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# What's special about human technology

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Human technology is difficult to understand because it is so complex. However, human technology evolved from the simpler technologies of other species. Comparison with these other technologies should illuminate why human technology is distinct. Some birds and primates make tools, or simple technological objects whose function is closely related to their form. Humans, on the other hand, make machines—relatively complex objects whose functionality derives from the interaction of parts with respect to one another (e.g. a bow and arrow). Making machines requires a cognitive advance called 'second-order instrumentality', or the ability to invest in the production of an object that only has utility as part of, or for the making of, other objects. This ability enabled human societies to develop specialised forms of organised production, which in turn allowed the stock of artefacts to diversify and accumulate, whereas the technological repertoires of other species remain at a relatively constant level of complexity.

*Key words*: Technology, Evolution, Instrumental thinking, Machines, Tool-making
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## 1. Introduction

Human technology is a complex phenomenon. Understanding such complexity can be made easier by exploring the history of how it emerged from simpler forms. A similar tactic has been employed by anthropologists to explain the nature of culture. Culture is perhaps the central concept in anthropology but, like technology, it is very complex.[1] The rudiments of culture, however, can be found in other species. Some anthropologists have therefore sought to understand how human culture evolved from the kinds of culture seen in our nearest relatives.

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[1] While some include technology within the culture concept, here I use the word 'culture' in the sense of information (such as beliefs and skills) acquired through social learning (Richerson and Boyd, 2005). This definition excludes the physical products of behaviour such as technology, leaving culture a purely psychological phenomenon.

Anthropologists have found that what distinguishes human culture from that of other species is its ability to accumulate. The 'stock' of culture a human group controls can increase from generation to generation, whereas the culture of other primates remains limited to a small number of traditions, or learned, group-specific traits (e.g. making a buzzing noise with a leaf to attract a mate, or wadding up leaves to sop up water like a sponge) (McGrew, 1992; Whiten *et al.*, 1999). The set of traditions exhibited by a primate group may change over time, but the total number of traditions remains roughly constant (Richerson and Boyd, 2005). (Strictly speaking, if there is accumulation, it must either be extremely slow—and hence hard to measure—or of recent origin in other primate and bird species, because they have had as long to evolve complex technology as *Homo sapiens*.)

The ability of human culture to accumulate has been put down to the psychological ability to engage in rapid social learning (Dugatkin, 2001; Tomasello *et al.*, 1993). Imitative and symbolic abilities allow our species to quickly learn new skills by inferring rules for behaviour from single observations of the behaviour of others (Deacon, 1997; Hurley and Chater, 2005). As a result, over generations, the content of human culture is 'ratcheted' up. (Boesch and Tomasello, 1998; Donald, 1991) The human ability to rapidly imitate is a psychological trait that leads to a qualitatively different evolutionary process in culture.

In this paper I suggest that in order to get a better understanding of human technology, scholars of technology should use the same tactic as the anthropologists: they should ask how and why human technology is different from that of other species. I will further suggest that the answer to this question is similar to that found by anthropologists with respect to culture: human technology differs from that of other species in being cumulative. I also posit that humans have a unique ability, which enables human technology to accumulate. I will call this 'second-order instrumental action': the ability to produce an artefact which only has utility in helping to produce (or as part of) other artefacts. The implications of this argument for our understanding of human technology will then be briefly discussed.

## 2. The technologies of other animals

Generally, three categories of things have been assigned to the word 'technology' (Mitcham, 1978). Technology can be considered a kind of

- knowledge: technique (the specialised know-how for inventing and making artefacts)
- activity: technique put into action in the production of artefacts
- product: artefacts (the material products of activity)

In fact, these three aspects cannot be separated. As a sustainable system, technology must be seen as composed of knowledge (of technique) that leads to practice (organised behavioural activity), which results in the production, maintenance or repair of material objects (i.e. artefacts). Without any one of these components, the system cannot evolve, which would mean that we could not account for the evolution of ever more complex artificial objects. Note that this definition includes 'information technologies', such as computers, 'social technologies', such as the internet (information machines that facilitate inter-human communication) and 'biological technologies', which enable the modification of organisms, such as the engineering of genetic material by machines.

