

**HUMAN COGNITIVE EVOLUTION, STONE AGE ARCHAEOLOGY AND BRIDGING THEORY
FROM A BOW HUNTER'S PERSPECTIVE**

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Bridging theory and bow hunting: human cognitive evolution and archaeology.

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Introduction

Recognising elements of a 'modern' mind, or complex cognition, in Stone Age archaeology is difficult and often disputed. A key question is whether, and in which way *Homo sapiens* thinking differs from that of other *Homo* species/sub-species. We argue that if the question of whether the modern mind is different from that of our ancestors or other members of the *Homo* family is to be fully explored, some focus should fall on technologies and behaviours unique to *H. sapiens*. Here we hypothesise about one such techno-behaviour, i.e., bow hunting (Fig. 1). This is different from, for example, symbolic behaviour for which there is also evidence amongst the Neanderthals (Mellars 2010). Other technologies and their associated behavioural repertoires,

such as the heat treatment of rocks to improve knapping properties and hunting with snares represent similar opportunities to explore the cognition of early *H. sapiens* (Wadley 2010, 2013).

Archaeology of bow hunting, bridging theory and cognitive interpretation

Archaeological evidence for bow hunting is thus far exclusive to *H. sapiens* (Shea & Sisk 2010), never having been found in association with other members of our family. Bow hunting was long thought of as a recent, Holocene, invention. But new evidence from southern Africa is pushing the innovation back to between 37 000 and 65 000 years ago (Backwell et al. 2008; Lombard & Phillipson 2010; d'Errico et al. 2012; Robbins et al. 2012), perhaps even to 71 000 years ago (McBrearty 2012). In the southern African context, we know that the techno-behaviour is associated with *H. sapiens*, because from at least 100 000 years ago humans here were anatomically modern, and features of the DNA profile of populations currently living in the region can also be traced back to at least 100 000 years ago (see Lombard et al. 2013 for cross-disciplinary overview). The antiquity of the finds indicate that bow-and-arrow technology could be relevant for investigating cognitive evolution.

Archaeological assessments of prehistoric cognition must rest on a series of bridging arguments (Botha 2010; Wynn 2009; Wadley 2013; Haidle 2014) (Fig. 2). In the case of bow hunting, archaeological data (A), consist mostly of stone/bone tools. The technical system (C) is inferred using artefact attributes and functional interpretations. Inferring the technical system from the archaeological evidence requires an explicit justification, or in Botha's terms, it requires that the argument be warranted. Here the warrant rests on Southern African ethnographic evidence of microliths used as arrow tips, and the temporal extension of this evidence into Later Stone Age assemblages, including actual stone-tipped arrows (Binneman 1994). This link in the inference chain is uncontroversial and is accepted by virtually all archaeologists of the South African Stone Age. A detailed reconstruction and analysis of perceptions and actions in the problem-solution sequences of manufacture and use of a bow-and-arrow set (Lombard & Haidle 2012) address the next bridging argument (C-D-E) (Fig. 3). These sequences describe how the activities were organized and what artisans had to know, conceive and do, to accomplish their goals (see Haidle 2014 for a more detailed discussion of cognigrams and effective chains in relation to bridging arguments).

The final bridge in a cognitive interpretation is an argument about the cognitive systems underpinning the different reconstructed activities. Many self-described cognitive interpretations skip this step, assuming that the number of elements and steps in a problem-solution sequence is somehow a direct measure of cognition. We emphasize that technical complexity may be the result of a variety of cognitive processes, the probability and plausibility of which has to be discussed in the interpretative process; but, although interdependent with cognitive performances, technical complexity is part of a behavioural pattern and cannot be a direct measure of anything cognitive. To argue about cognition, it is necessary to introduce a knowledge of cognitive systems. Thus, the final bridging argument (E-F-G) must be built by linking archaeological features to explicit hypotheses of cognition (Garofoli & Haidle 2014). The strength of the final inference rests on the power of the cognitive hypotheses employed and the success in linking technical components to components of the hypothesis. Strict parsimony must apply. The simplest cognitive system that can account for archaeological features must be given priority.

