The Evolution of Technical Competence: Strategic and Economic Thinking

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Abstract

This paper will outline a series of changes in the archaeological record related to Hominins. I argue that these changes underlie the emergence of the capacity for strategic thinking. The paper will start by examining the foundation of technical skills found in primates, and then work through various phases of the archaeological and paleontological record. I argue that the key driver for the development of strategic thinking was the need to expand range sizes and cope with increasingly heterogeneous environments.

Keywords: Human Evolution; Strategic Thinking; Archaeology; Hominins;

Introduction

In recent decades, discussions of human cognitive evolution have frequently focused on social skills. Humans are, so the argument goes, hyper-social. This hyper-sociality underpins all other uniquely human achievements, as it allows for, and requires, co-operation, co-ordination, pooled information, specialisation, language use, et cetera. Consequently, cognitive scientists have focused on the question: How did humans evolve to be hyper-social? Collections such as the Byrne and Whiten edited "Machiavellian Ape," (1988), and monographs such as Robin Dunbar's "Grooming, gossip and the evolution of language," (1996), to name but two, are early examples of work on the cognitive skills associated with social complexity. The implication is that human evolution has been shaped almost entirely by developments in the social sphere, and that the uniqueness of human beings is the result of our sociality.

In somewhat stark contrast archaeologists have developed increasingly sophisticated reconstructions of hominin behaviours associated with stone tools and other aspects of the material world. Rich behavioural reconstructions of our hominin ancestors in detailed ecological and social settings are becoming commonplace (See for instance Odell, 1996).

This paper is part of a broader project that integrates these two strands of research: the evolutionary cognitive sciences and the archaeological sciences. It takes a lead from Steven Mithen's (1996) "The Prehistory of the Mind," and subsequent work by people such as Thomas Wynn (Coolidge & Wynn, 2009; Wynn, 2002), showing that the archaeological and physiological evidence, coupled with that from cognitive science, constrains speculations about human cognitive evolution. Cognitive science and archaeology potentially illuminate one another.

On this view, tools, their manufacture and use, should not be incidental to our understanding of our evolutionary past: They should be central. This should come as no surprise to cognitive scientists. As the cognitive sciences increasingly come to see minds as embodied, extended, and embedded in their environmental contexts, stone tools become less the detritus of the human past, and more the fossilised hard parts of ephemeral thoughts.

This paper looks at one strand of human cognition: the ability to engage in strategic planning. I examine the archaeological record and seek to identify the emergence of this skill in its evolutionary context. It will do so by examining the archaeological record in a chronological order, showing the subtle shifts in skills that underpin stone tool making, starting with the primate background, and progressing through to the technologies associated with Homo sapiens.

The Shared Legacy

Extant primates are in fact the few isolated survivors of a diverse and widespread group that flourished in the Miocene (Cameron, 2004; Cameron & Groves, 2004). Of the large primates, Homo sapiens are most closely related to Pan paniscus and Pan troglodytes (the chimpanzees). Consequently, features shared by Pan and Homo are probably homologies: features common to all of the human ancestors.

Large mammals like the primates, particularly K-selected organisms, tend to have offspring that require high parental investment (Foley, 1987). Consequently, offspring tend to be born singly, and spaced apart to allow for long periods of growth, dependency and learning.

High levels of sociality and interaction, coupled with this long period of dependence, provides a robust platform for social learning in the primates, as it does in many other species (See for instance Rendell & Whitehead, 2001). Behaviour is structured by the opportunities provided by the physical environment through exploration and play, coupled with behavioural templates offered by the social environment. All the large apes learn from prior generations, Pan and Homo particularly so. As a result they have cultural inheritance (Laland & Hoppitt, 2003; McGrew, 1991; A. Whiten et al., 1999). Thus, we should consider culture a homology; a trait all human ancestors share.

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1 Recent genetic work has broadened the term Hominid to include the chimpanzees Pan paniscus and Pan troglodytes. The term Hominin refers to the Homininae, the bi-pedal primates: the Australopithecines and Homo genus.