If we allow that the 'system of knowledge' or technique for making artefacts need not be cognitively encoded, then technology is hardly a human invention.[1] Many animal species produce artefacts; in fact, ways of making durable, useful things out of physical materials have probably been around for half a billion years.[2] The earliest forms of technological activity came with invertebrates. Generally, invertebrates such as insects and spiders build structures that serve one of three functions: to create a home as protection from the elements or predators (e.g. termitarium), to trap prey (e.g. spider web) or for use in courtship displays (e.g. bowerbird bower) (Hansell, 2005). In any of these cases, the rules of construction are behaviourally simple (although in some 'higher animals' like birds, it can take years to achieve full mastery over their execution). Construction is essentially instinctual, with the individual animal responding to information left in the environment (perhaps by their own prior activity) using a small number of standardised behaviours (Gould and Gould, 2007). Materials are either collected or secreted and then used largely without modification (Hansell, 2005).

'Higher' animals, primarily birds and primates, also produce artefacts using quite different means. These artefacts tend to be micro-scale objects. Further, they are made—that is, worked with until they achieve functional form. For example, by observing a human model, a chimpanzee named Kanzi learned to flint-knap (i.e. bang flint stones together to form rock flakes sharp enough to cut through the flesh of prey), demonstrating an ability to use a found object (a stone) to make a flake artefact (Toth *et al.*, 1993). In most cases, use of the resulting object is 'endogenous': the artefact is manipulated in some way so that the animal achieves greater returns from behaviour. (By contrast, if the artefact is not actively manipulated, but rather treated as part of the environmental surround, its use can be said to be 'exogenous'.) In all cases, the resulting artefact is a simple tool. Production is also typically by individuals.

[1] Some definitions of artefacts are based on the notion of intentional *making*—that is, as an object that has been deliberately produced for a certain purpose, typically by human beings (Hilpinen, 2004; Kroes, this volume; Thomasson, 2007). For example, an object cannot be a chair unless it has been made with the intention to be a chair (i.e. an object that helps people to sit down). Such a definition has the desirable feature of distinguishing artefacts from biological organisms and other physical objects that are not the result of niche constructive activity. It also allows for a kind of distinction between *use* and *making* [e.g. through reliance on the notion of 'proper' function (Millikan, 1984)], and so seems to relate to the key feature of human technology identified here: the divorce of *use* from *making*. However, the emphasis on intentionality does not cover several novel human categories of artefacts (e.g. *networks* and *systems*), which evolve rather than being intentionally designed. Nor does an emphasis on intentionality deal well with the many cases of invention or *making* that are accidental (Vincenti, 2000). It also ignores the evolutionary history of technology in other animals, which is largely instinctual, rather than intentional (i.e. cognitive) in nature (Gould and Gould, 2007; Odling-Smee *et al.*, 2003). However, it appears desirable to define artefacts in such a way that non-human technologies are covered, thus increasing the range of explanation, as well as avoiding the suggestion that human technology sprang fully formed out of nowhere. I therefore define artefacts as the enduring forms or structures created by animals through niche constructive behaviour primarily to be used in a way that increases their biological fitness. This definition does not invoke intentional design as an intrinsic feature.

[2] The primary evolved function of technological activity must be to interact with the construction that results from this activity in such a way as to increase the animal's biological fitness. Thus, earthworms enrich the soil in which they live by continually burrowing through it, and make it more porous and aerated (Turner, 2002); but this is not the primary reason that earthworms move about, so soil modification is not a technological activity. However, spiders build webs so that they can better trap prey, so web-building is technological in nature. Technological activity is thus a narrower category of behaviour than niche construction (Odling-Smee *et al.*, 2003).