Expert cognition and bow-and-arrow technology

Teasing apart bow-and-arrow technology demonstrates an elaborate craft production, equivalent in its basic organization to current craft production such as blacksmithing (Keller & Keller 1996). Primary among these similarities is the overarching hierarchical outline of the task. There was clearly a large-scale goal and plan – the functioning system – that can be broken down into a number of more or less self-contained technical units or modules (Lombard & Haidle 2012). The cognitive requirements for the modules are rather different from those required to coordinate the entire task, and it is appropriate to treat them separately. Execution of the individual modules relies primarily on the resources of expert cognition (Ericsson & Knitch 1995; Ericsson & Delaney 1999). An expert performance has several attributes that distinguishes it from other activities:

- 1) Rapid problem assessment,
- 2) Rapid switching to alternative solutions when required,
- 3) Almost error-free execution,
- 4) Attention switching to other tasks without loss of information,

- 5) Restriction to a narrow range of expertise,
- 6) Years of practice to acquire mastery.

Expertise includes domains such as chess, sport, musical performance, and medical diagnosis (Ericsson & Delaney 1999) but is also at play in technical activities (Wynn & Coolidge 2004, 2010). An essential component to all expert performance is practice. Practice is essential because expertise relies on well-learned sequences of knowledge and action, constructed using two cognitive short cuts – chunking and chaining. Chunking involves dividing bodies of information or actions into smaller, more easily processed chunks. Chunks are then chained together into longer sequences by repetition; often a final element in one chunk acts as a cue for the initial element in the next. This organization is true for both verbal and procedural information and is most familiar in the motor routines of sport and instrumental music performance. Chunking and chaining must be learned by repetition.

This cognitive system is difficult to access *via* conscious attention, and the chunks and cues cannot be learned by volition. But expertise is not exclusively a domain of chunking and chaining and procedural cognition. Working memory (WM) plays a role, as most clearly described in the model of long-term working memory (LTWM) (Ericsson & Delaney 1999). Again cues are the key. The expert acquires a long chain of information through practice, and then attaches a kind of access button to it – a cue. When he or she retrieves the cue into WM, it instantly accesses all the information to which it has been linked (e.g., a chess opening such as ‘Sicilian defense’). One of the essential tasks in acquiring expert ability is assembling clusters of cues, referred to as a retrieval structure (Ericsson & Delaney 1999). An expert learns a huge number of retrieval structures, tied to almost every conceivable variation in the task condition. As a form of cognition, expertise is almost certainly old in an evolutionary sense. Chunking and chaining are old learning mechanisms, as is cueing. The size of expert knowledge is limited primarily by the size of long term memory. WM capacity is relevant only in the number of retrieval structures one can access at once, or probably more important for our current topic, the amount of free attention space available in WM after a retrieval structure has been activated.

Each of the technical modules of the bow and arrow could easily be learned *via* expert cognition. Within each phase the steps are chunks of procedure chained together, and the shifts in attention are similarly organized into a sequence, one cueing the next. Even the phases themselves can be executed in this string-of-beads manner (Gatewood 1985). Flexibility is built into the procedure. There are, for instance, at least four alternative ways to bend the stave (Lombard & Haidle 2012). Variation in local conditions and personal history cue the appropriate sequence of actions. The more staves the artisan produces, the more automatic the cognitive retrieval structure becomes. Decisions thus increasingly require less attention, i.e., less occupation of WM capacity. Producing a bow stave is a classic example of expert cognition at work. Even during the application of learned modules when the stave is fitted with a string to produce a composite tool, the bow falls easily within the domain of expertise.