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All apes are manually dexterous, and the great apes all show signs of basic tool using. Chimpanzees are notable for their use of percussive technologies, with nut cracking being a familiar example from a repertoire of percussive technological culture (Andrew Whiten, Schick, & Toth, 2009). The combination of manual dexterity and observation of parents manifests itself in long, and frequently complex, extractive foraging behaviours (Coolidge & Wynn, 2009). Apes are capable of learning long sequences of chained actions that lead to a goal.² So

² Like extended childhood, complex signalling or sociality, this is not a uniquely hominid trait. New Caledonian crows appear to
another homology of the hominins is this capacity for multi-stage food extraction, with preparatory activities that in some cases involve tools and tool preparation, as part of a chained sequence of behaviours.

Given this common ancestry, we can presume with a high degree of confidence that even before archaeologists can see tools in the archaeological record, early hominins possessed a substrate of skills associated with tools, tool manufacture, and manipulation of the external world. They engaged in long extractive foraging sequences. Their extractive sequences involved the manipulation of tools and materials. And, the sequences were learnt in a group context through observation of adults and peers, and were potentially fine tuned to the local environment. All hominins had tool making and tool using cultures.

The Australopithecines

With the drying of the east coast of Africa, pockets of the last common ancestor of chimps and humans found themselves in increasingly novel environments. Instead of homogenous forest habitats, the east coast of Africa became ecologically variable. There were areas of acacia forest, bushland, denser forested environments around rivers, as well as environments that were more open and savanna like. Early bi-pedal hominins, the Australopithecines such as *A. afarensis*, and *A. Australopithecus*, were in a heterogeneous landscape.

In such a heterogeneous environment, both extractive foraging sequences and cultural learning would play and increasingly important role. Extractive foraging, abetted by technical skills, may even have had an expanded role in the Australopithecine foraging repertoire. Cultural learning might have fine-tuned these skills to a new level of adaptive significance. A group with a cultural tool using skill such as marrow extraction from abandoned carcasses, or tuber extraction from the roots of a plant, may have had a crucial adaptive edge that enabled them to flourish, regardless of which disparate piece of the world they found themselves in.

The archaeological record of such skills is probably invisible. Rocks used opportunistically by hominins are indistinguishable from geologically abundant material (S. Savage-Rumbaugh & Lewin, 1994) without close microscopic examination that might reveal distinctive wear-patterns. However, we can assess the increasing importance of such skills by clues in the physiological record.

For a start, the emergence of bi-pedalism should not be underestimated. Overlooked in many modern studies of human cognitive evolution, bi-pedalism was long considered a major milestone by prior generations of paleoanthropologists (Landau, 1984, 1991). Bi-pedalism frees the hands, allows for the unencumbered arms to gesture, and crucially for our interest here, it enables hominins to carry things efficiently. Increased ability to carry things efficiently allows for the movement of goods between locations, and changes the potential uses of the landscape markedly. The efficient transfer of resources was potentially crucial, as it allowed for the exploitation of a range of habitats. One could forage in one location, but retreat to safety in another. One might process a food in one location, but consume it in another. This means that behavioural sequences associated with extractive foraging would have to stretch to accommodate this new possibility for the exploitation of space.

It's also worth noting that not just tools and food that could be carried: Infants, carried frontally, gain the potential to engage in dual monitoring of parents and their parents' world (S. Savage-Rumbaugh, 1994).

The Australopithecine Legacy

The Australopithecines were something more than upright chimpanzees. With the common ancestry of technologically aided food extraction, the Australopithecines were actively engaging with technology at some level. Crucially, bi-pedality suggests that transportation of foodstuffs and material over distances are features of the Australopithecine world. Behavioural sequences are under pressure to stretch...
to accommodate larger ranges. Individuals who could maintain an extractive foraging sequence over a longer distance would be able to exploit a great number of ecological zones.

The hominin baseline is then of a manipulative bi-pedal ape, actively engaging the physical world. It is not until the emergence of the Oldowan culture, in eastern Africa, dated to 2.6 million years ago and associated with the emergence of the Homo genus, that we start seeing definite archaeological evidence of tools.

**The First Tools**

We may think of rocks as fairly ubiquitous, but in fact, rock with the right properties for stone tool manufacture can be rare and difficult to obtain. The result is that stone tool manufacture is not just about the cost of the manufacturing labour; it is also about the cost of procuring materials. Groups that live near a raw material site are less constrained by procurement costs, while other groups may be forced to travel significant distances, or trade, for the best raw materials. Stone tool manufacture thus comes with some basic constraints that structure the optimal forms and behaviours associated with tools.