Most species make only one kind of tool, but some species make 'tool-kits'. For example, chimps use different tool*s* for extracting prey from hiding places, for personal hygiene (e.g. wiping away faeces) and for attracting the attention of conspecifics, particularly for mating purposes (e.g. whistling by buzzing a leaf) (Watts, 2007). Similarly, New Caledonian crows make several different kinds of tool*s* from different kinds of materials for a variety of tasks, modifying stems and leaves to create hooks and barbs, e.g. for removing insects from crevices (Hunt, 2000; Hunt and Gray, 2003; Kenward *et al.*, 2005) Crows can also pick up one tool, use it to extract a second tool from one enclosure, which is then used to obtain a reward from a second enclosure—a kind of 'meta'-tool use. (Taylor *et al.*, 2007) Similarly, wild chimpanzees in the central African rainforest spontaneously and customarily use a particular sequence of two tools to forage for termites—a stout stick to puncture the nest, then a smaller, more slender stick with a frayed end to fish out the insects (Sanz *et al.*, 2004).

Birds, primates and hominids all engage in complex sequences of behaviour to make tool*s*—what has been called a '*chaine operatoire*' (Leroi-Gourhan, 1993). The technologies of none of these species accumulate, so complicated making sequences do not distinguish human technology.

What then is it about human technology that is more sophisticated than this? No primate has yet been shown to make a complex artefact—that is, one with multiple interacting parts or what I will call a 'machine'. Neither have any complex artefacts been found in the archaeological record associated with early hominid species (e.g. *Australopithecus*, *Homo habilis* and *Homo erectus*). However, all contemporary human populations fabricate composite object*s* out of numerous component parts (Reynolds, 1982).

For example, human foragers make a bow-and-arrow to bring down large prey at a distance. In particular, an arrow has several parts, such as an arrowhead, shaft and fletchings, each of which is made of different kinds of material (stone, wood and feathers), individually, and then fashioned into a unit. An arrow therefore constitutes a simple machine: it is only thanks to the functionality of these parts when put together that an animal can be effectively killed with it; throwing an arrowhead, fletchings or shaft alone at an animal will not have this effect. Machines are thus distinguished by requiring that separate, simpler artefacts be produced independently, which are then put together to form a more complex whole with a new kind or degree of functionality. Further, when used together with a bow, a hunter can strike an animal dead at a greater distance than an arrow or spear flung by arm, so this more complex machine has even greater functionality than the arrow alone.

### *2.1 The divorce of making from use*

What is special about making a bow-and-arrow? It requires an individual to invest work in the production of an artefact, say the arrow fletchings, which is finished but not used immediately because, by itself, it does not have a function; it is only in combination with the other parts of an arrow that it achieves utility (at least as a hunting tool). Thus, the individual must move on to a second task, making the arrowhead, and then the third. Only once the arrow is finished does it have use value in bringing down a prey animal and thus providing some benefit.

Other species are restricted to two technological abilities: to produce an artefact that is then used, or to use one artefact to acquire another. These abilities can be combined; for example, New Caledonian crows can use one tool to get another and then use that one

(Taylor *et al.*, 2007). However, non-human species are not known to *make* one artefact that is then set aside or used to help *make* another (Hansell, 2005). That is, other animals exhibit make–use or use–use chains, but not make–make chains of behaviour. However, human tools are often used to make other tools or to assist in the making of a third artefact. For example, a knife can be made and then used to whittle wood into arrows. Only by engaging in make–make chains can we account for the distinctive characteristics of human tool-making: composite tools (i.e. machines such as pulleys, windmills, automobiles) and tools used to make tools.[1] It is this ability that must have arisen sometime in the human lineage.

### *2.2 The psychology of divorce*

On what psychological trait does this ability to make an artefact that only has use together with, or for making, another depend? An individual can engage in behaviour either as a means (or instrument) to an end, or as an end in itself.[2] For example, someone can pursue an education either because it will land them a good job or for the love of learning itself. Endogenous use can thus be functional (e.g. wielding a hammer to pound a nail), or instrumental, with the goal to make another artefact or to acquire knowledge (e.g. wielding a hammer to make a machine or practicing skills for artefact-making). Non-human animals can make a tool as an end in itself (i.e. for its ability to increase the user's power over the physical or social environment), but do not make one that has only instrumental value. Non-human animals value artefacts for what they can help them do, not for what they might contribute to some other goal.[3]