This kind of thinking is not a recent evolutionary acquisition. It was well within the cognitive range of Neanderthals and all early forms of *H. sapiens*. Elements of chunking and chaining, and thus expertise, can be traced back to early stone tool production at least 2.6 million years ago (Semaw et al. 2003). It is probable that an increase in LTWM capacity accompanied the transition from *Homo erectus* to *Homo heidelbergensis* (this would be consistent with increase in brain size), but basic expert cognition would appear to have evolved much earlier. We suspect that even *H. heidelbergensis* could have learned to execute most, if not all, of the isolated modules associated with producing a bow and arrow. But we also aver that they probably could not have invented a bow and arrow, and almost certainly could not have conceived of, and organized, the entire system. Something more than expertise is required.

Episodic memory and bow hunting

It is impossible to detect how bow-and-arrow technology was first invented. Parsimony requires that we assume the simplest form of innovation was in play. In technology this involves fortuitous mistakes, or attentive small modifications of known procedures. Both rely on free attention space in WM, that is, someone needed to ‘notice’ the fortuitous mistake or alternate step (Wynn & Coolidge in press). There is no reason to deny this ability to early *H. sapiens*, Neanderthals or *H. heidelbergensis*. The bow and arrow required many innovations, and they may have occurred over a shorter time span than innovations in stone-tipped spears, suggesting

that more people had excess WM capacity, or that there was a greater excess of capacity. But there is something about the bow-and-arrow system as a whole that implies an important development in cognition – bow-and-arrow manufacture requires a much longer temporal extension of activity, stretching consideration of forthcoming conditions much further into the future. The evidence here comes not from the technical modules themselves, but from the overarching plan of a complementary set of different composite tools as summarized in the effective chain of thought and action (Fig. 3).

To produce and operate an effective bow-and-arrow system, one must be able to access the entire system in attention, at least occasionally. Both elements, bow and arrow, need not only adjustment to the final goal, but have also to be conceived in relation to each other. If an arrow is made, not only the peculiarity of the envisaged prey is taken into account, but also the specificity of the bow as a technological complement. Without this, one could not plan to acquire the disparate elements necessary for the different modules, or make sure that required materials were available. And the best way to do this is to place oneself in an imagined future state and evaluate the imagined future situation. Expertise cannot do this. It cannot account for the reactivation of all the modules over temporal and spatial gaps. A more specific cognitive model candidate for the understanding of this scale of the technology is that of episodic memory. We propose that episodic memory is directly linked to bow-and-arrow use and may be considered a necessary, but not sufficient, condition.

Episodic memory allows for the recall of past experiences (Tulving 2002; Tulving & Kim 2007). When people recall a past event, they mentally travel back in time. However, they are aware that the conscious re-experience of the event is qualitatively different from the initial experience of that event. Thus, episodic memory involves the recollection of events and other elements associated with those events (event clusters), involving a special kind of awareness that if events can be re-imagined, and even modified (consciously or unconsciously), then time itself is subjective. The conscious awareness of one's self in a past memory and/or one's conscious manipulation of a past memory is what Tulving referred to as *autonoetic awareness*. Tulving further hypothesized episodic memory was a recently evolved phenomenon and is probably unique to *H. sapiens*.

Humans do share this kind of memory with most animals, but at some point in recent human evolution, true episodic memory evolved and hominins became unique. Earlier hominins were probably capable of acquiring and using these past events (i.e., knowledge). Tulving (2002) proposed that they could solve present problems based on past experiences, but that they were probably unaware that they were doing so. Here, we might elaborate upon our reference to ‘true’ episodic memory. Although the terms episodic memory and autobiographical memory are often bandied about as synonymous, we would propose that autobiographical memory is a subset of the broader category of episodic memory, the latter of which is certainly characteristic of many animal species (e.g., Allen & Fortin 2013). Autobiographical memory, however, involves a clear sense of one’s self in the event’s recall; it may be unique to *H. sapiens* and recently evolved.

