

E.S Lohse

Measuring Prehistoric Strategies: Flakes, symmetries and balance in stone tools.

Department of Anthropology, Idaho State University.

Lohsern@isu.edu

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Introduction

Recent work has highlighted potential for research into how stone tool technology reflects conscious problem-solving in designing and implementing strategies for extraction of resources relative to survival. Intriguing observations and questions abound but a straightforward and productive venue can be phrased relative to two basic propositions: (1) complexity is reflected in ability to design and perform series of steps to manufacture and use stone tools relative to practical requirements in extracting energy; (2) prehistoric problem-solving is recorded in manufacture and use-wear diagnostics preserved on the surfaces of stone tools. These propositions can be addressed through an explicit interpretive framework that forces analytical protocols that harness high tech computer hardware and software applications that can explore the surfaces of stone tools at very high levels of resolution. These applications can record and map surface diagnostics that reveal discrete decisions of prehistoric knappers and users of stone tools. Careful examination of tool surfaces records stratigraphic overlays of evidence of manufacture, attrition resulting from use, and overlapping residues, all indicative of discrete steps in problem-solving. Applying these techniques to stone assemblages spanning important periods identified in hominid evolution shows high promise for refining measures of evolving cognitive complexity. Applying these techniques in hunter-gatherer research can provide insights into questions of differential energy investment in the

extraction of resources as in documentation of extensive versus intensive procurement strategies.

This study draws upon accepted models for human cognition and learning and prior assessments of cognitive complexity drawn from analysis of stone tools. Postulates are presented to guide future research based on analysis of stone projectile points diagnostic of Paleoindian and Archaic periods in northwestern North America. These mark periods thought to evidence a shift from highly mobile societies focused on harvesting game herds to relatively less mobile societies harvesting a broader range of resources in a more limited area. Societies in the two different stages are also thought to have shifted resource extraction strategies in line with increasing population densities on progressively less lenient resource landscapes. Shifts in extraction strategies and in more or less intensified use of specific resources relative to operational parameters imposed by climatic changes and rising population densities should be reflected in the decisions central to manufacture and use of stone tools. Factors include materials selected, adherence to design specifications, investment of energy in creation, and use and re-use of stone projectile points.

To explore these issues we must understand how humans plan, design, implement and modify technological systems relative to demands of their physical environment and precepts and standards set by their cultural systems. The knappers of stone tools and the users of stone tools are exemplars of their societies and the tools are made and used within strenuous cultural parameters as well as within simple expedients of resource capture.

Models for Cognition and Learning

A principal form of mental representation is use of cognitive mapping (Smyth et al. 1994). Individual routes are linked to form encompassing maps or plans (Appleyard 1976). This mapping, however, often lacks specifics and tends to simplify complex actions greatly (Byrne 1979; Tversky 1981). This process is labeled chunking, and entails the macrolinking of scripts with cognitive maps (cf. Hampton and Morris 1996:158). In this view, knappers map out stratagems that produce requisite goals within proscribed actions defined by traditional knowledge. Correct routes are developed and variation in stratagem or production is confined by known solutions and marginal innovation. A knapping tradition then is seen as grounded in accepted experience or knowledge, and actions occur within schemata and scripts needed to follow defined routes.

Norman (1981) proposed an activation-trigger-schema (ATS) model that controls action sequences. Each knapper has a large number of schemata or organized knowledge sets, which include procedural knowledge to control

motor activity. Schemata have limited ranges of knowledge and per force many schemata must be linked and controlled under higher level schemata. The higher order parent schemata establish intention. The duration required for completion of an activity requires several intentions to be active at the same time. The well practiced skills of the expert knapper will require specification of only the higher level schemata. Activation of the lower level components of the action sequence will cause completion of the action without intervention of higher level schemata except at critical decision points. Each activated schemata has set specific conditions that are required for it to be triggered. Schemata are prompted by higher-level schemata and by environmental cues. Once activated, the schemata must be triggered by appropriate conditions. The skills actions are employed without thought as knowledge applied to practical problem.

Development and use of schemata separates expert and novice knappers. A knapper's developing expertise will channel or construct what is and what is not recalled. Use of schemata allows rapid classification of what is seen or heard as either familiar and normal or unusual and needing attention. Schemata also provide indices for efficient recall. Studies of expert and novice actors' recall of complex events like sequential moves in a chess match show that experts outmatch novices 4:1 (DeGroot 1965; Chase and Simon 1973; Chi 1978; Baddeley 1990). Chase and Simon's (1973) study showed that chess masters memorized larger groupings of pieces at a glance, chunking meaningful relationships of pieces involved in attack, defense, and support contexts. Similar studies have produced comparable assessments for games of GO, baseball, and soccer. Interestingly, Morris et al. (1985) showed a very high correlation for real soccer scores drawn from actual matches and significantly lower correlations for simulated scores. These authors also found a high correlation for correct recall based on emotional attachment to the teams involved. Studies have shown that we are best at recalling standard schemata and scripts, and that we are good at recognition and poor at specific context of actor and action. Chunking inside scripts allows us to store less information and yet be able to reference observed information quickly. Scripts facilitate information processing and action. Expertise sharpens recognition, information storage and retrieval, and speeds application to problem. A stone tool tradition is essentially schemata or knowledge applied in standard scripts for action in problem-solving contexts.

Results of an action or set of patterned actions for completion of a task must be assessed as successful if a skill is developed or improved. Feedback on the state of action and its success is important for skill acquisition and improvement. Feedback is portrayed within open and closed loops. Skills that can be modified by feedback during performance are known as closed loop. Other actions, particularly those that are performed at high speed or are highly automated, are often not readily modifiable during performance, and are described as open loop. Open loop skills can be modified by knowledge

of their success but only by chaining the next attempted action. A good indicator of the modifiability of skill performance is simply speed at which the action takes place. Christina (1970) suggested that a minimum of 200 msec was required to make use of visual feedback during performance. Smith and Bowen (1980) have suggested 100 msec. Any movement faster than this is unlikely to be modified during performance through visual feedback. Many skilled actions, once acquired, do not require significant feedback during performance. Henderson (1975) identified two principal types of feedback: kinesthetic and intrinsic. Kinesthetic feedback entails constant monitoring of physiological systems to ensure proscribed motor response. Intrinsic feedback is any information that comes as a natural consequence of the action itself. A large part of intrinsic feedback consists of visual information. Another source of feedback is termed extrinsic or augmented feedback, which consists of information beyond what the individual experiences such as feedback from a coach or mentor. One of the simplest and yet most important skills is hand-eye coordination where we move our hands in a proscribed manner to accomplish a specific task. Fitts (1954) demonstrated that there is a direct relationship between the speed with which a movement can be carried out and the distance to be moved and the size of the target. This relation has been phrased as Fitts Law (movement time is proportional to the logarithm of twice the distance to be moved divided by the target width) (Keele 1981). The smaller the target, the slower the movement, and the more time elapsed before movement is initiated (Klapp 1975). Welford (1968) found that movement toward targets consists of two components: the ballistic movement and the honing phase. The ballistic movement is fast and encompasses most of the distance from starting point to target. The honing phase requires institution of control as distance to the target narrows. Visual information, of course, becomes increasingly important as distance to target narrows.

Plans and goals shape our behavior in a dynamic hierarchical system that constantly shifts and changes as it responds to environmental cues. Our behavior is organized to fulfill our plans, and our plans will change or fail constantly. Miller et al. (1960) emphasize that our lives have structure, and that we constantly construct plans to facilitate movement large and small. They admonish that relationship between individual and environment is significant but that interactions are complex and depend to a large degree on the knowledge or conceptual framework of the individual in the environment. Individual behavior is seen as being organized simultaneously at several levels of complexity. Miller et al. proposed two general concepts: the Plan and the Image. A Plan is any hierarchical process that can control the order in which a sequence of operations is to be performed. An Image is all the accumulated, organized knowledge that the individual has about his or her self and his or her relationship with the cultural world (world view and physical environment). Any individual has a store of Plans for potential use. Executed plans are processed in a quick-access working memory, which

serves to store steps completed and plot actions to be implemented. Miller et al. built a Test-Operate-Test-Exit unit or TOTE to model planning and action. This is a simple flow chart that outlines transfer of control of processing through series of tests for incongruity with the Plan, employment of a solution operation, and circuiting of test and operation until test conditions have been fulfilled. No incongruity brings implementation of the next stage in the program. TOTE units will be assembled in hierarchies, which embed lower level instructions within higher levels of the Plan. Hierarchical plans resemble schemata, which organize past experience in interpretation and control of actions. These schema were assumed by Bartlett (1932) to be operative in any well-adapted response. Action models often utilize schemata rather than Plans and TOTES, because these emphasizes feedback. Feedback, while important, is complex to model, and some researchers argue that emphasis on feedback obscures definition of the operative stages of the TOTE. The use of schema theory lessens the chance of continuous looping within the test under study.

Heuristics are the most common problem solving methods. Newell and Simon (1972) have used means-end analysis to construct a computer simulation program called the General Problem Solver (GPS). This simulation essentially breaks down the main goal into subgoals. At different junctures the disparity between current state and end goal is assessed, and appropriate subgoals for successful movement are identified (Anderson 1985). This system has been successfully applied to puzzles. Eysenck and Keane (1990) have argued that GPS may not be applicable to real life problems that involve far more background knowledge than puzzle problems. In real life, the end goal is often not known or only vaguely identified. Real world problems are often ill-defined and require considerable knowledge manipulation. There are also often strong emotional ties in real life problems that negate wider ranges of logical movements or solutions. A significant bias is the difference between novice and expert problem solvers.

Experts solve problems with greater speed and ease, make fewer meaningful errors, and can tackle more complex problems. Experts need not be smarter, they simply have more knowledge of the domain in question, and are able to maximize employment of well organized knowledge to assess the problem quickly and efficiently. They chunk information by general pattern and relate these to prior patterns assigned meaning in similar contexts. They then are superior at processing problem-relevant schemata or knowledge structures.

Creative thinking, in general, is based on ability to produce novel and appropriate ideas from old mental structures. Keane (1988) has shed light on reactive thinking via investigation of analogical thinking. Key insights emerge by likening one thing to another and using that analogy to explore unnoticed aspects of the problem domain. Links between problem solving and memory seem absolute. Information about the problem and the knowledge from which

the analogy is generated have to be organized so that the two domains can be brought together and compared simultaneously. Schank (1982) has shown that reminding and analogy are the key processes in memory and form at the highest levels of abstraction Thematic Organization Packages or TOPS. TOPS are used to link disparate ideas. Creative and analogical thinking clearly relies on the ability to recognize and exploit common structures or patterns in contexts that seem markedly different in content. Barnes and Hampson (1993) have argued that problem solving relies heavily on general pattern recognition skills as well as on specific knowledge about the problem domain.