How do humans convince themselves of the utility of instrumental tool-making activity when no immediate benefit comes from it? Complex artefact-making requires the ability to reach a goal that is seen as only one step on the way to a more distant objective (e.g. the finished arrow as an interim goal on the way to constructing a weapon). Psychologically, this kind of production requires an individual to be willing to invest in something without immediate utility—that is, as something only valuable in a future context requiring further effort to attain. Because it involves second-order making, I will call this psychological ability 'second-order instrumentality': it is the ability to make an artefact having no intrinsic value, which is useful only as a means to an end.

Other animals can engage in complex sequences of activity that provide no immediate benefit—for example, making structures, investing in social reputation or defending territory. Temporal separation of *making* from *use* takes place in many contexts (e.g. birds can make a nest some days before laying eggs in it, thus delaying the gratification of using the

[1] According to Mitcham (1994), Aristotle was the first to distinguish types of making: cultivating and constructing. Cultivating involves helping nature to produce more perfectly or more abundantly the things it produces 'naturally' (e.g. agriculture). Construction involves producing things not found in nature, even in rare instances (e.g. chairs or computers). However, cultivating in the sense of agriculture or genetic engineering requires, as a prerequisite, the constructive making of implements, so I take cultivation to be a particular kind of use of artefacts to manipulate organisms and concentrate on the constructive making of new kinds of artefacts in this account.

[2] Max Weber (1978) called the former '*zweckrational*' behaviour, the latter '*wertrational*'. He believed *zweckrational* behaviour to be the highest form (i.e. most human), which is consistent with the argument here that instrumental behaviour only occurred with the evolution of modern humans.

[3] Note that it is not the ability to engage in instrumental behaviour *per se* that separates us from other animals because artefact production is instrumental behaviour. In humans, it is artefact use which can also be instrumental, because use can be put to the production of another artefact. Indeed, some artefacts only have utility as a function of their ability to help people make other artefacts (e.g. machine tools).

object they have invested in), but this is not the kind of means-versus-ends divorce of which I speak, because then the investment in structure, reputation or resources can be used (e.g. the territory can attract a mate). However, an arrow cannot be used in isolation (at least not for its proper function; it can be used to cut things because it is sharp). Recursive making requires hierarchically nested behaviour: the ability to invest in a product that is itself only an investment in future production. The result behaviourally is one episode of effort that is then followed by another. Further, the intermediate goal achieved by accomplishment of the first object's production has no intrinsic value.

In a recent, comprehensive review of the evidence for human versus non-human psychological abilities, Penn and colleagues (2008) put forward a 'relational reinterpretation' hypothesis. Crudely put, it states that only humans engage in mental operations on abstractions—that is, we possess the ability to manipulate and reinterpret mental representations such that they form high-order relational structures. For example, writing an academic paper about human versus non-human technology requires an ability to create a model of the chimpanzee mind and compare it with a model of the human mind—what can be called 'meta-representation' (Aunger and Curtis, 2008; Sperber, 2000). Second-order instrumentality can be considered a form of this kind of thinking, which is demonstrated during the making of complex artefacts.

It is likely that the ability to pursue an over-arching objective (e.g. make a bow-and-arrow) through a variety of chains of actions that achieve intermediate goals requires an ability called 'executive control', which allows a person to put one task in abeyance (in memory) while another is executed and then to retrieve the other task and execute it (Jackson *et al.*, 1999). Only in this way can complex tasks be flexibly sequenced to overcome obstacles as they arise. This ability is associated with the front-most part of the pre-frontal cortex (Koechlin *et al.*, 2003) and is probably of recent origin (Streidter, 2005). It is also one of the last abilities to develop within the individual brain (Luciana *et al.*, 2005). As expected, then, the special traits of human technology (e.g. composite tools) appear to be of relatively recent origin in the human evolutionary record (Stringer, 1992).