Episodic memory is not perfect. It is not reproductive, but it is constructive, and it is therefore subject to all kinds of errors and illusions (Schacter 1999). It may be that these imperfections of the episodic memory system may well have led to the ‘fortuitous’ mistakes we referred to earlier in the simplest forms of innovation. Numerous examples reside in the literature of these inaccuracies including the well-documented vagaries of eye-witness testimony and confabulations, where people intentionally or unintentionally mix the past with both fact and fiction often without a complete awareness of doing so. Thus, it has long been noted that episodic memory is “fundamentally constructive, rather than reproductive” (Schacter 1999; Addis et al. 2007; Schacter & Addis 2007; Addis et al. 2009). Schacter and Addis (2007) consequently proposed a constructive episodic simulation hypothesis, which allows for the recombination of past details or imagined events in the future into novel configurations. These simulations can recall past events in a highly flexible manner in order to enhance the success of immediate or distant future actions.

Schacter and Addis (2007) reasoned that, as the future is not an exact representation of the past, the ability to simulate future events must be inherently flexible in order to recall, extract, and recombine aspects of past events to ensure the success of future actions. Their concept of constructive episodic simulation may be the critical cognitive component for bow-and-arrow

technology as well as its ‘inexact’ nature, as we referred to earlier. Their concept may support our key bridging argument for the nature of a cognitive system as a whole, which can activate, deactivate, and reactivate expertise modules over temporal and spatial spans.

Tentatively bridging cognitive and neural spheres

It has been proposed that a sense of self and self-representation may have its neurological foundations in the superior medial parietal lobes, i.e., the precuneus (Lou et al. 2004). Again, it may be no mere coincidence that episodic memory has also been linked to the precuneus as well as prefrontal regions and medial temporal regions (e.g., Schacter & Addis 2007; Schacter et al. 2007). We have already intimated this interrelationship between recalling the past, simulating the future, and one’s sense of self (although perhaps the latter is not a necessary condition but it may well be) may rest upon similar neuronal substrates (e.g., Okuda et al. 2003), particularly the precuneus (Addis et al. 2007, Buckner & Carroll 2007; Spreng & Grady 2010). Provocatively, Bruner has recently found evidence for precuneal expansion in recent *H. sapiens* not shared by Neanderthals (Bruner 2004, 2010).

Conclusion

It appears that the cognitive requirements for bow-and-arrow technology, or those that are operated ‘out of sight, but not out of mind’ such as snares (Wadley 2010), may have required a fully modern episodic memory system: a cognitive system that is capable not only of autobiographical memory retrieval, but also of constructive episodic memory simulations. If the latter suppositions find further support, then the early makers of bow-and-arrow technologies in all likelihood possessed a fully auto-noetic awareness. The latter conclusion may also be bolstered by a recent finding that, in an event-queuing paradigm, it is unlikely that future prospection relies solely upon autobiographical/episodic memory networks (D’Argembeau & Demblon 2012). D’Argembeau and Demblon argue their findings strongly suggest that personal goals, which rely upon personal abstract knowledge, provide an important framework for the overall organization of imagined events. Thus, future imagined events “may be linked together in broader event sequences on the basis of their causal roles in achieving personal goals” (Tulving 2002:166). Finding evidence for a sense of self in the archaeological record is a Herculean task. However, recent work (D’Argembeau & Mathy 2011; D’Argembeau & Demblon 2012), which

demonstrates that a personal sense of self and awareness of one's goals is critical to linking and organizing successful future simulations, may provide a tenuous basis for a near modern or fully modern sense of self and auto-noetic thinking, possibly before 60,000 years ago.

References

Addis, D., Pan, L., Vu, M.A., Laiser, N., & Schacter, D. 2009. Constructive episodic simulation of the future and the past: distinct subsystems of a core brain network mediate imagining and remembering. *Neuropsychologia* 47:2222-2238.

Addis, D., Wong, A. & Schacter, D. 2007. Remembering the past and imagining the future: common and distinct neural substrates during event construction and elaboration. *Neuropsychologia* 45:1363-1377.

Allen, T. A. & Fortin, N. J. 2013. The evolution of episodic memory. *Proceedings of the National Academy of Sciences*, 110 (Suppl 2):10379-10386.