Once we recognise constraints, we can then start understanding optimal tool manufacturing, given the likely adaptive pressures. Take as an example a group that forages along a riverine environment for carcasses suitable for marrow extraction. On discovering a carcass, a nearby rock from the rivers edge is used to break open long limb bones, and marrow is retrieved. If the tool ‘breaks,’ another rock can be picked up and used. Once the task is finished, the tool can be discarded, as continued foraging in this environment suggests a ready access to raw materials. Tools are cheap.

Some suggest that this scenario is not too far removed from the earliest hominin tool making. Mode 1 tools (See Evolutionary Timetable) are simple cobbles with flakes struck off. They have frequently been made and deployed locally, although there is some evidence of transportation. Both in procurement costs, and manufacturing costs, these tools are ‘cheap,’ with low investment encouraged by the readily available raw materials.

In chimpanzees, the inability to transport materials long distances means that behavioural sequences—from tool preparation to processing to acquisition to consumption—will be physically and temporally compact. Materials and targets will be physically contiguous. With bi-pedalism, the ability to transport both tools and spoils means that hominin actors are less tied to specific environments.

However, this forces the behavioural chain to stretch temporally and spatially over quite different areas, with longer time frames, in the face of potential distractions. The extractive foraging sequence is no longer compact.

**Decoupling Representations in Time and Space**

Kim Sterelny, following Peter Godfrey-Smith (Godfrey-Smith, 1996), has argued that interactions with other organisms—either intra or inter species—drive the decoupling of representations from single inputs, and eventually drive the decoupling of behavioural outputs as well (Sterelny, 2003). Predators and prey actively deceive one another, and this pushes the organism to use multiple features of the world to detect other organisms. In some cases, this can also lead to decoupled behavioural outputs: flexible responses to the information in the world.

With the Australopithecines, and then more completely with Early Homo, we see pressures for decoupled representations in new domains: the displacement in time and place of components in a behavioural chain. The components of a chain of behaviour occur in physically, temporally, and consequently, perceptually de-coupled ecological zones. The agent must re-couple them across the behavioural sequence. The Hominin actors can’t use local physical cues to guide behaviours; they must drive behavioural sequences using other means. Early Homo in particular needed to represent phases of a behavioural sequence independently of stimulus, and to maintain these in the face of distractions and more immediate concerns such as navigating terrain.

This is quite likely to be adaptively salient to hominins in a number of ways. For a start, it allows the exploitation of novel heterogeneous landscapes, with potentially distinct zones of raw material acquisition and potential foraging. With this cognitive skill in place, the two ecological zones do not need to be perceptually contiguous. There is no physical cue to trigger the next stage of a behavioural sequence, so the hominin must be motivated internally or by other means, perhaps socially.

Once in place, this skill also allows for the exploitation of bigger ranges. Group range size probably increased in the early Pleistocene, as the increasingly dry landscape required greater areas to support groups. Increasingly elastic

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**Figure 2: Homo Tool Making.** With the emergence of Mode 2 tools, we start to see the increasing modularisation of the various aspects of the behavioural chain. The raw material/tool-making task tends to remain fairly linked in both time and space. What's more, this modularised behaviour may have been subject to selection independently of deployment (See text). Tool deployment however can be displaced from these earlier behaviours. This allows for an increase in range size, and the deployment of tools in places and times well removed from raw materials. Raw materials no longer constrain deployment.
behavioural chains, even if still rather rigid and stereotyped in sequence, allows for the exploitation of these expanding, complex ranges.

This need to maintain behaviours over increasing distance was aggravated by the increasing seasonality of the early Pleistocene (Foley, 1987). Seasonal resources have to be harvested when available, and opportunities taken. Flexibility in the face of changing seasonal resources would also confer adaptive advantage on individuals and groups. 3

The picture that emerges is then of agents with learned behavioural chains associated with tool use, behaviours under constant pressure to stretch to accommodate increasing physical and temporal displacement. Individuals who can maintain behavioural chains over longer distances, and perhaps maintain such chains in the face of distractions, would have more opportunities, and do better, than those that simply forgot what they were about when not confronted with the direct stimulus.

