ern hunter-gatherers. Both species were social foragers facing different adaptive problems.

One conclusion to draw from the recency of hunter-gatherers is that the hunter-gatherer way of life is *the result, not the cause,* of evolution in human psychological mechanisms. Between the emergence of a hunter-gatherer lifestyle 200,000 years ago and the spread of anatomically modern humans out of Africa 80,000 years ago (cf. Capelli et al. 2001; Thorne et al. 1999), only 120,000 years, or 6,300–8,000 generations[2] elapsed. The claim that humans have a large number of psychological adaptations with special design features for anything like the modern hunter-gatherer lifestyle is difficult to reconcile with these numbers.

I hope that collaborations between archaeologists and cognitive psychologists will become more common. The type of task analysis Wynn does for hominid toolmaking over time should be taken as a model for steps 2–3 in characterizing a psychological mechanism. Archaeology can help define adaptive functions for certain abilities by identifying the relevant time and selection pressures. Archaeology can also rid evolutionary psychology of vague assertions about "Pleistocene hunter-gatherers." Spatial cognition, cooperation,[3] living in small groups, and hierarchy negotiation are all adaptive problems that should be referred not to "our hunter-gatherer ancestors," but to earlier time periods, with other patterns of social organization and foraging.

Knowing one's ancestors is centrally important in the mythology of hunter-gatherers all over the world. If evolutionary psychologists really want to take a lesson from hunter-gatherers, we had better start talking to our ancestors. Wynn has shown us one way to do so.

NOTES

1. For example, Buss 1999; Cosmides 1989; Cosmides & Tooby 1987; 1992; Ellis 1992; Kurzban et al. 2001; Silverman et al. 2000; Wright 1994.

2. This assumes generation times ranging from 15–19 years of age (Bogin & Smith 1996; Dean, personal communication, 4/12/02; Dean et al. 2001; Smith & Tompkins 1995).

3. Stone et al. (2002) define the EEA for social exchange as at least as long ago as the Miocene.

Thinking and doing in cognitive archaeology: Giving skill its due

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Abstract: Wynn shows that intentionally standardized artifacts (handaxes) provide evidence of the ability to conceptualize form (symmetry). However, such conceptual ability is not sufficient for the actual production of these forms. Stone knapping is a concrete skill that is acquired in the real world. Appreciation of its perceptual-motor foundations and the broader issues surrounding skill acquisition may lead to further important insights into human cognitive evolution.

Wynn presents a valuable example of the way in which archaeology can contribute to our understanding of human cognitive evolution. Particularly important is his insistence that cognitive archaeologists should avoid traditional archaeological typologies in favor of psychological theories and methods. However, this still leaves the question of *which* psychological theories and methods should be applied.

Insofar as a Grand Unified Theory of human mental life does not appear to be on the horizon, a somewhat pluralistic approach to this question is probably most appropriate (Pickering 2001). The set of theories and methods that proves to be most illuminating will largely depend on what questions are being asked. Wynn chooses to base his analysis of the archaeological record on a fairly traditional theoretical framework derived from cognitive and developmental psychology. This framework is essentially *computational* in that it seeks to explain diverse overt behavior in terms of underlying formal cognitive operations (e.g., "frame independence" or "coordination of shape recognition"). Because Wynn, like many cognitive archaeologists, is primarily interested in using artifacts as evidence of abstract conceptual capacities, this framework is particularly well suited to the questions he is asking.

However, abstract conceptualization is not the only (nor perhaps even the most important) mental process involved in stone tool making, a fact that is reflected in some of Wynn's previous work (e.g., 1993a; 1995). Stone knapping is, first and foremost, a concrete and practical skill that is acquired and performed in the real world. The implications of this for cognitive archaeology are best appreciated from a theoretical perspective that draws on elements of ecological psychology (Gibson 1979; Michaels & Beek 1995), cultural psychology (Bruner 1990; Vygotsky 1978), and the dynamic systems approach (Bernstein 1967; Thelen & Smith 1994).