Backwell, L. d'Errico, F. & Wadley, L. 2008. Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. *Journal of Archaeological Science* 35:566-1580.

Binneman, J.N.F.1994. A unique stone-tipped arrowhead from Adam's Kranz Cave, Eastern Cape. *Southern African Field Archaeology* 3: 58-60.

Botha, R. 2010. On the soundness of inferring modern language from symbolic behaviour. *Cambridge Archaeological Journal* 20:345-356.

Bruner, E. 2004. Geometric morphometrics and paleoneurology: Brain shape evolution in the genus *Homo*. *Journal of Human Evolution* 47:279-303.

Bruner, E. 2010. Morphological differences in the parietal lobes with the human genus: A neurofunctional perspective. *Current Anthropology* 51: S77-S88.

Buckner, R.L. & Carroll, D.C. 2007. Self-projection and the brain. *Trends in Cognitive Science* 11:49-57.

D'Argembeau, A. & Demblon, J. 2012. On the representational systems underlying prospection: Evidence from the event-cueing paradigm. *Cognition* 125:160-167.

D'Argembeau, A. & Mathy, A. 2011. Tracking the construction of episodic future thoughts. *Journal of Experimental Psychology: General* 140:258-271.

d'Errico, F., Backwell, L., Villa, P., Degano, I., Lucejko, J., Bamford, M., Higham, T.F.G., Colombini, M., Beaumont, P.B. 2012. Early evidence of San material culture represented by organic artefacts from Border Cave, South Africa. *PNAS* 109:13214-13219.

Ericsson, K. & Delaney, P. 1999. Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance, in A. Miyake & P. Shah (eds) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*: 257-297. Cambridge: Cambridge University Press.

Ericsson, K.A. & Kintsch, W. 1995. Long-term working memory. *Psychology Review* 102:211-245.

Garofoli, D. & Haidle, M.N. 2014. Epistemological problems in cognitive archaeology: an anti-relativistic proposal towards methodological uniformity. *Journal of Anthropological Science* 92:7-41.

Gatewood, J. 1985. Actions speak louder than words, in J. Dougherty (ed.) *Directions in Cognitive Anthropology*: 199-220. Urbana: University of Illinois Press.

Haidle, M. N. 2014. Building a bridge – an archaeologist's perspective on the evolution of causal cognition. *Frontiers in Psychology* 5, Article 1472: 1-15. Doi: 10.3389/fpsyg.2014.01472.

Keller, C. & Keller, J. 1996. *Cognition and Tool Use: the Blacksmith at Work*. Cambridge: Cambridge University Press.

Lombard, M. & Phillipson, L. 2010. Indications of bow and stone-tipped arrow use 64 000 years ago in KwaZulu-Natal, South Africa. *Antiquity* 84:635-648.

– & Haidle, M.N. 2012. Thinking a bow-and-arrow set: cognitive implications of Middle Stone Age bow and stone-tipped arrow technology. *Cambridge Archaeological Journal* 22:237-264.

– Schlebusch, C. & Soodyall, H. 2013. Bridging disciplines to better elucidate the evolution of early *Homo sapiens* in southern Africa. *South African Journal of Science* 109: 27-34.

Lou, H.C., Luber, B., Crupain, M., Keenan, J.P., Nowak, M., Kjaer, T.W. ... Lisanby, S.H. 2004. Parietal cortex and representation of the mental self. *Proceedings of the National Academy of Sciences*, 101:6827–6832.

McBrearty, S. 2012. Sharpening the mind. *Nature* 491:531-532.

Mellars, P. 2010. Neanderthal symbolism and ornament manufacture: the bursting of a bubble? *PNAS* 107: 20147-20148.

Okuda, J., Fujii, T., Ohtake, H., Tsukiura, T., Tanji, K., Suzuki, K., et al. 2003. Thinking of the future and past: the roles of the frontal pole and the temporal lobes. *Neuroimage* 19:1369-1380.