Allied to this is the fact that tools become valuable. Regular, and adaptively salient tool manufacture and use, while still simple and to some extent self-taught, would nevertheless show signs of deliberation. The essential point to grasp however is that behaviours need to maintained without immediate stimulus, and across increasingly diverse zones. The development of these skills provides a base upon which to build further skills.

**Mode 1 to Mode 2 Tools**

The picture thus far is that of a stereotyped behavioural sequence under some pressure to become more flexible, maintained in the face of distractions, and performed across increasingly large temporal and spatial distances. With the emergence of the Erectines, this pressure becomes increasingly acute. What does the archaeological record suggest is happening at this stage of human evolution? With its emergence out of Africa at the beginning of the Pleistocene, the Erectines inhabited a broad swathe of Eurasia from Western Europe, across to China, down through Indonesia. This pattern of spread is one shared by the larger predators and other mammals at this period (Foley, 1991). The Erectines need for food and raw materials for tool making, suggest that its daily and seasonal range sizes needed to be increasingly large, encompassing diverse environments. Additional evidence is again physiological; *Homo erectus* lower limb lengths increased proportionally to body size compared to earlier hominins (Plummer, 2004) to reach that of modern humans, enabling both longer distances to be traversed to exploit larger ranges, and possibly endurance running to be a feature of *Homo* behaviour. The increased seasonality of yearly environments meant *H. erectus* had to cope with changing foraging situations. Longer-term fluctuations in climate, with increasing glacial/inter-glacial cycles, would favour groups that could learn and adapt to changing conditions over generations.

*Homo erectus* thus appears to be exploiting increasingly diverse habitats, dealing with constant changes in habitats across various time scales, and managing to do this across larger areas.

**The Cognitive Solution**

With the greater range sizes of the Erectines, and more variable habitats, behavioural sequences are under increasingly pressure to stretch. One solution is to allow these sequences to actually break: to partition the sequence into separate modular tasks. The tasks can become motivationally distinct.

With later Mode 2 tools, we see two sets of evidence that suggest this disassociation of tasks is happening: Raw material transport, and tool investment. Ben Marwick, in his paper on the evolution of language, points out the increasing distances of raw material transportation over the Pleistocene (Marwick, 2003). The raw materials associated with Mode 1 tools were rarely transported more than a day's walk in distance. By the late Acheulean Mode 2, and into Mode 3, transport distances can in some instances become substantial 40-50 kilometer treks or even longer. This suggests that the economics of stone tools are becoming increasingly important. It also argues that tool use can no longer depend on a direct perceptual and behavioural link between raw materials and their deployment. Raw material acquisition and tool manufacture were temporally and physically distinct from tool deployment.

The second sign of disassociation is the evidence of increasing investment in tools. Late Mode 2 Acheulean tools show signs of increasing re-touch, and finer work on the tools. Some late Mode 2 tools seem to be almost over worked, and some show no sign of actual use. Kohn and Mithen suggest that well made tools may have acted as sexual signals (Kohn, 2000; Kohn & Mithen, 1999). Tool making can undergo selection independently of deployment. Be that as it may, the increasing investment in tools by late Erectines is not in dispute. One could certainly argue that the tools were made independently of deployment considerations.

**Cognitive Linking**

The transition from Mode 1 to Mode 2 represents the emergence of behaviours that are not coupled together by direct stimulus, but linked cognitively. Lack of space precludes a full discussion of this behavioural link, but one point is salient here: the desire to make a tool of a particular type need not be via internal representations of potential use. The tools themselves and their presence within the group can act as an external motivation for much of the tool making activity. Everyone else has a tool, so maybe I should too. Everyone else is carrying a tool, so maybe I should too. Tools become social objects, in addition to their role as tools. Just as juvenile Chimpanzees might be motivated to imitate parental activities such as ant-fishing with no

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3 As far as I am aware there is no evidence of seasonal commuting for hominins at this time. Seasonal commuting probably requires a depth of information indicative of a rich cultural knowledge base of a sort only language could provide.
thought of a food reward, the stimulus for tool manufacture might well be independent of its practical function.