Cognition normally follows well practiced routes, with little need for conscious thought. This has been described as the skill stage, wherein normal routines are successfully run (Rasmussen 1986). At some step, however, there will be an error, representing the potential inadequacy of learned habits. Here, we move to the second level which Rasmussen terms rule-based. The individual examines the current situation and draws from memory rules that might be applied. The next stage Rasmussen terms knowledge-based, wherein the individual deduces new information given basic principles and knowledge of the situation. Problem solution requires adequate representation. Then a goal must be set. This allows the individual to call up a vast body of knowledge that might be successfully applied. Mental operations may then be performed that manipulate part of the problem. Any of these four elements may fail, and lead to inappropriate strategies for problem solution. Most often, our representations-goals-past knowledge-methods are appropriate. This represents the success of the individual's cultural praxis or solution framework.

Unsuccessful strategies often result from inadequate representation of the problem. Goal formation can often be inappropriate because the problem-solver seeks to link current state to goal state at too fine a level or correspondence. It can be seductive to match the current state to the desired end state as a suitable heuristic or rule (i.e., normal enforced). Inappropriate use of past knowledge also often encompasses enforced normalcy, where the individual insists on classifying and perceiving objects in terms of their normal uses. Maier (1931) coined the "two string problem" where participants were put in a room with two strings tied to the ceiling. They were instructed to tie the two strings together but the strings were too short for the participant to hold onto both at once. The room held various props including chairs and a pair of pliers. Most participants tried the chair but couldn't solve the problem. The solution was to tie the pliers to one string, and set the string in motion with these as the pendulum, which would allow the participant to move to the other string and catch the pliers, thereby allowing the strings to be tied together. Problem-solving then required the participants to change their view of pliers to pendulum. Duncker (1945) referred to the inability to envision alternative uses of everyday objects as functional fixedness. In this example,

Duncker asked participants to place a candle on a door. He gave them a candle, a box of matches, and some drawing pins in another box. The correct solution was to pin the drawing pin box to the door and use it as a platform for the candle. Participants often failed because they could not envision the box as a candle holder. Birch and Rabinowitz (1951) demonstrated that repeated use of an object in a normal context dulled participant's vision of use of the object in a novel context. Conversely, novel uses for objects are enhanced with exercises that minimize functional normalcy and presents hints of alternative uses. Cofer (1951) shows that when participants had learned words like rope, pendulum and swing in a memory experiment prior to Maier's two string problem the likelihood of success was increased. Successful completion of the problem, of course, becomes part of the participants' knowledge base and will be used in ensuing experiments.

Stone Tool Schemata

Schemata and scripts act to channel actions but they also serve to sharpen memory (Alba and Harder 1983). Schemata guide the selection of what is being encoded. They allow abstraction of information and thereby streamline storage. They enhance interpretation by providing relevant prior knowledge to aid comprehension. They also importantly, provide integration by forming a single, holistic memory that links the three previous operations. Schemata provide the framework for storing, retrieving, and implementing knowledge. Schanks (1982) added to the conception of scripting activities and behaviors, and included plans, scenes, memory organization packets (MOPS), and thematic organization points (TOPS). Plans cover specific motivations and goals, and are a low level in the cognitive structure. Scenes involve a setting, a goal and actions designed to reach a specific goal. Each scene becomes part of many memory organization packets. Higher level analogies are linked at thematic organization points. Although critics of schemata theory suggest it may be too simple for describing complex events (Alba and Hascher 1983), this conception seems compelling for modeling stone tool manufacturing strategies.

Knappers employ stone production strategies that reflect extant cultural patterns, practices and expectations. As part of tool-making traditions, artifacts are realizations of mentefacts. These mentefacts include design and production solutions geared to culturally proscribed goals and norms. Extant knowledge frameworks are schemata (Bartlett 1932). Schemata are built through experience that guides the interpretation of new information. Schemata also act to control participant's actions. This maintained knowledge base corresponds to Minsky's notion of a frame and represents effort expended to structure chunks of knowledge. Schank and Abelsen (1977) identified scripts that we use to make habitual sense of commonly experienced structured events. Use of these schemata and scripts allows the

knapper to make sense of what to do next as the inherent basic part of planning and problem solving.

Skills once acquired, are often assumed, but in reality, acquisition of finely patterned sensory motor skills can be tiresome and frustrating. Knapping is a motor skill that requires use of sensory information to select and modify movements. It is also a conscious intellectual exercise or cognitive skill that depends on processing information as schemata or scripts to establish routes for task completion. Explanation of how to flake stone is relatively easy but successful manufacture of stone tools is difficult. Propositional knowledge refers to knowing facts while procedural knowledge is knowing how to do something. Of course, having procedural knowledge does not grant the knapper or researcher propositional or declarative knowledge (i.e., old axiom that “those who can’t do, teach”).

Practice is key to developing procedural knowledge, and improvement with practice appears to be a logarithm of the time taken to carry out the exercise. Skill is seen to decrease in direct proportion to decreasing amounts of practice time (Seibel 1963). This relationship is called the log linear law of practice (Newell and Rosenbloom 1981). A principal feature of skilled performance of a motor skill is economy of effort, including experts being better at sequential organization and coordination than novices. Another feature of practice is fine tuning of parameters needed for controlling movement. Practice also builds capacity for chunking information.

Stages in skill development have been defined (Fitts 1954; Fitts and Posner 1967). The cognitive phase depends upon understanding what is involved in a particular action sequence. The learner needs to consciously recognize environmental cues and identify movements to be implemented. During this phase, instructions and demonstrations are essential. This is a period of learner concentration and task experience requires considerable effort and memory load. The learner will struggle to perform several new actions simultaneously and will be unable to extend outwardly as in casual conversation during the task. The learner is developing propositional knowledge necessary for the skill. This is a period of memorization, where the individual is developing procedural skills for implementing knowledge smoothly. The next stage is the associative phase where parts of the required skill are tried out and a set of appropriate actions are assembled. This is when the learner develops control over the exact movements of the hands or other body parts for the proscribed sequence of actions. Old models are applied and new patterns are developed in this phase. This is the time when practice applied is critical: chunking of information, integration of skill components, and tuning for a specific task. The last stage is the autonomous phase, wherein the component parts of the skill are increasingly integrated. Expertise is seen in less conscious selection of plan and movement. Skills in this stage can be carried out simultaneously with other activities.

The work of Schneider and Shiffrin (1977) offers insights into skill acquisition that are informative for lithic analysts. These authors distinguish between controlled processes (Fitt's cognitive stage) and automatic processes (Fitt's automatic stage). Control processes have limited capacity and thus only a limited amount of such processes can take place at one time. Control processes also required conscious attention. They are, however, flexible and can be employed in differing circumstances. Automatic processes enhance capacity and require little conscious attention, but once learned they are very difficult to modify. The hard won development of expertise requires at first formal training in a tool making tradition, and then once learned and automated to the expert level, knappers will find it very difficult to abandon unconscious schemata, plans, and stratagems for effective action. Tool making traditions are recognized by archaeologists simply because of the conservatism attached to the learning of complex skills like flintknapping.

Bartlett (1932) and Schmidt (1975) have developed the idea of schemata for capturing skilled movement. Innovations in complex actions are not absolutely new, but rather manufactured out of learned schemata of movement and interrelationships. The general nature of the response to employ is remembered but the particular or new response is constructed within the current framework of interrelationships and feedbacks. Importantly, schemata set expectations of what will happen next and assign importance to particular variables in the perceived context (Neisser 1976). In flintknapping, schema will determine the important actions to be taken given the observed environmental cues. Schmidt (1975) referred to these as recognition schemata that help in guiding movement through generating expected consequences of feedback from the movement that is compared to actual feedback obtained. Henderson (1975) studied expert dart throwers who could give a good assessment of the accuracy of the throw even without sighting simply by feeling the dart leave their hand.

Assessments of Cognitive Complexity from Analysis of Stone Tools

Wynn (1993) described tool behavior as a layered cognitive system comparable to that described by Van Sommers (1984) for drawing. This view models the sequential action of tool behaviors as organized on multiple levels simultaneously. Patterns of thinking and principles of organization at each level precondition actions taken at the next. Wynn proposes that there are three layers of thinking in tool behavior: biomechanical, action sequences, and problem solving. Biomechanics is the lowest level, consisting of constraints imposed by anatomy and physiology. Tool behavior is sequential, with action chains strung together as discrete episodes terminating in results as artifact forms or completed tasks. Gatewood (1985) described learning in this mode as serial memorization on a task by task basis, with no regard initially for systemic understanding. As novices become masters, smaller discrete tasks are strung into larger action complexes, which eventually

become hierarchies of routines and sub-routines (cf. Piaget 1960:121 on sensori-motor intelligence; Greenfield 1991 on hierarchically organized sequential behaviors). Problem solving adjusts behaviors to tasks at hand. Creative application of sequenced behaviors is often described as operation of constellations of knowledge wherein discrete episodes require unique associations of process, materials, implements and desired endpoints (cf. Dougherty and Keller 1982 on taskonomy; Keller and Keller 1991:9). These constellations come into being creatively, as solutions to identified problems. Goals are constantly altered as feedback between the image of the task and the actual events required as part of the process of problem solving are employed. Constellations will be repeated and once conscious tasks encompassing goals and selected elements will be replaced by recipes. Routine will become very strong and artisans will not recognize discrete action chains, only the proper or most efficient way to proceed. Pye (1964:9) notes that ascription to problem solving does not entail the maxim that form follows function, indeed there are a broad set of constraints on forecast successful solutions. Forms are practiced solutions and constitute cultural or individual expressions of learned plans of action (Lemmonier 1986 on traditional technical systems; Sackett 1982 on style in archaeology; Wynn 1989 on the geometry of stone tools).

Artisans fix symmetries in memory in real, virtual and conceptual space. Van der Leuw (1994) describes two significant steps: search for perspective or problem definition and definition of dimensions that afford solutions. The former is nonlinear and time consuming, the latter instantaneous and linear (the recipe applied). Chaines operatoires describe the steps and decisions required to produce a specific end product. These are the activity chains and problem solving processes every artisan goes through in producing successful forms. Schlanger (1994:144) describes this as a trajectory of induced transformations from natural raw material to cultural matter. Leroi-Gourhan (1964:164) asserted that the elementary components and constituents of action are integrated in a necessary and logical enchainement of stages and sequences in the process of transformation. These operations are held to be rigorously chained, each conditioning the next, and are laid out with clear foresight in a problem solving environment (cf. Lemmonier 1976: 106). The chaine operatoire is a trajectory, wherein there are intersections of succeeding, simultaneous and overlapping moments. It is not a linear process though it has a beginning and end (raw material to finished form). There are in fact multiple options within broad parameters and the flexibility to proceed is enhanced with the expertise of the artisan. There may be two kinds of tasks or events: those that are flexible and variable, open to alteration, replacement and idiosyncrasy, and those that are fixed, immutable and strategic in design and execution. These latter cannot be bypassed or deferred without compromising success of the product. These are the strategic moments that give the chaine operatoire directionality, and which can be used to mark the state and processes through which matter and

action interact. Lemmonier (1980:1) defines chaines operatoire as socialized action on matter, where techniques are apprehended through three orders of facts: suites of gestures and operations (techniques), objects (results of actions), and specific knowledge (connaissances).