From this divorce of using from making in object-making, I argue, everything else about human technology follows. The first thing that the divorce of making from use allowed was the production of complex objects—that is, artefacts (like the bow-and-arrow) that only achieve functionality through the interaction of multiple parts. No other animal manufactures such machines, though humans have been making them for perhaps 150,000 years (a hafted spear perhaps being the first compound artefact) (Aunger, 2007; McBrearty and Brooks, 2000).[1]

### *2.3 The consequences of divorce*

The ability to engage in instrumental making had other consequences as well. For example, if an individual could produce artefacts without immediately feeling they had to be used, they might also think that they never need be used. Instead, they could have another form of instrumental value: as objects with value not to oneself, but to others. This logic leads naturally to the possibility of exchanging the product of their labour with another individual in return for something else of value (Smith, 1904). In this way, technological activity could be integrated into economic activity such that a market in produced goods arose.

[1] Chimps use a stone hammer to crush nuts against a stone anvil, but do not make either the hammer or the anvil (Boesch and Boesch, 1983; McGrew, 1992).

With the ability to acquire at least some of what they needed through exchange, individuals could then begin to specialise technologically—that is, produce a narrow range of artefacts that could serve as their contribution to the economy and for which they got a 'living' (White, 1966). Given specialisation in production, artefacts could become more complex, since individuals could develop particular skills for making this smaller assortment of artefacts. These individuals—craftsmen in effect—could then diversify, each kind of craftsmen and the kinds of artefacts they made becoming even more specialised thanks to the ability to exchange these artefacts not only for consumption but also for each other's production (Henrich, 2004).

These positive feedback loops between specialisation, exchange and diversification continued until the present day, when the scale and kinds of artefacts being produced are beyond the imagining of those living even of a couple of centuries ago. Larger and larger groups of people have learned to collaborate in the production of ever more specialised products, and the scale of the markets in which these artefacts are exchanged have become global (Castells, 1996). In this way, the complexity of contemporary human technological endeavour can be seen as the natural outcome of an original divergence between making and use.

## 3. Conclusion

In anthropology, considerable controversy remains about just what accounts for the difference between the human way of life and that of our nearest relatives. We are constantly learning new things about the capabilities of other species that diminish the uniqueness of human life-ways. For example, other primates engage in many behaviours once considered quintessentially human: meat eating, group hunting (Boesch and Boesch, 1989), intra- and inter-group combat (Goodall, 1986), deception (Hirata, 2006) and even political manoeuvring (de Waal, 1982). Primates also exhibit many of our most sophisticated psychological abilities, including reciprocity (de Waal, 1982), morality (at least the notion of fairness) (Brosnan, 2006), punishment for norm violators (Bekoff, 2004) and the ability to use symbols, perhaps even syntactically (Arnold and Zuberbühler, 2006). It is therefore foolish to make qualitative claims of distinction about human psychology.

However, it will always be necessary to invoke some factor to account for the fact that no other species has developed technologies in which the complexity of its products are increasing *with acceleration*. As a result, no other species is in danger of causing global catastrophe due to changing the planet's climate, for example, because no other species has a technological 'footprint' of sufficient size.

What 'extra' capability do humans have? In this paper, I have argued that one feature that distinguishes humans is the fact that they produce increasingly complex and varied artefacts. No other species exhibits technologies that accumulate in this fashion. Further, this paper has attempted to identify how this distinguishing feature of human technology occurs, suggesting it is a particular kind of psychological ability (otherwise other animals would be creating machines, given their tremendous adaptive significance): an ability to engage in what can be called 'second-order instrumental action'—that is, making an artefact that only has utility in making, or by serving as a functional part of, another artefact. The result of this ability working over time is the incredibly sophisticated technologies we see around us. This feature is not qualitative in the sense of being an all-new kind of process, but rather constitutes a modification of something other animals can do, but which nevertheless can produce outcomes of the requisite complexity, in the form of complex artefacts, to explain how Western societies have acquired such power over the environment. Complex culture alone is not enough to explain human evolution. It is also the co-evolution between people and the increasingly sophisticated things they produce that renders human life-ways so different from those of other species.

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