Robbins, L.H., Campbell, A.C., Brook, G.A., Murphy, M.L., Hitchcock, R.K. 2012. The antiquity of the bow and arrow in the Kalahari Desert: bone points from White Paintings Rockshelter, Botswana. *Journal of African Archaeology* 10:7-20.

Schacter, D. 1999. The seven sins of memory: Insights from psychology and cognitive neuroscience. *American Psychology* 54:182-203.

– & Addis, D. 2007. The cognitive neuroscience of constructive memory: remembering the past and imagining the future. *Philosophical Transactions of the Royal Society B* 362:773-786.

– Addis, D.R., Buckner, R. L. 2007. Remembering the past to imagine the future: The prospective brain. *Nature Reviews Neuroscience* 8:657-661.

Semaw, S., Rogers, M.J., Quade, J. Renned, P. R. Butler, R.F., Dominguez-Rodrigo, M., Stout, D., Hart, W.S., Pickering, T., Simpson, S.W. 2003. 2.6-Million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. *Journal of Human Evolution*, 45:169-177.

Shea, J.J. & Sisk, M.L. 2010. Complex projectile technology and *Homo sapiens* dispersal into Western Eurasia. *PaleoAnthropology* 2010: 100-122.

Spreng, R.N. & Grady, C.L. 2010. Patterns of brain activity supporting autobiographical memory, prospection, and theory of mind, and their relationship to the default mode network. *Journal of Cognitive Neuroscience* 22:1112-1123.

Tulving, E. 2002. Episodic memory: from mind to brain. *Annual Review of Psychology* 53:1-25.

– & Kim A. 2007. The evolution of foresight: What is mental time travel, and is it unique to humans? *Behavioral and Brain Sciences* 30:334-335.

Wadley, L. 2010. Were snares used in the Middle Stone Age and does it matter? A review and case study from Sibudu, South Africa. *Journal of Human Evolution* 58:179-192.

– 2013. Recognizing complex cognition through innovative technology in Stone Age and Palaeolithic Sites. *Cambridge Archaeological Journal* 23:163-183.

Wynn, T. 2009. Hafted spears and the archaeology of mind. *PNAS USA* 106:9544-9545.

– & Coolidge, F.L. 2004. The expert Neandertal mind. *Journal of Human Evolution* 46: 467-487.

– 2010. How Levallois reduction is similar to, and not similar to, playing chess, in A. Nowell & I. Davidson (eds.) *Stone Tools and the Evolution of Human Cognition*: 83-104. Boulder: University of Colorado Press.

– in press. Technical cognition, working memory, and creativity. *Pragmatics & Cognition*.

Figure Legends



Figure 1: San man hunting with bow and arrow, Kalahari, Northern Cape, South Africa (photograph used with permission from Ariadne van Zandbergen©, The Africa Image Library).

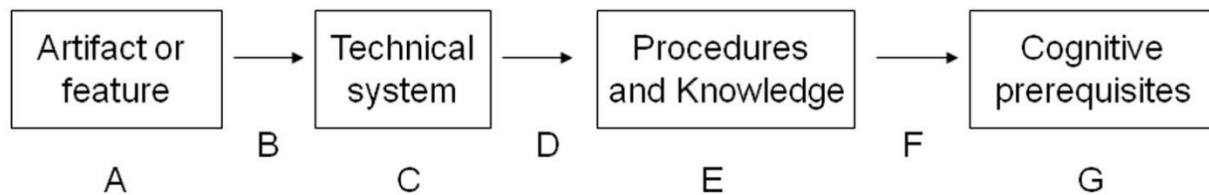


Figure 2: Graphic representation of a series of bridging arguments for archaeological assessment of prehistoric cognition (after Botha 2010; Wynn 2009).