The application of chaines operatoire to guide lithic research is appropriate because stone is durable, with strong directionality in its reductive technologies, and preserved diagnostics of sequential actions. Study of stone involves work in lithic experimentation and knowledge of the cognitive structure of human behavior. Lemmonier's identifies three orders of facts: objects refers to both tools and other products like debitage; operations as evidence preserved on the tool or in the assemblage and as inferred from replicative work; and knowledge brought to bear including understanding of human cognition (cf. Geneste 1988a, 1988b on Mousterien assemblages as indicative of economic systems of production; Boeda 1988a, 1988b on the concept of Levallois reduction strategies). Crucial is necessary negotiation between the ideal image of the knapper and what can be accomplished given less than ideal material or circumstances (cf. Pelegrin 1990 on the conceptual schema operatoire). Inputs and outputs will interact with one another, and contingent decision making is a normal part of the artisan's work.

There is strong potential for inference from stone tool technology applied to constraints predicated on prehistoric economic decisions. Pelegrin (1991) addresses this when he characterizes a scale of conceptual knowledge (connaissances) acquired by knappers through memorization of concepts (mental representations), memorization of modes of operation, and use of procedural knowledge (savoir-faire) that can be ideational or derived from physical movement. Understanding how the chaine operatoire acts within practical constraints of the prehistoric societies' perception of material and economic choices becomes the goal for constructing strong inferences about past economic behaviors.

Study of Prehistoric Projectile Points as Indicative of Energy Investment

Review of cognitive and learning models and assessments of evolving complexity from analysis of stone tools reveals some useful tenets that can be used to direct future work. Some central propositions include hierarchical decision trees, investment of effort directly related to measures of durability, designed multifunctionality, and curation and reuse. Analysis of stone tools can assess the nature of problem-solving in design decisions implemented through hierarchical decision chains as in the use of chaine operatoire constructs wherein a stratigraphic analysis of the artifact's surface is performed. Analysis can also address issues of durability, multifunctionality, curation and reuse, through assessment of design symmetry, cross-sectional

strength, uniform surface reduction, breakage, dulling and resharpening. Tangential variables include aesthetic qualities like incorporation of high quality materials in production models and integration of natural properties in design parameters as in orientation of long axis to color character. This paper considers several approaches as indicative of explanatory power embedded in stone tool analysis: design reflects mentoring, problem-solving, energy investment and aesthetic sense.

Stone tools (forms, shapes, mass, finish) are storehouses of information. For the analyst, digital images of stone artifacts serve as databases: rich information is preserved in uncompressed files that can be used and reused by analysts to a far greater and more significant degree than can spreadsheets or data fields. For the prehistoric makers, stone tools embodied cultural precepts concerning how things should be made, used, and conserved. Designs in themselves constitute histories of idiosyncratic approaches to invention, problem-solving, teaching and learning. Stone tools are then images: as digital recordings for data preservation and as snapshots of how cultures and their artisans designed their world. A stone tool is a sort of map of how human beings thought about their world, harvested resources, and invested time in extracting food and symbolizing values and aesthetics. They have breadth, height and form: scale, elevation and relief. All can be mapped and interpreted just as one can read a map of a geographical area. Landmarks and distributions of manufacture and use-wear variables are signposts to negotiating prehistoric decision making and intent. Attempts at understanding implementation of stone technologies in this view verge on melding past cognitive structures with those of the contemporary analyst. Signs are not easy to read, however, and the analyst must be concerned with grounding observation and interpretation in an explicit framework that emphasizes robust discriminating variables highlighting universals embodied in material constraints, application of principles of fracture mechanics, assumptions about human teaching and learning styles, and very human concerns about maximizing return for effort invested. Richard Feynman, summarizing the explosion of the space shuttle, made this simple observation: "For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled." (Feynman 1988: 237). The real world has robust material constraints that cross-cut cultural intents. This observation alone signals our ability to understand to some degree what past cultures intended to do.

Today's scientist need not be overly concerned about applying our understanding of guidelines for human behavior to past actors. We are not practicing magic, claiming a mindlink. We are only acknowledging universals in how humans reason in pragmatic and symbolic environments. Close adherence to universals of behavior and natural constraints allow us to extend understanding to the point that we feel we have connection with past design, intent, and use. Past actors may have lived in a magical rather than

scientific world but the two frameworks are remarkably consistent: both offer explanation of action in the face of natural constraint and both adhere to fundamental precepts. Magic after all acts as violating the universal laws of nature while science proclaims understanding of those same laws. Magic requires the same understanding of those universals as does science. Edward Tufte (1997:55) describes magical performances as knowledge revealed about the frontview (what appears to have been done) that fails to yield reliable knowledge about the concealed backview (what is actually done). This is the audience's misdirected assumption about symmetric reliability and this is what makes magic. Comprehensive visual accounts should simultaneously depict the revealed and the concealed. As such, magical explanations are intriguing exercises in design and presentation. Magical and scientific designs are in fact teaching and learning environments, and any good prehistoric mentor would have grounded lessons in the same conjunction of magic and applied scientific principles.

Symmetry

Human beings in learning and working environments respond to features, often labeled as words that serve as codes. Words represent simple and complex features, and these in combination constitute processes. This is a cultural geography of the physical space made up of features and processes. A catalog of features is developed that focuses attention and directs work as in problem solving or everyday movements. What emerges is a cognitive map that is used to enable the human user to move through physical and conceptual space. Classifications will differ but the shared structure enables learning and mutual interactions.

Symmetry is a key feature in mapping cognitive landscapes. Symmetry can take many definitions, but in the sense of making stone tools, refers most specifically to bilateral symmetry as in two halves matching. Other meanings can involve mathematical transformations, rotations about an axis or centerpoint, or uniformness of texture or color on a surface. Humans work in environments perceiving differences or contrasts, and explicit and implicit measures of symmetry are effective orienting features in our mapping strategies. It is important to note though that assessments of symmetry also apply to irregular shapes, surfaces, colors, and any of a wide range of measurable contrasts. It is also important to recognize that breaking symmetry is a powerful teaching and learning tool. Disrupting symmetry is an effective mode of establishing meaning. A break in symmetry marks a feature on an interpretive landscape.

Structures that influence mental activity are strongly constrained by physical realities as when a knapper makes a statement in the creation of a stone tool. The knapper has an ideal goal in mind but must relate actual action sequences to quality of raw material and successful completion of task

moments. Symmetry becomes a powerful referent for measuring skill, assessing cultural conceptions, and establishing meaning. The basis of archaeological typologies is the simple but powerful assumption that “types” exist, that what the analyst perceives and classifies as distinctive forms are in fact close replicas of mental templates employed by prehistoric artisans. Symmetry is a profound measure that connects analyst and maker.

Archaeological types are traits and can be described as features. The analyst apportions reality in this way because human beings activate neural nets in our visual systems through focus on features, on faces, on traits and characteristic parts. Mukerjee (1996) reported on engendering faces, documenting a computer analysis of black-and-white images of male and female faces. Using digital imaging analysis, an average face was constructed. The centerpoint and size of each image was standardized and patterns defined by comparing position and extent of facial features. Eigenvectors were defined and the resulting images were termed eigenfaces (Stewart and Cohen 1997: 174-175). The eigenface is an unusually prevalent pattern in the correction terms to the average face. This is of course analogous to a facial landscape with attendant features arranged according to plan or function. The researchers in the experiment found for human faces a single eigenface, representing the difference between male and female faces in the sample. The interesting slant is that the differences can be portrayed as a one-dimensional set of images, as a single variable measuring the amount of eigenface added or subtracted. Stewart and Cohen cite the example in suggesting that our visual system employs a fairly simple parallel processing mechanism to distinguish male and female by looking at faces. We can use this assumption as archaeologists to assert that the basic concept of symmetry operated over a long span of hominid evolution, and that we can employ symmetry analyses to explore a range of evolutionary and adaptive issues. We as analysts will employ comparable mental maps as part of our wired visual system, and we will recognize past mental templates: our types and the significant features defined can be held to mirror prehistoric models and meanings. We are practicing science, but science is a conceptual map built for human neural nets, and as human scientists we will recognize important faces from the past as we consider tools from the past.

Interpretive Context

Science, in itself, constructs mental maps. A goal of science is to explain the natural world, ranging from simple causality to elaborate chains of explanation. One powerful approach is reductionist, with its focus on internal structure: laws of motion, law of gravity, laws of aerodynamics. The result are general principles that interpret complex phenomena. Reductionism presents a clean cognitive map with meta-features and carefully defined layers of escalating or descending complexity. Another powerful approach is contextualist, where the view shifts from internal to external. For example,

what external constraints molded the object under examination. Archaeological classification can be exceedingly reductionist. We draw up types based on morphology for instance, or correlate morphological types with chronological layers. This type of approach negates any explicit tie with prehistoric cognitive maps, and instead, is simply a handy means of heuristic classification. This is comparable to John Searle's thought experiment of the "Chinese Room," wherein a person seeking to understand Chinese manipulates huge stacks of paper according to rigid pre-prepared instructions. Questions in Chinese come in from the outside, pieces of paper get moved around, and an answer in Chinese will eventually go back out. Yet, we know the person cannot speak Chinese, so we have to assume that real intelligence cannot be reduced simply to a set of underlying rules. The experiment rests, of course, on a false analogy. A proper inference would be that the entire room, rules, paper-pusher, etc., is analogous to a person who understands Chinese. The person in the room would be analogous to one nerve cell in a Chinese speaker's brain. According to Stewart and Cohen (1997: 180), since the room can carry on Chinese conversations flawlessly, the whole system must be held to "understand" Chinese (analogue for that system or understanding in the individual). A major flaw in the Searle mind experiment is that the fact that something is possible in principle, is much less informative than the fact that it is impossible in practice (Dennett 1991). For example, the instructions on paper would have to contain contingency plans for every possible Chinese question. They cannot simply be a huge catalog of questions and answers, no room would be large enough and no scheme could be far reaching enough. The rules for moving the paper would have to be devised by a fully fluent master of Chinese.