What we see then with Mode 2 tools is the increasing behavioural separation of tool manufacture and tool deployment, and the need for a new kind of link between the two. Tool manufacturing becomes less linked to tool use to accommodate the increasing rarity of raw materials, and increasingly diverse and seasonal habitats of the Erectines. The imperative to make a tool becomes independent of the use of the tool.

**Mode 2 to 3 transition**

The transition from Mode 2 to Mode 3 tools (from Lower to Middle Paleolithic in Europe, and Early to Middle Stone Age in Africa) roughly coincides with the end of the Erectines, and the emergence of the Archaic sapiens. I say 'roughly,' because tool making cultures do not represent the output of a species. Modern human groups make Mode 1 tools today. Different groups of hominins make different selections of tools. Nevertheless, it is fair to say that the emergence of a new evolutionary grade within the hominins, the Archaic Sapiens, roughly coincides with the emergence of a new technology: Mode 3.

Mode 3 tools are characterised by a prepared core manufacturing process. Rather than creating a large enough flake from a cobbler that can then be worked into a handaxe, Mode 3 manufacture involves the deliberate shaping of a core from which flakes are struck. It is in effect a two stage manufacturing process: preparing raw materials and manufacturing tools become separate tasks. This is a more efficient way of making tools, although necessarily more skilled.

Additionally, Mode 3 tools also marks the appearance of more obviously specialised tools. There are new tools used for distinctive tasks, and in addition the increased use of alternative materials such as wood (Coolidge & Wynn, 2009).

We also see evidence of raw material transport distances increasing still further. With the emergence of late Archaic Sapiens and *Homo sapiens*, these transport distance start to look like potential trade routes, with raw materials being carried some hundreds of kilometers from sources of supply to places of manufacture and deployment (Again, see the article by Marwick, 2003).

Archaic Sapiens inhabited an increasingly diverse range of habitats. *Homo Neandertalensis* appears to be a highly specialised, cold adapted descendent of earlier Archaic Sapiens. Archaeology shows distinctive cultural traditions as commonplace.4 Given that *Homo Heidelbergensis* is likely to be the common ancestor of both *Homo sapiens* and *Homo Neandertalensis*, species which both show evidence for the capacity for language (Lieberman, 1998; Maclarnon & Hewitt, 2004), it seems highly probable that all the Archaic Sapiens were language using species. To what extent, and in what form, they used language, is difficult to say. Nevertheless, language is quite likely to have played a role in fine tuning cultural transmission, making regional specialisation possible.

While much remains controversial, the archaeological and physiological evidence clearly indicates that Archaic Sapiens possessed the capacity to think beyond the here and now, and behaviorally flexibility above that of the Erectines.

**The cognitive skills of Mode 3 tools**

At this point our behavioural chain (raw material acquisition → tool manufacture → tool deployment) has become a set of discrete modular behaviours. Using prepared cores itself allows raw material acquisition and tool manufacture to become distinct. Prepared cores are not only efficient ways of using raw materials; they also produce blanks that can be reshaped to a variety of ends. Given the presence of wooden spears, and the probable preparation of hides and other materials, the production process itself seems to become decoupled from specific uses. However, while the behaviours of Archaic Sapiens are increasingly discrete, the evidence also suggests that they could accommodate strategic and tactical considerations. For instance, there is reason to think that differing seasonal environments with concomitant changes in available resources (in game, other foods, or access to raw materials) played a role in Archaic Sapiens decision-making processes. Archaeological evidence suggests that Archaic Sapiens could exploit seasonal resources (See for instance Avery et al., 1997). Changing political relationships with neighbouring groups could also affect access to resources.

Archaic Sapiens had to integrate information across a number of domains, and much of this information was not proximal; it was remote, 'theoretical' information. In making their decisions, Archaic Sapiens had to keep in mind the value of a scarce or difficult to obtain raw material, what to manufacture, and possible alternative resource acquisition strategies.

**Multiple levels of control**

The emergent picture of Archaic Sapiens is one of accommodating three different types of information: broadly strategic information, the specifics of particular tasks, and the relationship between particular tasks.

