviors. With standardized cost-benefit/perception surfaces almost any kind of spatial behavior can be modeled, not just extractive ones.

The potential is there to model everything from very specific activities to very general trends. Because the probability surfaces are standardized to range from -1 to 1, it doesn't matter how many variables are included or excluded from the analysis. Accuracy and precision can be judged on a post-model comparison with known sites or by peer consensus (in cases of very restricted occurrences or behaviors which may have left little or no archaeological component).

The second way in which it differs from land evaluation is in the sense that it is focused. In other words, since perception is based on a focal point, or a spatial limitation of cultural or temporal affiliation, suitability surfaces (i.e. those derived by modeling cost-benefit) are qualified by an additional layer of likelihood. This perspective allows, or benefits from, the incorporation of specific historic events, least-cost path analyses, or even the use of spatial proxies not causally related to the behavior being modeled (cf. Whitley 2002).

Heritage Management

In essence, the framework as described above is a procedure for developing representations of *cognitive landscapes* and integrating them into socioeconomic models of spatial utility. Because the framework is flexible, it can be as complex or as simple as we see fit. Since it is causal explanatory, we can address very detailed causes and effects or place them in broad categories. As it applies to managing archaeological heritage we are more likely to develop models which create larger generalizations that are not focused on agency or complexity to the same level of detail as specific research issues, but additional interpretive levels can always be added within the same framework.

In addition to the modeling of past site selection, it should be clear that our modern perceptions, classifications, and evaluations, themselves, are an entirely different cognitive process to model. Each of the intentional behaviors have their own relationship to what we perceive to be archaeological sites and landscapes. In order to manage these resources for future generations of both the public and research specialists, we need to determine what we mean by terms such as *significance*, *preservation*, and *management*.

Only when we know which behaviors are of most interest for management and for research can we begin to make decisions about preservation. It is clear that some sites (e.g. small lithic scatters) may not be as significant as others (e.g. large villages). If we use a single formula correlative type predictive approach, we are relegated to a high-low potential summarization that leaves open the question of: high potential for what? Obviously, it should be more important to manage and preserve certain kinds of sites. Management priority can be ranked on a scale of 0 (no importance) to 1 (highest priority) and multiplied by the site selection surfaces for each behavior type and temporal period producing probability surfaces that incorporate both behavioral and management issues.

Similarly, the condition and post-depositional alteration of land units strongly affects how we identify and manage archaeological resources. In fact, on-going and past disturbances are processes which need to be modeled in their own way. The probability surfaces related to behaviors and the management priorities are strongly affected by what has been left undisturbed to date. If we examine the number and kind of disturbances and what their affects have been (or might be) on each land unit, they too can be scaled between 0 (completely destroyed) to 1 (no disturbance) and multiplied by both the management priority and the site selection surfaces.

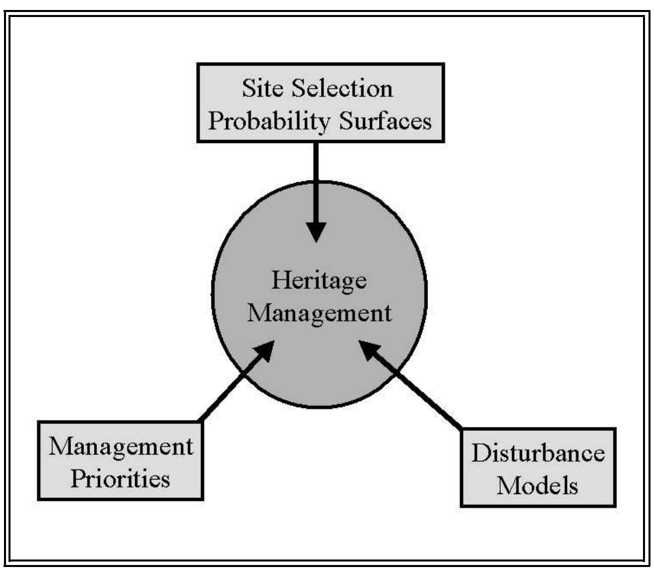

Figure 4. Intersection of models for Heritage Management.

The full probabilistic assessment of site potential in a heritage management situation is an intersection of three different models; *site selection*, *management priority*, and *disturbance* (Figure 4). In a research context, the latter two models need not apply, however, they could be used as the driving force for setting research trajectories.

Conclusions

Placed in the context of the earlier discussion of theoretical and practical dichotomies within typical predictive models, the approach outlined above has the following characteristics:

1. *Management and Research* - It is applicable to either situation. Management applications, in practice, would be more generalized and incorporate greater detail in priority and disturbance models. Research applications might emphasize more agent-based variables and highlight very specific behaviors.

2. *Causal* - It employs a clear use of cause and effect relationships outlined in a Bayesian network (cf. Pearl 2000).

3. *Explanatory* - It uses a causal-reference model of scientific explanation (cf. Salmon 1998) that allows an understanding of statistical relevance and is based on logical relationships.

4. *Cognitive* - It elaborates and quantifies the processes of cognitive decision making, based on a logical understanding of observed and implied cause and effect, and thus fits entirely within the realm of Cognitive-Processualism (cf. Renfrew 1994).

5. *Indeterministic* - It does not rely on determinism or strictly ecological variables and large populations of site types or characteristics. It allows agency, complexity and the acceptance of human free will.

6. *Probabilistic* - It incorporates both likelihood of use (i.e. perception) and suitability (i.e. cost-benefits), hence it provides not just possible areas of site selection, but probable ones.

Ultimately, I think causality-based cognitive probabilistic modeling provides the best theoretical and practical approach to managing archaeological resources and building cognition and decision-based research trajectories. Though it involves a more complex means of quantifying and standardizing individual variables, based on expert systems knowledge, it provides a better payoff in terms of explanatory understanding of both site selection decision making and cognitive processes in general. This in turn is the very reason why our archaeological heritage is "...both a source of the European collective memory, and ... an instrument for historical and scientific study" (van Leusen et al. 2002:1).

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