The "Chinese Room" metaphor warns us that logically developed classification systems, databases, and retrieval systems can establish types of objects and create solid statistical bases for discrimination but these do not inform us about their prehistoric makers. As analysts, we must attempt to place artifacts into their contexts of design, manufacture, use and re-use. The artifact forms constitute mental templates that have embedded meaning related to cultural mores, standards, economic decisions, and adaptive strategies.

Context for analysis of stone projectile points includes variables relating to effective use of available raw materials, aerodynamic design, assurances of durability, and aesthetic standards. Prior research has demonstrated ability to separate distinctive styles of points over a long span of time. Statistical separation of diagnostic types is an easy, straightforward reductionist process. The more difficult task is to attach contextual meaning to prehistoric statements embedded in manipulating variables of symmetry, durability, and manufacturing and use contexts.

Movement: Ideals and Information Transmission

Information and meaning are encoded in images. The analyst of past images can depend upon symmetry as a concrete link, as well as on variables of size, cross-section, and surface finish, as clear indicators of prehistoric thinking. The analyst will proceed in a reductionist mode, breaking variation into defensible heuristic classes indicative of time, space, or economic task, but the analyst must remain cognizant that encoded meaning from the past will only be found in a contextualist analysis. To effect a contextualist perspective, we must accept proposed universals in perception and encoding, and then move to define variable contexts in which these prehistoric artifacts were made, used and reused. Important contexts include but are not limited to, changes in population balance relative to resource productivity, changes in social socioeconomic organization moving toward increasing complexity, and changes in projectile propulsion systems emphasizing greater and greater efficiency. Knapping itself produces definable trajectories or directionality. Analysis pursues protocols modeling theories and produces bias or directionality. Prehistoric artisans solved problems relative to parameters defined by world view, and per force, produced a narrowed range of designs over time, effecting developmental trajectories.

Directionality, key to productive analysis, is keyed to problem solving within patterned cultural perceptions. Large complex problems will routinely be broken down into smaller less complex problems more amenable to resolution through use of practiced activity chains or programmed responses. Segal (1994:25-26) asserts that any analysis of problem solving has four components: identify the problem space as that range between the initial and goal states (Newell and Simon 1972); identify intermediate states between the initial and goal states (only trivial problems will allow direct movement from the initial state to the goal state); identify what needs to be done (movements as transformations); identify the resources (knowledge, skills, material, time) needed to execute each move. Directionality is achieved/defined by tracking moves from stage to stage.

A self-reflexive view is important: for analyst or knapper or tool user. Problem solving differs from novice to expert. If the problem is familiar, and the problem solver is an expert, the solution may be automatic. Expert knowledge and skill enhance the initial state and bring it closer to the goal state (thorny problems for the novice are trivial to the expert). Complicated problems require that the expert employ accepted or standard procedures. Self-reflexivity alone enables the analyst to explore the mind and message of the prehistoric artisan and sample the viewpoint of the culture mentoring the artisan. This is not a mystical association. The analyst performs a reductionist classification, scanning for and recording important variables diagnostic of manufacture or use across the surface of the stone tool. Careful examination at microscopic and macroscopic levels produces relief maps of the artifact surface and records stratigraphic overlays of variables diagnostic

of different stages of production and use: initial and ideal goals. The analyst is “reading” evidence for the individual life history of that tool. Information is transmitted, with accurate reading enhanced by knowledge held by the analyst.

Prehistoric Solutions: Practical Problems

A simple approach to studying stone projectile points entails basic description of coarse variables held indicative of investment of energy. Potentially meaningful measures include size (large, moderate, small), material (local or imported), cross-section (trapezoidal, lenticular, irregular), aesthetic (symmetry- exact, moderate, rough; finish- complete, bilateral, incomplete), user profile (strong, moderate, weak), and repair (high, moderate, low). Size can be related to basics of the propulsion system employed (hand-held spear, atlatl, or arrow). Material can be characterized as to local or distant source, representing choice in selection and transport. Cross-section can be related to strength required for plan of use (e.g., thicker, stouter for a hand-held spear and thinner and lighter for the point tipping an arrow). Aesthetic measures are more subjective but can be explicitly categorized, as in effort expended to completely or systematically reduce a surface. User profile refers to the amount of wear or attrition present on the point. Repair refers to care taken in resharpening dulled or broken edges, or in redesign of the point to a preferred shape given significant breakage.

Propulsive System Parameters

Setting projectile points into the context of their makers requires that we apply universal principles that define technological constraints and potentials. First we need to envision that points were affixed to shafts and used in a range of applications dependent in part on the propulsive systems employed. Evidence for past projectile systems in the archaeological record consists principally of stone projectile points. Archaeologists have used elaborate point typologies to draw temporal divisions based on the rising and falling popularity of particular styles. Unfortunately, archaeologists have tried to stretch interpretation to argue that stylistic types are indicative of function, and further that one can travel from the point up the projectile staff and on to the propulsor.

There is clearly a trajectory ranging from larger points to smaller points over the span of the last fourteen thousand years that probably indicates refinement of projectile systems where emphasis was on higher velocities and maximum penetration using smaller missiles. But one cannot argue issues like efficiency and tactics of weapon use based on the least significant design element of the missile: the point at the end of the shaft.

How do you increase velocity? You decrease the size of the missile shafts, the size of the points arming the shafts, and the surface drag of the vanes stabilizing the shafts. Rheingans' (1947) studies on the external ballistics of arrows demonstrate that the important variables in increasing velocity are the force of the bow, the efficiency of the bow, and the mass of the arrow. Holding the propulsor constant, it was found that velocity relates directly to head-on resistance (square of the diameter of the arrow), the skin friction of the arrow shaft (length and diameter of the arrow), and the skin friction of the feathers (total area of both sides of the feathers). Feather design is responsible for the largest part of drag on the missile, approximately double the coefficient derived for the surface of the arrow. Manipulation of arrow length and diameter directly effects velocity. A decrease in arrow diameter dramatically increases velocity by decreasing surface area and head-on resistance.

Practical limits on reducing missile length and diameter, and thus drag, are set by the design of the propulsor. The shaft must be stiff enough to allow effective transfer of energy from the propulsor to the missile. If the missile shaft is too stiff or too supple, force will be diminished. For archery, this constitutes arrow spine.

Why do you want to increase velocity at the expense of mass and knockdown power? Any number of plausible scenarios may emerge. It is possible that larger points on slower missiles with proportionately greater knockdown power might be tailored for executing larger game. Spears, for instance, act best on stationary or relatively immobile targets, like mammoths bogged down in a marsh. Atlatls are better suited to mobile game because of their greater range, penetration, and rapidity of fire. Bows and arrows are the ultimate in range, penetration, and rapidity of fire, perhaps coincident with greater reliance on smaller and more mobile animal species like deer and antelope. Greater missile velocity is enhanced by smaller missiles, and velocity increases range and penetration. Smaller missiles are more easily portable, and thus contribute to a faster rate of fire. Hayden (1981:529) characterized shifts in propulsive technologies as basic adaptive innovations that essentially increased resource reliability and reduced energy expended. This observation, simply put, is seen to be coupled with increasing population densities, reduced foraging ranges, and increasing reliance on technological refinements to intensify extraction of resources from smaller unit areas (cf. Chard 1975: 155; Klein 1977:122). The transition from Paleolithic to Mesolithic or Archaic hunting and gathering societies throughout the world sees a shift toward greater and greater refinement and standardization in stone tools. Mulvaney (1969: 153) describes this as an increase in the tempo of technological innovation in Australia, and coincides with development of a "Small Tool Tradition" c. 4500 years ago. Hiscock (1994:1) summarizes this shift as a mid-Holocene transition from flake-tools to production of typologically regular and finely made flaked implements. He explains this

technological shift as an aid in reducing risk. Gould (1991) identified routine switching of risk reducing strategies by Australian aborigines. Hiscock and Torrence (1983, 1989a, 1989b) cite long term strategies that show continual application as in development of specialized tool kits (cf. Ebert 1979; Shott 1986). Bifacially flaked stone points are described as having significant advantages in themselves: small and easily transported, they can serve as cores for generation of smaller sharp flakes, they can be extensively resharpened, and their form and properties lend potential for multiple functions (cf. Bleed 1986; Jeske 1989; Kelly 1988; Kelly and Todd 1988).

This research from Australia suggests that the selection for lighter missiles and penetration over knockdown power need not be the result of diminished populations of large herd animals, as some have suggested. In fact, human groups were always concerned with hunting smaller species and the pressure for this refinement is probably best judged as a constant through time. Archaeologists recognize that small and medium sized animals were taken by hunters throughout prehistory. Flannery (1968:72-73) noted that wherever there were adequate samples of archaeological animal bones from the southern Highlands of Mexico, white-tailed deer and cottontail rabbit were far and away the most important game animals in all periods. Parmalee et al. (1972:57) note that white-tailed deer were the most common game animal during the Pike-Hopewell and White Hall occupations of the Apple Creek site, Illinois (A.D. 200-700). Wood and McMillan (1976: 223-231) record that in the Ozark Highlands, deer were the emphasized game in the Dalton Horizon (c. 8500-7500 B.C.), but that smaller animals were emphasized in subsequent Archaic I-II Horizons (c. 6600-6300 B.C.), with deer hunting regaining importance in Archaic Horizon III (c. 1100-100 B.C.). Smith (1975:137), in characterizing exploitation of species in the central section of the Mississippi Valley from c. A.D. 700-1700, concluded that deer, raccoon, and turkey were the intensively exploited game. Frison (1978: 348) states that faunal assemblages in the Bighorn Basin are dominated by mule deer and mountain sheep remains from the Paleo-Indian period until the Late Archaic and Late Prehistoric periods, when bison and antelope remains increase. Livingston (1985) documented an emphasis on hunting white-tailed deer and mule deer from prior to c. 4000 B.C. to the historic period along the middle Columbia River on the Columbia Plateau. It would seem that the pressure for smaller projectiles and penetration over knockdown power may have been constant, and that selections for particular attributes of weapon systems may have been independent of environmental or cultural events.

How do we propel the missiles, knowing that big missiles require more strength to be thrown at higher velocities? The earliest missile systems were arguably spear thrown by hand. The next major innovation was probably a machine to store energy, imparting higher velocities and easing strength requirements: the throwing stick. The throwing stick has been described as a simple extension of the arm but in terms of physics, it can be designed

efficiently to function as a flexible lever. A lenticular cross-section on a wooden throwing stick is comparable to one limb of a bow. The next innovation in propulsors was the bow and arrow. The bow might cavalierly be described as two throwing sticks stuck together at the grip. These innovations can be described as design thresholds:

Threshold 1: The spear allows delivery of the stone point. The spear depends on heft and the physical strength of the operator to a high degree. The operator supplied the force necessary to ensure penetration. The heavy spear and large point supplied great mass, and produced massive tissue damage and trauma.