As Wynn states, "even [the] simplest of knapping actions requires directed blows" (sect. 2.1). In fact, many archaeologists have noted the perceptual-motor skill evident in the earliest stone tools (Ambrose 2001; Ludwig & Harris 1998; Semaw 2000). A great deal of experimental work is needed to describe more rigorously the skills associated with particular prehistoric technologies, but the preliminary PET research (Stout et al. 2000) cited by Wynn does suggest that even simple flake removal places significant demands on the dorsal visuomotor control system (Milner & Goodale 1995) of modern humans. Although perceptual-motor skill is often dismissed as trivial or primitive compared to abstract conceptualization, such skill is an impressive achievement requiring the discovery of dynamically stable behavioral solutions to inherently variable motor problems (Reed & Bril 1996). Huge portions of the modern human brain are involved in this process, including areas like the cerebellum, superior parietal lobule, and premotor cortices that appear to have experienced preferential expansion during human evolution. The sophisticated perceptual-motor skills that typify human sport, art, and craft can take years of dedicated practice to acquire, and are as reflective of human mental uniqueness as more "cognitive" behaviors like visualization and language.

Ethnographic studies of stone knapping (Roux et al. 1995; Stout 2002) indicate that, even in sophisticated modern technologies, mastery of the elementary percussive action is the most fundamental and time-consuming aspect of skill learning. Effective flaking is a specialized form of perception-though-action that allows for the discovery and stabilization of larger scale patterns (strategies) in necessarily variable reduction processes. Less skilled knappers can readily conceptualize or describe an appropriate reduction strategy, but they do not actually *comprehend* it in the concrete sense required for performance.

Wynn has previously pointed out (Wynn 1995) that skilled tool use is only developed through long periods of practice and observation. In modern humans, such learning occurs through guided participation in a *community of practice* (Lave & Wenger 1991). The social situation *scaffolds* (Wood et al. 1976) learning by providing opportunities for participation at appropriate levels of difficulty (i.e., within the *zone of proximal development* [Vygotsky 1978]) using culturally provided material and conceptual tools. Motivational and affective elements critical to learning (Damasio 1994; Greenspan 1996) derive from the culturally constructed meanings (Perret-Clermont et al. 1991; Fogel 1997) of participation. This is exemplified in the modern stone knapping craft of Langda village in Indonesian Irian Jaya (Stout 2002).

Over evolutionary time, this distinctly human, cultural, mode of learning came to replace the primitive hominoid condition. Modern chimpanzee societies scaffold skill acquisition to a degree (Boesch 1991), but lack the added dimension of cultural meaning and structure. In the absence of cultural facilitation of more intensive and/or protracted learning (as seen, for example, in captive "enculturated" apes), efficient nut cracking may approximate the upper limit of skill acquisition possible in chimpanzee societies. Premodern hominids clearly came to exceed this limit, perhaps through some "proto-cultural" adaptation such as the *mimetic culture* proposed by Donald (1991). Careful attention to the level of skill indicated by premodern stone artifacts may help to chart the course and timing of this critical development in human cognitive evolution.

As Wynn has shown, the conceptualization of form and symmetry is necessary to the production of standardized artifacts like later Acheulean handaxes. This is just the tip of the iceberg for cognitive archaeology, however, because such conceptualization is by no means sufficient for actual tool production. Thinking about knapping and actually knapping are closely related but diagnostically different mental behaviors (cf. Thelen & Smith 1994). Wynn has demonstrated the promise of psychologically informed research on stone tools, and it is to be hoped that he and others will continue in this vein to address the many exciting questions that remain.

Natural selection of visual symmetries

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Abstract: Implicitly, Wynn's target article starts from the transformational definition of symmetry. Unlike his suggestion, this traditional definition and the recent holographic definition are relevant to the discussion on the cognitive evolution of visual symmetries. These definitions reveal underlying properties and, thereby, they support the natural selection hypothesis. The holographic definition even agrees with an indirect test of this hypothesis.

In the course of evolution, our visual system became attuned to only a few of the innumerably many kinds of regularity in the world. A common idea in perception research is that each of these few regularities was selected because of its individual functionality – for the rest, these regularities are considered to be unrelated to one another. Remarkably, however, the visual regularities are practically the same as the regularities that are relevant in nonvisual domains such as crystallography and molecular biology. This domain-transcending relevance suggests that there might be a more fundamental property that is characteristic for only these few regularities. In fact, two such properties have indeed been found. One is the property of invariance under motion, as put forward in the traditional transformational approach (see, e.g., Palmer 1983). Another is the property of invariance under growth, as put forward in the more recent holographic approach (van der Helm & Leeuwenberg 1991; 1996; 1999).