Wayne Christensen suggests that in skilled tasks, this movement between different types of information is frequently necessary (Christensen, 2009). Christensen takes a lead from aviation psychology, where they differentiate between the necessary levels of awareness required by pilots. To achieve the various tasks of flying, navigating, and communicating, pilots needs to bring to the fore different kinds of awareness at different times. They need spatial awareness to locate their aircraft relative to the ground, other aircraft and destinations. They need system awareness to manage the information about their aircraft: its fuel levels, engine speeds and so forth. And finally, they

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4 Hence the profusion of names for archaeological "cultures" for this period: the Mousterian, the Châtelperonian, the Aurignacian, etc.
need task awareness to guide them through a particular action or set of actions at a particular time, such as landing. At various points these different levels of awareness will come to the fore, guiding actions. The various levels of awareness will fit together, integrating into a big picture. Whilst the pilot is focusing on task awareness for takeoff, there needs to be background awareness of system and spatial information. One envisions a constant movement between these types of awareness: a dynamic system of control.

With this in mind, Christensen suggests that for skilled action we might see a range of levels of control. Actors might have something resembling a self-model that provides information on personal goals and skills. A strategic task model provides information about the strategic context and the role played by a current task within a broader set of tasks. Then there might be a situational model; where am I now, and what am I doing. Finally, there might be the direct motor control model that controls actions.

While we might not agree with Christensen's breakdown of control, his underlying point is clearly important. Individuals must integrate information across a variety of domains, moving between different levels of awareness and types of information at different stages of behaviours, and, crucially, allowing different levels of awareness to constrain and inform one another. The degree of care I need in a motor task in stone tool manufacture is dependent upon many factors. Am I making a tool that requires reliability over long time frames, and making it out of a rare material? If so, this should constrain my actions, making me cautious, thoughtful and prepared to invest a great deal of time in the manufacturing process. Alternatively, perhaps I am among peers, and we are engaging in competitive scavenging with members of the carnivore guild. Raw materials in the form of larger rocks and cobbles are available. At this point, investment in a tool is unwarranted. The best tool a rock can be is a missile… and I effectively throw away what I might at another time think of as a valuable resource.

With the emergence of Mode 3 tools, we see the culmination of a process begun by our Australopithecine ancestors. As environments became spatially and temporally fragmented, individuals did better if they could maintain integrated but complex foraging behaviours across these disparate zones. Ideally, they maintained these behavioural chains in the face of distractions. Over time, with this fundamental skill widely established, individuals did better if they could modularise these behaviours, maintaining the links between the relevant acts cognitively rather than relying on direct stimuli. According to the archaeological record, this appears to have happened in two stages. In the first stage, tools were made prior to need. The tools were not specialised, suggesting that they were made for a generic future, so the tool-making task was in some sense de-coupled from the specifics of deployment. Nevertheless, increasing transport distances for raw materials in the later Mode 2 suggests that there was the decoupling of manufacture and use that allowed this to occur.

In the second stage of this process, with Mode 3 tools, we see the modularised tasks — raw material acquisition, tool manufacture, and tool deployment— being re-integrated cognitively. Internal cues replace external perceptual signals of what to do next. Tools are made in the context of broader strategic and economic concerns.

**Summary**

We have explored the archaeological evidence of evolving technical competence. In particular, we have looked at the skills necessary to achieve the economic and strategic elements implied by various hominin tool types.

Starting with extractive foraging, hominins have increasingly incorporated tools into behavioural sequences designed to supply immediate needs. For the Australopithecines, such behaviours were increasingly crucial parts of their lifeways. The Pressures of larger and more heterogeneous day ranges exploited by Early Homo forced their behavioural sequences to stretch over longer time frames and more diverse environments. Those individuals who could maintain linked behaviours in the face of distractions —who could bear tasks ‘in mind’— would be advantaged by their greater flexibility. Tasks and goals would become de-coupled from immediate stimuli.

With the emergence of Archaic Sapiens, increasing exploitation of larger range sizes and the buffering of skills by more directed pedagogy and social organization allowed behavioural sequences to be integrated with strategic, multi-factor information. Hominins could engage in behaviours without direct stimulus, but with long-term goals and high-
level constraints in place. Hominins, from this point on, are strategic thinkers.

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