Threshold 2: The throwing stick and dart, by virtue of magnified energy stored in the lever as the operator propels his arm forward, imparts greater velocity to the missile. The dart does not have the mass of the spear, but carries far greater knockdown power by virtue of its greatly increased velocity.

Threshold 3: The bow and arrow is an even more efficient machine, storing energy as the operator pulls back the string, bending the limbs into a full arc. When released, the limbs impart high velocity to the missile by way of the string. The arrow has greatly diminished knockdown power, but terrific penetration supplied by the high velocity imparted to the shaft.

Since we are dealing with a technological trajectory of refinements in propulsive missile systems, we cannot expect clear boundaries demarcating points of one weapon system from points of another weapon system. We can probably separate the norms or clusters associated with one type of weapon from another, but we are not going to be able to definitively assert when one system replaced another, nor why the innovation was adopted. We must acknowledge that there are a wide range of options in the employment of design variables that are directly related to weapon performance. For example, Clovis points can be shot on an arrow. Clovis point width and size would increase knockdown power over a short distance but at heavy expense in loss of cast and instability and inaccuracy over distance. Cheyenne arrows in the late nineteenth century were often armed with cut-down steel knife blades that were up to 13-15cm in length and weighed in excess of ten grams, constituting about one-fifth of the short arrow. These were poor flight performers, but highly functional missiles given the Plains Indian practice of riding up alongside the buffalo and discharging hefty arrows at point-black range from powerful sinew-backed bows. The big steel blades enhanced penetration and cutting and hemorrhaging in the body cavity of bison.

A conservative hypothesis is that flaked stone projectile points get smaller over time because prehistoric missile designers are selecting for increased velocity and more portable, replaceable missiles. Large dart-sized points could be used on arrows but they would impart increased surface drag to the shafts, lowering velocity and limiting cast. Mass would increase drag but introduction of larger points on small shafts would necessitate changes in shaft diameter and require larger feather vanes to enhance flight stability. Larger diameters impart the necessary increase in rigidity for effective transfer of energy. The system parts are interchangeable if accommodation is made relative to basic laws of physics effecting efficient transfer of energy and aerodynamic performance. So, the trend in smaller points over time reflects the trajectory showing diminished missile size over time but larger points could have been hafted on arrows.

More ephemeral but interesting issues can also be addressed. Notches on projectile points become obvious biases in archaeological interpretation. Archaeologists type flaked stone projectile points by configuration of hafting elements. These do certainly reflect changing stylistic preferences but functional importance is debatable. For the archer, hafting elements are essentially passive design attributes representing arbitrary aesthetic elements that fade in and out of popularity in the archaeological record. Paiute arrows in the Great Basin in the nineteenth century were armed with Desert Side-notched point types. Researchers have assumed that notches must have direct correlation with method of hafting. Yet, these Paiute points are hafted to the arrow with a combination of pitch and sinew wraps. Pitch alone would be sufficient, and this haft would not require side notches. Lashes utilizing the notches would also be fine, without pitch. The hafting elements appear to be more style than function, and yet, can find expression in multiple ways in different cultures sharing the pervasive stylistic form.

Certain assumptions can be advanced: (1) flaked stone projectile points are the least important element of the prehistoric propulsive weapon system; (2) morphology of projectile points can have variable significance, from strictly stylistic to functional import, and these may retain passive significance as skeuomorphs; (3) flaked stone projectile points have mnemonic import simply because they are expensive products, costly to manufacture compared to other forms that might be used like sharp flakes or fish spines; (4) hafting elements like notches are conservatively more stylistic than functional in terms of weapon systems design. Any number of types might be drawn that reflect these variable venues for analysis. Flaked stone points simply tip arrows. These are not reliable indicators of design aspects of prehistoric missile systems, except in the grossest perspective of relative position on a temporal trajectory of design modifications tending toward enhancing missile velocity and portability. Point types are probably best considered as stylistic preferences, as cultural statements, reflecting weapon design, group

preference, and past use. Points are powerful indicators of encoded meaning and bland indicators of past propulsive weapon system designs.

Issues of Durability and Re-Use

Effectiveness of projectiles can be related to design relative to durability (mass, cross-section) and maintenance of form and edge for potentials of reuse (profile, use). Instances of redesign, modification, hafting and rehafting, and resharpening are all documented in the archaeological record. Use-wear analyses document life histories for projectile points that reveal deep meanings documenting prehistoric decision making processes. Classifications record trends masking discrete problem-solving embedded in everyday prehistoric praxis.

Shea and et al. (2001) have produced an interesting paper on usability of Levallois point designs in the Middle Paleolithic of the Levant. There is a clear shift in the archaeological record that sees a replacement of larger and longer points in the early Levantine Mousterian to more variable morphologies in the later Levantine Mousterian (Bar-Yosef 1995). It is inferred that the larger, longer, early styles were probably designed for use as knives as well as points, and further, that this is not a development related to a shift in hunting of new or different game species. Later assemblages dated c. 47,000-130,000 years ago, show shorter and broader points. Observations and experiments by Shea and his co-authors indicate that these later squatter forms are more effective as spear points. They conclude that this shift may be correlated with a change to "intercept" hunting strategies and greater concern with reliability-enhancing stone weapon armatures (Shea et al. 2001: 814; cf. Lieberman and Shea 1994; Shea 1998a, 1998b: S51).

Studies like those of Shea and others around the world highlight the need for careful qualitative and quantitative examination of types of stone tools. Past typological studies have shown that separation in style over time is possible. There are also indications that some types or styles are correlated with specific economic activities or specific cultural or ethnic groups. An abstract example of possibilities in elaborating typologies is the work of O'Brien et al. (2001), who demonstrated the value of cladistics in reconstructing phylogenies of Palaeoindian points in southeastern North America. In their conclusion, they cite Clarke (1978: 262) on taking care not to interpret affinity relationships as descent trajectories. Arrangement of styles over time merely highlights the need to develop alternative hypotheses of development. Clearly, one robust approach is to examine indications of wear indicative of discrete uses. Redundant use pattern or patterned tool use should be preserved in embedded attrition patterns on stone tool working edges and surfaces. It is assumed that prolonged, patterned use of a tool edge or surface will produce attrition of those edges or surfaces in direct proportion to

duration of work, force applied, material used for the tool, and the type of material worked.

Multiple biases or variables will intervene in inferring tool use or function, the types of materials worked, or patterns of use reflected. Proper inference will always depend upon intersection of physical and analytical attributes. Reduction of lithic mass to produce smaller tools and tool edges will often result in areas of manufacture that are larger than areas of wear. The analyst must not assume that flaking on a tool object edge or surface equates with wear. By extension, the analyst should not assume that a particular tool object form has been used for a specific use or task (e.g., an obvious projectile point form may have been used as a graver-saw-knife, defined kinematically).

The overriding bias in any wear analysis is recognition of redundant patterning so embedded in the topography of the stone tool that it removes (1) enough of the original edge or surface to conceal its original extent or character and (2) any evidence of prior use patterns. If all use patterns are equally intense and encompassing of edge or surface, the analyst may not be able to define tool use beyond the last documented or obvious application.

Working Assumptions

A1. Patterned use attrition will be preserved on prehistoric stone tool edges and surfaces.

A2. Prolonged, patterned use of stone tool edges or surfaces produces attrition of those edges or surfaces in direct proportion to duration of work, force applied, material used for the tool, and the type of material worked.

A3. Multiple biases or variables will intervene in inferring tool use or function, classifying the types of materials worked, or descriptions of patterns of use reflected.

A4. All stone tools have potential for multiple uses and may be re-designed for new use scenarios.

Working Assumptions

B1. Potential for inference is directly proportional to embedded patterned use of specific tool forms.

B2. Accurate inference will be negated by intensive use and re-use of stone tool forms.

Behavioral Context

Stone tools are outputs of stone technology, which can be taken to refer to all activities involved in the acquisition of raw lithic materials. This encompasses manufacture, distribution and exchange, maintenance, consumption, and reuse and recycling of stone tools (cf. Torrence 1989:4). Industries for comparison, entail utilization of materials for forms relative to a specified technology and within parameters imposed by the selected raw materials. Tool-using, procurement, production, and maintenance are one of the primary means humans use to reduce potential effects of risk (Torrence 1989:4). Torrence addresses tool-using as a fundamental aspect of human behavior, wherein optimization theory is argued to be the most relevant mode of analysis (cf. Stephens and Charnov 1982; Stephens and Krebs 1986; Smith 1986; Winterhalder 1986). Tools are seen to be created and employed to satisfy a perceived need and to accomplish tasks that are susceptible to selective pressures. Successful optimal technologies are created, and these should be discernible in the archaeological record. Technology is seen to be a particular adaptation created within general principles of optimization that operate relative to strictures of specific local conditions, and within parameters of perceived need and physical restraints embodied in use of different materials.

The Artifact as Site: Use-wear analysis characterizes the artifact as a bounded activity site (cf. Lohse 1996). Analysts map topography and cultural or natural residues as preparation for delineation of overlapping residues and use-wear patterns incurred over the span of the artifact's use life. Topography must be defined and interpreted relative to an explicit inferred model of production, and a manufactured landform or history base map is created. Identified landmarks of knapping include flake scars and arris boundaries. Once manufacture topography is defined, the analyst proceeds to define successive instances of use-wear and residue formation by looking at the relational array of manufacture and use-wear attributes as layers or spatial formations with incompletely overlapping boundaries. Points of overlap and incomplete correlation become key mapping points for teasing out artifact life histories, just as points of disjuncture define superimposed layers in an archaeological site excavation ([Figure 8: Artifact Maps and Profiles](#)).

Reading of artifact life histories is clear conceptually but difficult in practice (cf. Ragir 1993; Gowlett 1986). Intensive use will destroy or damage pattern recognition potential on the surface of the artifact in the same way that intensive use of a site obscures or destroys fine-scale primary activity contexts ([Figure 9: Sorting stratigraphy](#)). Artifacts are more clearly read if they are little modified or used. This observation promises high potential for use-wear analyses since it implies that the ubiquitous stone artifact offers easily read behavioral information. Absolutely essential is that tools must be

read in context of the larger assemblage in which they were found (one must read the whole book, not selected pages or disparate sentences).

The analyst must look for discernible landmarks, and then attempt to link fragments of spatial and temporal evidence indicative of certain uses. Totally obscured or overlapping distributions will negate any attempt to discern the artifact's life history, except to note the obvious last instance of attrition or residue relative to the manufactured form. It is paramount that a manufacture element base map be created so that any separation of overlapping or non-overlapping attrition and residue patterns may be made.