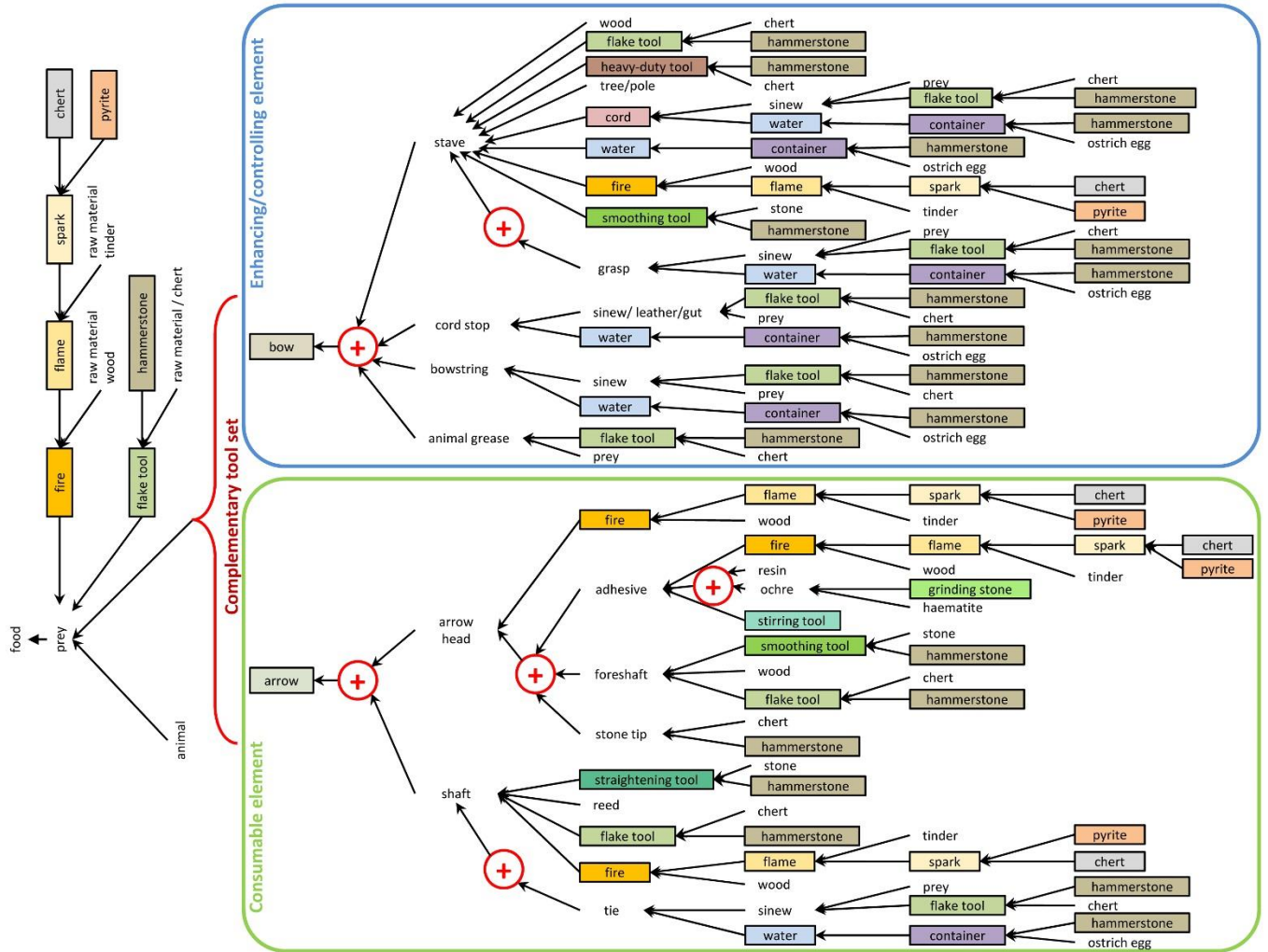


Figure 3: Hypothetical, effective thought-and action chain for a bow and stone-tipped arrow reconstructed from experimental, archaeological and ethnographic information (adapted from Lombard & Haidle 2012).