As I elaborate in a moment, the transformational property relates to the external structure of regularities and is relevant in object recognition; the holographic property relates to the internal structure of regularities and is relevant in object perception (which precedes object recognition). Each of these two properties is, in a formal mathematical sense, characteristic for only a small set of regularities. The two regularity sets, thus defined, not only overlap largely, but also agree well with the regularities that are generally considered to be the visual regularities.

Although Wynn argued that such definitions are hardly required, he used the very specific transformational terminology by referring to the visual regularities as being symmetries that are reflectional, radial, rotational, or translational. Reflectional symmetry corresponds to mirror symmetry which, together with a kind of broken symmetry, forms the holographic regularity called bilateral symmetry; radial, rotational, and translational symmetries are variants of the holographic regularities called repetition and alternation.

Be that as it may, Wynn does not seem to realize that the transformational and holographic properties open the possibility that evolution has selected a central visuo-cognitive system that embodies one or both of these underlying properties. In other words, the existence of these underlying properties supports the idea that certain regularities became visual regularities by natural selection at the level of regularity-processing systems, rather than by, say, sexual selection at the level of individual regularities. Moreover, as I discuss next, favourable towards the survival of such a naturally selected system, are factors that run parallel to the transformational and holographic properties.

First, the transformational property of invariance under motion specifies visual regularities as being configurations which, if present in an object, yield the same retinal image after translations and rotations that let the object move as if it were rigid, even if it is not. This transformational invariance is a property of many flowers and crystals, for instance. The functionality of transformational invariance in object recognition is favourable towards its survival embodied in a regularity-processing system. That is, successful recognition of a transformationally invariant object, like a cube, can occur fairly independent of the viewpoint position taken by the observer (see, e.g., Enquist & Arak 1994).

Second, the holographic property of invariance under growth is the primary characteristic in van der Helm and Leeuwenberg's (1991) definition of visual regularity, and may be illustrated as follows. Living organisms generally grow such that their body shape remains basically symmetrical – that is, the symmetry structure is invariant under body growth. Similarly, the repetition structure of, for instance, a queue of virtually identical penguins remains a repetition structure when the number of penguins increases – that is, it is invariant under queue growth. The symmetry structure of a body grows cell by cell, and the repetition structure of a queue of penguins grows penguin by penguin, so that the holographic growth steps can be said to specify the constituent parts of each regularity.

The foregoing illustrates that holographic invariance relates to the internal growth structure of regularities – as opposed to transformational invariance, which relates to the external motion structure of regularities. Despite this difference, the functionality of transformational invariance in object recognition is also favourable towards the survival of a regularity-processing system that embodies the holographic property. After all, as mentioned, the holographic and transformational regularity sets overlap largely. By specifying the constituent parts of regularity, however, holographic invariance seems more fundamental: It specifies the intrinsic character of regularity, rather than just a transformational consequence of regularity. Furthermore, holographic growth seems a useful model of the way in which the visual system builds up its representation of regularities. Indeed, in contrast to the transformational approach, the holographic approach provides a fairly comprehensive explanation of the human perception of not only perfect but also imperfect regularities (see van der Helm & Leeuwenberg 1996; 1999).

For instance, the well-known phenomenon that mirror symmetry is the best detectable visual regularity by far (see, e.g., Barlow & Reeves 1979) is holographically explicable. Holographically, it is therefore no surprise that mirror symmetry intruded into various visuo-cognitive domains – including the domain of mate assessment, where a preference for more-symmetrical mates has been found (see, e.g., Møller 1992). Related to biological growth, these domains provide two further factors that are favourable towards the survival of holographic invariance embodied in a regularity-processing system. First, in scene perception in general, mirror symmetry is preeminently a cue for the presence of a living object. Second, in mate assessment in particular, the degree of (a)symmetry in an organism's body shape seems to be correlated with the organism's health in terms of genetic quality, developmental stress, and reproductive success (see, e.g., Møller 1990). Hence, the holographically-explicable high salience of mirror symmetry is functional in both domains.

Finally, several holographically explicable peculiarities suggest that our far ancestors indeed perceived regularities in the same