It is important to recognize that the "life history" of the artifact is derived from the macroview of archaeological excavation of the entire tool form, or the delineation of attrition and residue patterns ("life history" is not synonymous with "use life"; cf. Shott 1989). Analysis at the attribute level will require microexamination of the attributes and attribute clusters that comprise the attrition areas and layers of residue defined at the level of artifact view. This view no longer concentrates on the overall form of the object, nor on the extent of the attrition zone or residue layer, except in so far that the analyst slides the tool zone under magnification view to ascertain the character of the viewed area. Attributes and attribute clusters are defined, and their spatial relationships assessed in the same way that a landscape is scanned under variable perspectives including angle of view and lighting. The analyst is seeking clear, definitive characteristics and relationships defined vertically and horizontally on the artifact landscape.

At this stage, the analytical view has moved from gross artifact morphology to mapping of the surface. Uncovering an artifact's archaeological life history requires characterization of distinctive attributes and attribute clusters of attrition and residue in the magnified view. As the analyst pursues attribute identification and mapping, the analysis becomes more and more abstract. Distinctive sites and site clusters on the topographic surface and erosion of the original surface are the object of study, and the exercise becomes one of pattern recognition. The analyst's perspective slides constantly from the attribute to the object surface to the overall object morphology, just as the magnified view zooms up and down through a range of magnifications to maintain perspective.

The Analyst's Cognitive Map: Looking At Projectile Points

The analyst, charged with separating manufacture and wear episodes, as outlined above, must attempt to reconstruct the schemata of the prehistoric makers and users. By extension, the analyst must note diagnostic attrition or wear on one end or edge or surface and then rotate the artifact to inspect opposing points, edges or surfaces for evidence of how the tool was anchored for use. Prehension and hafting can impart direct and indirect wear.

Hand gripping will probably leave only subtle direct evidence (cf. Keeley 1982:807; Owen and Unrath 1989). A hand grip, however, is often indicated by the placing of deliberate retouch backing on an opposing edge (Odell 1980:412). Hafting leaves distinctive evidence dependent on the type of haft employed: wedged, tied or glued (Keeley 1982:799). Wedged and tied hafts may allow movement of the tool in the haft and use wear may develop as flaking, abrasion, striations or polishing. Mastic or glued hafts will allow no movement, but termination of use wear patterns and breakage locations, and residue will often be well preserved.

Context is key to application of any intensive examination. Cultural assemblages without adequate context are low priority collections for functional study. Artifacts in the conception put forward here, must be read in the systemic context of their production and use (cf. Schiffer 1987). This requires that the physical elements of the primary assemblage must have been collected or measured in some meaningful analytical framework (e.g., Kintigh 1989; Hiscock 2001, 2002; Shott 2000). Such a framework is explicitly designed to discriminate between cultural and natural factors of deposition, and to bridge phenomena recovered in the context of the archaeological record to the analytical laboratory by testable hypotheses put forward in explicit behavioral models. Field methods must be sufficient to to earmark assemblages with natural and cultural integrity (e.g., a lithic assemblage representative of staged reduction from a structured activity context like a cache or hearth or house floor). The inherent, overriding assumption is that primary activity residues will be found in the archaeological record, but no assumption is made that these will be clear or unequivocal associations (cf. Schiffer versus Binford over the infamous "Pompei premise" in Binford 1981 and Schiffer 1985). The analyst must expect: (1) complete or reasonably complete recovery of all necessary assemblage characteristics; (2) complete documentation of all pertinent spatial, physical, and inferential information (site excavation records, published reports, conservation records); (3) adequate sample size to warrant careful selection of objects for analysis and preservation of detailed qualitative and quantitative measures of characteristic formal attributes. Lohse (1994) has promoted a framework for recognition of sites and artifact assemblages with necessary documentation. Minimum provenience requirements must be met, or the basic operating assumptions for this kind of analysis cannot be met. The analyst will be irretrievably drawn to questions of adequate context and sample size.

The analyst must avoid any semblance of an open-ended or cursory analytical exercise. Use-wear analysis is expensive and must be focused on high priority or high potential assemblages. Stone tools must be considered within the context of comparable stone detritus. Edge and surface attrition must be considered together with residue overlays. Characterization of stone tool attrition and residues must consider depositional contexts, correlating

tools with detritus, with residues, and with organic artifacts representing the same prehistoric activity context. Lines of evidence must be linked, and plausible inferences pursued based on critical examination of assemblage characteristics relative to models defined on the basis of mechanics of stone fracture and behavioral models of tool manufacture and tool use. The clearest evidence in the end will be measured overlay of organic residue extent atop diagnostic patterns of surface and edge attrition on the stone tool and comparison of that tool with other diagnostic elements of an assemblage within defined activity site context (e.g., bison hair fragments in a mucillagenous mix of blood and fluids adhering to flake scars in a pattern indicative of cutting and scraping in meat and hide on a resharpened blade). The analyst can then measure plausible inferences to be drawn against empirical evidence. Inference will then be upheld rather than assumed.

The value of Schiffer's studies (1972, 1976, 1987) lies not in specific findings or inferences drawn, but in the conception of transformation of contexts in the archaeological record. Analysts bring models to interpret results of transformations, and not to identify past activities. Following Neustupny (1993:47-48), transformations of cultural material continue throughout the assemblage's life history in the archaeological record, and through phases of analysis and conservation in laboratory drawers and computer data banks. From a behavioral modeling perspective, the analyst must seek to lessen systemic noise produced by the ever changing relations between natural and cultural contexts. The basic premise is that behavioral information increases directly with human modification and use. In the extreme sense of physical decay, information will be irretrievably lost as the object degrades to a natural state. Fortunately, careful analysis focused on transformation processes can offer reasonable, testable propositions about what should be found and what should not be found given documented cultural and natural contexts. The analyst must establish the chain that creates a life history for the object under study: formation phase, use phase, and transformational phases up to context of recovery. Transformation classes will include variable outputs, spatial changes, and formal or physical changes, all of which are directed or mediated by cultural and natural processes. Analysts must fingerprint probable transformations as to fragmentation, accumulation, and reduction (Neustupny 1993:54-64). Processes of reduction are particularly relevant in defining systemic context for objects under study. Diagnostic elements of activities will be lost, per force, so analysts must try to identify elements that are robust physically and behaviorally. For stone tools, we must acknowledge that curation will transport selected artifacts in and out of primary activity contexts (cf. Andrefsky 1994; Bamforth 1985, 1986; Hoffman 1991; Kuhn 1989, 1992, 1994; Lurie 1990). Spatial configurations are expected to change as will artifact morphology on highly utilized or highly curated forms. The analyst will be able to recognize curated artifacts in direct proportion to the degree of spatial and physical change (e.g., a significantly reused or resharpened tool in an exotic material found within a bounded activity

context). Systemic noise produced by heavy curation is acceptable, since it can be identified and dampened through requisite assumptions concerning behavior relative to sensitive artifact classes. This noise will be dampened simply by acknowledging that ubiquitous stone detritus from directed knapping episodes will retain in the specific (attributes and form linked) and in the aggregate (classes and correlations of classes) all the earmarks of decisions made in the staged task-production environment. Most outputs, by virtue of having limited formal intent and irregular shape or limited size, will be found in situ, in primary associational context, barring natural disturbance. Ravages from natural processes on detritus may be a profound bias, but this noise is also dampened simply by characterizing the natural processes acting on defined cultural contexts (e.g., active versus low-level transport on cultural surfaces or within bounded cultural features). Ubiquitous detritus will give the analyst the necessary baseline for reconstructing stone tool manufacture and tool use on site. The analyst should be able to project classes of formal outputs, characterize what is present in the assemblage, and relate information recovered directly to probable site activity contexts. The incomplete nature of the archaeological record is a given, but the use-wear analyst strives to recover information through an imposed analytical system that explicitly aims to fill in voids in preserved formal and spatial data arrays.

Evaluation of site potential and significance is of considerable importance (cf. Lohse 1994). In general, archaeological sites must be excavated in natural rather than arbitrary levels and provenience data must include associations measured and collected as cultural and natural features. Stone use-wear analysis is a time intensive, expensive procedure, and artifact samples should be selected from excavations that record minimal contextual information at least at the level of measured association within cultural and natural features. Further, collection must include at least samples of all cultural and natural materials within those cultural and natural features so that earmarks of manufacture, wear, and residue on the surface of the stone tool sample may be compared with other characteristic elements of the depositional unit. Found or excavation context may then be comparable to the analytical framework applied to the material.

Points are Good Indicators: Stone projectile points are readily recognizable forms for archaeologists ([Figure 5](#)). Identification usually rests simply on recognized morphologies held indicative of projectile point design (e.g., lanceolate and variable triangular forms with separable hafting elements). So persuasive is the assumption of design closely tied to function that most archaeologists show little hesitation in applying the functional label to these forms and in inferring site use from the presence of forms as a focus on hunting. Typologists often assume, usually implicitly, that different types of projectile points indicate ethnic or cultural differences as well as temporal divisions (cf. Lohse 1995; Odell 1981). Comments concerning their spatial

and temporal distributions usually entail some aspect of prehistoric ethnicity as well as detailed discussions of temporal distribution or overlap.

Assumptions regarding projectile point identification include: (1) traditional, projectile points are carefully designed lenticular forms with symmetrical tips, blade margins, and hafting elements (caveat: In the later prehistoric periods, these point types become smaller with neck widths reflecting closely arrowshaft diameters (usually less than 1cm); (2) functional, projectile points are forms capable of being hafted in arrowshafts and showing surface attrition, polish, and residue held indicative of being hafted and/or used as a projectile point (caveat: North American projectile points tend to be made within highly stylized designs but assemblages should be examined for evidence of projectile use of different less patterned artifact forms); (3) practical, we may expect a wide range of forms to have been used as projectile tips and some obvious projectile point design forms may not have been used as projectile tips at all.

Adaptations and Innovations in Propulsive Systems

Reference to prehistoric propulsive systems is endemic to archaeological reconstructions of the prehistoric past. Small symmetrical bifacially flaked stone tools found in the archaeological record are commonly referred to as points or arrow points, and their presence post-2000 years ago is often cited as evidence of the development or adoption of the bow and arrow. Further, inferences often assume that the bow and arrow replaced the atlatl and dart projectile system because it was somehow more efficient. This notion of progress or increasing efficiency in design as a motive force in development and adoption of technology is usually left as an implicit

Archaeologists persist in debating whether different types of projectile points best afford stylistic, functional or technological inferences. The archaeological record, ignoring unusual instances of preservation, supplies only bits and pieces of stone. These are limited indicators of complete technological systems. Stone projectile points were only the tips for insertion of projectiles propelled in variable projectile systems. We have proposed in this paper that diminution in size of stone projectile points over time reflects a design trajectory that emphasized smaller and faster projectiles propelled by increasingly efficient machines. We take a conservative stance, and assume that trends from larger to smaller missiles evidence past designer concern with enhancing missile velocity and penetration at the expense of knockdown power.

A design trajectory for enhancing system efficiency is an elegant model but stone projectile points carry other information as well. Within the general trajectory of decreasing point size there was considerable leeway for differing cultural expressions. There are also a wide range of research approaches.

Cultural Types

Archaeologists depend on identification of types in flaked stone projectile points to define temporal periods (eg., Lohse, 1985). Some researchers expect these types to identify prehistoric cultural groups, and adhere to the traditional model of plotting the temporal and spatial distribution of these types to document prehistoric migrations and influences of one sort or another.

Functional Types

Other archaeologists expect to derive detailed functional information from projectile point types. These researchers use attributes of wear, coupled with inferences based on morphology, to identify prehistoric activity patterns.

Cognitive Types

Still other archaeologists emphasize flintknapping replicative studies, and maintain that any value to be derived from analyses of flaked stone projectile points resides in understanding the techniques of production.

Most contention would evaporate given explicit divisions in analysis. Flaked stone projectile points may be examined differently by different analysts with different concerns and goals: projectile points can be valid chronological indicators (culturally preferred styles); projectile points can be studied as tools, and attributes measured to infer use; projectile points can be made in different ways as outputs from distinct techniques of production. Such distinctions are easy to draw, but in practice, analysts will tend to champion one venue over another.

Points and Shafts: D.H. Thomas (1978) published "How projectile points got the shaft." He used 118 arrows from the American Museum of Natural History collection, 14 arrows from a quiver found in Pueblo Bonito, and a total of 10 hafted atlatl darts from sites in the western United States. Thomas wanted to see if he could statistically separate arrow points from dart points, and whether he could predict shaft variables given projectile point variables. Thomas concluded that larger arrows had larger points; that there was a low correlation between arrow point size and shaft size; that dart point size showed little correlation with dart foreshaft size; and that dart foreshafts are larger than arrow shafts. Multivariate discriminant analysis showed width to be the most discriminating variable. Discriminant analysis also produced a set of classification functions that Thomas felt would discriminate between arrow and dart points.

Of course, finding that larger points tend to come on larger shafts and that dart foreshafts are bigger than arrow shafts, are obvious conclusions. These

simply reflect the diminishing size of shafts over time. Width was the principle discriminating variable simply because there is an obvious correlation between relative width of point and shaft diameter. Thomas' classification functions are a tactical problem. Lohse (1985) applied these formulas to an assemblage of projectile points from Chief Joseph Dam in northeastern Washington State that ranged in age from c.6000 years ago to the historic period. Thomas' classification functions labeled 94% of the specimens dart points, even though over 15% of the points were small side-notched and elongate barbed forms post-dating 1000 years ago, and commonly held to be arrow points. This discrepancy can be attributed to the obvious bias in Thomas' experiment: projectile points from different areas differ markedly in dimensions, even though of comparable if not identical stylistic types. We might conclude that using any sample population of points from one area to classify points in another is a suspect exercise. Size is not an independent variable. Material, desired form, and technique can all affect size parameters. Missile shafts decrease in size over time, and point types can demarcate sections of time, but there is no direct relationship between point types and prehistoric missile systems.

Another ramification of not clearly separating out "types of types" of flaked stone projectile points is clear in the exchange between Flenniken and Thomas (Flenniken and Raymond 1986; Thomas 1986). Flenniken and Raymond maintained that morphological projectile point types are not consistently reliable temporal or cultural markers. They selected a larger corner-notched type, the Elko Corner-notched, as the temporal type to evaluate, and determined that considerable changes in morphology occurred with breakage and subsequent rejuvenation. In their opinion, the specific Elko reduction sequence was the better temporal and cultural scale. Thomas contested their position, and argued that a more constructive approach would be to accept the concept of inevitable error and attempt to isolate and define sources of variability that represent temporal distinctions. He noted that his typological studies simply identified series of operationally defined attributes, and that these attributes are melded into a dichotomous key designed to force unlabeled specimens into accepted types. He argued that tool use and maintenance could not a priori preclude use of flaked stone projectile points as time markers.

The definition of temporal types cannot be dependent upon stylistic, manufacturing or functional analysis venues. Types can be defined in any or all of these analytical divisions. In essence, if a morphological or functional or technological type is demonstrated to have limited temporal distribution, it is a valid temporal type. Moreover, if a type or cluster of attributes can be correlated with proscribed use, it has functional significance. If a certain projectile point style is shown to be the result of a specific production sequence, it has technological significance. Types of types simply supply heuristic order convenient to the goals of the researcher. Contention persists

because we cannot agree on terms that we clearly associate with the various analytical venues. This was the essence of R.C. Dunnell's (1978) article on style and function in archaeological analysis. Dunnell candidly argued that archaeology has adopted "the ritualistic judgements of science without the commensurate performance criteria" (1978:193). He attributed this failing to well entrenched schools of archaeological interpretation: "Culture History," with its reliance on common sense and no formal reliance on theory; "Cultural Reconstructionism," where emphasis is on material residues of past cultural systems and heavy reliance is placed on behavioral correlates; "Processual-Scientific Archaeology," where the goal is to generate laws guiding cultural behavior. These schools are still in competition, though "Postmodernism" is now on the table as well. Old theories may no longer find currency but past thinking and precedent surely does guide research. Dunnell's (1978) remedy was to emphasize evolutionary archaeology, where we account for structure and change in terms of evolutionary process. In this view, origin and invention are sometimes held as trivial concerns: invention is seen as analogous to random mutation. How and why become the important questions. Continuing resolution will require clear formulation of inquiry, definition of appropriate terms, and controlled experiments conducted with scientific rigor. Style and function are clearly different avenues of research. Style refers to material culture forms that do not have detectable selective values central to the adaptive fitness of the prehistoric population. Function refers to artifact forms that directly affect the fitness of defied prehistoric populations. Function is certainly not synonymous with use.

Context must be defined for study of prehistoric aboriginal projectile systems. That context will require per force explicit discussion of design parameters and use patterns of the system or system parts under study. Objects will be given meaning as physical matter, as energy or information exchange, as to use, and as part of a code, set or structure defined by the prehistoric user or by the researcher. Hodder (1987:2) admonishes that instead of "skimming over the surface of the data, using the hypothetic-deductive method to test general theories against decontextualized bits of pieces of societies, the aim ... is to ground theory more carefully in data." Projectile point types should then be studied as symbols as well as styles or functional tools or technological endproducts. The boundaries or distinctions we set between studied types are highly variable, and inexact depending upon the nature of our inquiry.

Archaeological traits and measurable attributes exist because cultures define and maintain patterns to reinforce values, beliefs, rules and behaviors. To that extent, they are not arbitrary creations of the researcher. A style belongs to, or can be part of, a culture or of groups of cultures. A tradition encompasses aspects of these shared cultural patterns passed on from generation to generation as part of socialization. All societies adhere to norms that each individual member is expected to conform to. Leeway is, of

course, allowed in every culture. That leeway will be reflected in different elements of style, function, and technology. To set analytical context, we can declare that our study is object-centered, unlike "culture," "style," "type" and "norm," which are broad cultural patterns. It is the relationships defined for objects as parts of cultural systems that contribute to meaning. We set the operating parameters, and define the context for analysis and discussion. Any number of limiting dimensions can be defined: spatial, temporal, depositional or typological.

The analyst should seek to clarify the network of patterned similarities and differences that relate to the object and the questions asked. An obvious productive venue can focus on aboriginal projectile propulsion systems and can examine how and why different systems are adopted. This moves beyond standard archaeological preoccupation with types of stone projectile points and seeks to develop a broader context exploring the basics of how projectile shafts were propelled. To move beyond speculative inference requires examination of the mechanics of projectile propulsion and the historic record of aboriginal propulsion systems design and use.

Efficiency: Many studies implicitly and explicitly attempt to explain significant changes in missile systems as predicated on a striving for efficiency, however measured. Points do get smaller over time, so we know that there is directionality. We can assume that relative size of the points is related to the size of projectile shafts. We assume that there is a sequence of development from hand-thrown spear, to throwing board, and to bow and arrow in the prehistoric arsenal. We can consider this in light of mechanics of propulsion predicated on seeking more efficient transfer of stored energy to the projectile. Societies apparently strove to fire faster, lighter projectiles, giving up mass and knockdown power for portability and penetration. This is a distant view, defensible, but without insight regarding the motivations of the actors.

"Progress" is a relative concept, assigned based on the explicit concerns of the analyst, and related solely to the measures imposed in the study. Studies of technology increasingly show a serendipity in development, with multiple options and multiple branching developments. Innovation and adoption are often conditioned by factors other than rational problem solving, and greater efficiency is often declared posthoc by an analyst (cf. Bury 1932; Nisbet 1980; Winner 1977). Motivations of actors in the adoption of innovations can only be clearly understood in historical contexts relating textual and firsthand accounts. General patterns of human behavior and processes of adoption can be summarized but need not accurately reflect specific events.

Six assumptions commonly emerge in archaeological and anthropological theorizing on why and how technological changes come about: innovation brings improvement in performance of the artifact; advancements in

technological design bring about betterment in peoples' lives and accelerate growth of social complexity; technological progress can be gauged in quantitative measures like speed, efficiency, and power; humans control the timing of development, direction, and influence of technological changes; higher levels of technology ensure greater control over nature; and the highest levels of technological development are expressed in terms of parallels to Western civilization (cf. Basalla 1988:211).

Traits Signal Behaviors? Strategems ... Ethnicities

Archaeological examples of these lines of thinking abound. A. Bryan, in his overview to a volume on early man in America, clearly associates changes in technological design of missile systems with an ill-defined betterment of lifeway: "... reached into their toolkit and developed similar but technologically and morphologically discrete hunting equipment in order to better economic adaptations to their respective environments (1978:307). Bryan conjectures about why there are a number of distinct flaked stone projectile point types in the Paleoindian period, which he labels traditions, which could not have been derived from the so-called Clovis technological complex. He falls into the conceptual trap of labeling changes in projectile point morphology as progressively more efficient adaptations. He also makes the conceptual leap of correlating discrete areal and temporal distributions of archaeological artifact types with inferred differences in environmental settings, and inferring relationships of increased efficiency through perceived specializations in technology. He assumes this without defining any operational basis for recognizing meaningful design changes, and so, cannot hope to specify why changes occurred. This unaccountable relationship between efficiency and specialization also finds expression in Jennings' description of "Archaic efficiency" on the North American continent, wherein he explicitly defines technological advance as leading to specialized rather than all-purpose tools (Jennings 1989:120).

While refinements in technological design may result in highly specialized forms, specialization cannot be held as a true measure of adaptive efficiency nor indicative of an advance unless this is carefully defined in a specific context. Jennings is referring to changes in technology that he links with development of broad spectrum hunting and gathering economic strategies in the Archaic period of North American prehistory. This is a correlation of changes in the design of tools and the creation of new forms with perceived changes in adaptive strategy. Correlation cannot serve as explanation, and it would seem better to define any postulated advances in the context of technological design efficiency, efficiency in extractive systems, or the like. Without explicitly defined context for the notion of progress or technological advance, Jennings is left with manipulating traits very like Bryan (1978), and suffers the same logical impediments. Correlations of broadly defined traits, cultural and environmental, are presented, and then reasons inferred for

these changes based on generalizations on human behavior. There is no explanation as to why changes occurred within relevant technological trajectories.

Bar-Yosef and Kuhn (1999) carry a similar discussion based on the significance of blade technology in assessing human evolution: assumed correlations between blade-making, Upper Paleolithic industries, and anatomically and behaviorally modern humans. They point out that early researchers assumed linkage and significance, and many analysts persist in carrying these inference forward. Yet, blade technology predates the Upper Paleolithic and there is no demonstrable rationale for linking blades with any specific anatomical or cognitive development. Measures of efficiency like greater cutting edge per unit and greater conservation of material through deliberate preparation and use of cores can be applied to explain the advent of this set of techniques, but clearly their development cannot simply be linked with arrival of modern humans. Blades often were fitted to composite tools but there are other solutions, as in Australia, where microlithic components of composite tools were made using small flakes. Obviously, there are development trends aiming at enhanced efficiency, and these can use a range of pragmatic reduction techniques dependent upon learned action chains applied, raw materials available, logistical planning, etc.

Bipolar flaking techniques have also been cited as indicating particular important shifts in socioeconomic organization and use of locally available materials to ensure success of proscribed tasks. Hiscock (1996), in consideration of mobility and associated technology in the Kakadu coastal westlands of Australia, acknowledges that bipolar knapping is considered advantageous when residential mobility is low. Intersite assemblage variation in this area was cited as evidence for seasonal abandonment of land areas. Assemblages were seen to be commensurate with distinctive toolkits: stone points were rarely used in the dry season; use of higher ground in the wet season and reliance on hunting terrestrial animals caused use of more stone pointed projectiles (Schrire 1982; White and Peterson 1969). More recent reviews have dismissed seasonal abandonments, but retain the idea that assemblage composition directly reflects the kinds of tool using activities (Meehan et al. 1985). Hiscock's (1998) paper adds concern with mobility to design of the tool kits and relates interpretation to adequate measure of the preserved assemblages. He suggests that presence of bipolar cores is a better measure, citing work by Parry and Kelly (1987) who argue that bipolar stoneworking became more frequent in North America as residential mobility decreased. Efficient use of material was presumably less important. Hiscock points out that bipolar techniques are neither inherently standardized nor nonstandardized, neither expedient nor wasteful, and he states that Parry and Kelly err in assuming that these techniques reflect lack of concern with material conservation. He notes that bipolar techniques are used when cores are difficult to stabilize in the removal of flakes. These can be used to extend

the use of smaller cores for groups camped some distance from ideal lithic sources. Bipolar reduction also helps use of curated artifacts found abandoned on old site surfaces. Carrying these observations forward, Hiscock found that floodplain margin sites contained higher proportions of bipolar cores than woodland sites. He interpreted this as indicating lower residential mobility along the flood plain margins.

We can escape some of these conceptual pitfalls by rigorously outlining our methodological imperatives: assume universals in human learning and training, employ universals of physics and fracture mechanics applied to manufacture of stone tools, assume an inherent cultural interest in minimizing risk, and acknowledge that all human manufactures carry explicit and implicit encoded information. The analyst must develop an explicit framework that keys identifications and descriptions to conservative assumptions embedded in our knowledge of human cognition and behavior in a world of physical constants ([Figures 11](#) and [12](#)).

For instance, we should define attributes on flaked stone projectile points that relate to prehistoric missile system design, development and performance (technological context). Analysis requires study of principles of aerodynamic design and actual preferences for materials and forms as pragmatic solutions. For the archaeologist, there are significant limitations: not all parts of the systems are preserved in the archaeological record; users cannot be observed; there are not historical eyewitness accounts. Observed attributes or characteristics can only be used to infer basic design limitations that can be used to aid the analysts' reconstructions. These design variables must be weighted, and those that are essential highlighted. Associations of important design attributes will dictate system parameters. As a basis, we should acknowledge that: flaked stone points are insignificant parts of prehistoric propulsion systems; some point attributes (barbs and notches and haft thickness) probably reflect strategic concerns; changes in point dimensions may reflect intentional refinements in methods of missile delivery; overall morphology and aesthetic quality reflect social and cultural values.

Conclusions

This paper has emphasized a number of key concepts in the interpretation of stone tools as indicative of prehistoric thinking and problem-solving. Three major conceptual schools dictate the goals of stone tool analysis: chronology, functional efficiency, and replication. Each one of these approaches, in isolation, is limited in its ability to represent the cognitive structure of the prehistoric knapper. Practical keys for the archaeological analyst include understanding of how humans learn and apply knowledge in practical situations, and how problem-solving strategies may vary within wide parameters imposed by social, economic and material constraints. Analysts are free to explore different theoretical slants as long as accepted basics of

human behavior are identified within explicit scenarios defined by specific social, economic and material variables. That is, societies with simple technologies will operate closely within the physical restraints of their exploitable environments. Solutions will tend to be direct and elegant though design forms will be embellished with meaning and expression.

We can make three practical assumptions regarding discernible differences in point form:

PA1. Knappers will design points as a balance between function first and style second.

PA2. Extensions of idealizations of functional form and style will be limited by material quality.

PA3. Tool use strategies will be predicated upon practical exigencies that we may label efficiency.

Typologists have demonstrated that diagnostic North American stone projectile points break out in three principal clusters that probably represent significant changes in prehistoric propulsion systems (e.g., Holmer 1986; Lohse 1985; Thomas 1981; and others). Arguably, the larger thicker Paleoindian points tipped spears, the middle-sized Archaic points possibly served darts, and the smaller Late Archaic points were likely arrows. All styles show a range of functionality embellished by prehistoric knappers as mnemonic presentations showing social identity and meaning.

We can identify the following operative scenarios:

S1: Large Paleoindian points have thick symmetrical cross-sections, large hafts, long blades with long cutting surfaces, and beautifully flaked surfaces. These characteristics indicate concern with creation of durable strong multifunctional blades hafted to hand-held shafts generating high torque in thrusting, cutting, scraping and dismemberment. Use-wear will show microflaking, microrfractures, striations, abrasion, residue, resharpening and reworking. The high aesthetic investment shows care and pride in manufacture, and expectation of low incidence of loss and breakage.

S2: Middle-sized Archaic points have thinner lenticular cross-sections, thinner moderate-sized hafts, smaller thinner blades with less cutting edge, and less carefully flaked surfaces. Lack of aesthetic investment seems apparent and reflects higher incidence of loss and breakage commensurate with shafts that are thrown at higher velocities and range.

S3: Small-sized Late Archaic points have thin lenticular cross-sections, small thin hafts, very light and short blades with negligible cutting edge, and

highly variable surface flaking. These characteristics indicate use on small shafts and little concern with functionality beyond penetration of the target. Aesthetic investment is largely confined to reduction in size of elaborate styles first used in the earlier Archaic period. The points show little investment of effort beyond rudimentary flaking to two-dimensional form. These small points were quick to make and indicate high loss and breakage ratios.

We can postulate that functional concerns directed the manufacture of stone projectile points within gross parameters defined largely by the propulsion technology employed. Within these general design parameters (e.g., size, mass, configuration), aesthetic concerns were paramount. There were a wide range of acceptable shapes and these were delineated in whole or part by need for marking cultural or ethnic identity. At the static level of classification, analysts should first separate functional design variables from mutable cultural variables, relate these to reconstructed contexts for socioeconomic action patterns, and then correlate identified characteristics with important elements found in assemblages and in assemblage distributions on the prehistoric action landscape. At the dynamic inferential level, analysts should interpret patterns observed in the distribution of manufacture and use-wear attributes on the surfaces of the artifacts relative to known cognitive and behavioral patterns in human development and action. "Reading" stone projectile points requires explicit recognition of (1) design parameters or possibilities, (2) environmental or economic limitations, and (3) evidence of use and planning preserved in the elements of manufacture and wear preserved on tools.

A singularly important part of future research rests in developing explicit, rigorous models for analysis of flaked stone tools. Theoretically, these models might profitably address economic practices, cognitive development, or the use of stone tools on a symbolic level. Methodologically, these models can make use of innovations in analysis, perhaps assessing stone tools at the attribute level and at the level of artifact landscapes as addressed here.

Gowlett (1996) characterized archaeological analyses of stone tools, and concluded that aspects of function, economy, style, and symbolic transfer commonly receive attention. Gowlett argued for attention to how stone tools constituted "visiting cards" that indicate past behavior in geographic and temporal frames. Gowlett also highlighted analyses of stone tools as indicators of past problem-solving strategies or schema. Analytical models will have to be tied to experimental data and must have the potential of objective testing. Profitable venues will include controlled basic research into motor learning, explanation of closed-loop notions of error detection and correction, provision of operational definitions for all constructs and suggested experimental variables, and definition of experimental paradigms for testing.

These analytical models will involve measurement of qualitative and quantitative variables, and our success at teasing out socioeconomic contexts from forms of stone tools and patterns of wear on their surfaces may be greatly enhanced by application of computer-driven digital imaging techniques. Measurements at the pixel level are now possible, which turns the surface of the stone tool into a culturally defined activity landscape. Further, high resolution digital images effectively store information for future examination, greatly enhancing our ability to corroborate previous tests. This new analytical rigor must in turn be directed by theoretical sophistication, bringing knowledge of human cognition and behavior, and application of universals in physics and fracture mechanics to the study of stone tools. Recent emphases on mathematical models to aid in exploring material constraints and behavioral potentials are promising, and can be greatly aided by application of high resolution digital imaging (e.g., Brantingham and Kuhn 2001; Lohse 1985, 1996, 2000; Tankersley 1994). Rigorous analytical models produce data that can be fed into hypotheses phrased in evolutionary theory. Researchers in this area are disinclined to accept “behavioral phylogeny” that links technological achievements to supposed hominid species or to accept simple measures of “efficiency” based in correlating specific morphological traits with inferred specializations in socioeconomic strategies. Recent technological advances coupled with cognitive theory and phrased in evolutionary ecology models promise dramatic new insights in “reading” stone artifacts.

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