

The Natural History of Technology

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Abstract

This paper urges that a fundamental distinction be drawn between 'instinctive' and 'intelligent' technologies. Most organic tool usage can be regarded as relatively straightforward extensions of normal processes of adaptation, broadly similar to other uses of external structures such as nests. Intelligent technology, by contrast, assumes the ability to appreciate the objective potential of things in ways that are not predefined by existing adaptive needs. In order to demonstrate this point a three-phase sequence is sketched out, with strictly instinctive and strictly intelligent levels separated by an era of 'sensorimotor' tools use.

1. Introduction

Thus have we no just quarrel with Nature for leaving us naked; or to envy the Horns, Hoofs, Skins, and Furs of other Creatures, being provided with Reason, that can supply them all.

Sir Thomas Browne, *Religio Medici*

An illustrated encyclopaedia of zoology should no more picture *Homo sapiens* naked than it should picture... the black bear... wearing a clown suit and riding a bicycle.

Daniel Dennett (1991: 416)

All kinds of tool and technology serve essentially the same purpose: to externalise various functions, organic and intelligent, and so to allow the tool-user's phenotype to use aspects and components of its environment almost as though they were part of our immediate anatomy. In place of bodily adaptations we employ made tools and invented techniques. As human anatomy shows, this externalisation of function can have direct effects on evolution. Leaving aside the role of technology as a vehicle for the formation of intelligence itself, not only basic biological functions but our very anatomy has been modified by our technological prowess. For example, tools make *Homo's* gracile anatomy possible. By the standards of other hominids we are markedly slight. Our ability to clean, pierce, cut, crack, scoop, soak, cook, preserve and generally pre-process food allowed us to dispose of (or never acquire) the mechanisms needed to eat a far wider range of foods than our dentistry and digestive systems could manage unaided. At the same time our ability to hunt with weapons and traps, skin animals, tan hides, make fire, build shelters, transport objects with baskets, carts and beasts of burden over great distances and generally offload various technical functions onto nature allowed us to take the same feeble anatomy into the most hostile of climates and terrains, from the Great Rift Valley to the canyons of New York to the abyss of deep space.

So technology plays a major role in humanity's very original response to the 'expensive-tissue' problem (Aiello and Wheeler 1995). In place of a trade-off between tissues (e.g., brains and guts), we make our technology (and through it the rest of nature) pay for our massive capabilities. Of course, we have not really finished the job. For example, we have yet to address the problem of readapting our very anatomies to reflect the consequences and capabilities of our technology. As a result, a huge proportion of human mortality is caused by our own accomplishments - our diet, our lack of exercise, our pollution of our own environment, our constant over-reaching solutions and our constantly overweening ambition. Even so, we outlive practically everything else on the planet and the *possibilities* opened up by the beckoning future are truly staggering (even if the immediate future looks a good deal more precarious than it did half a century back), so clearly the price has been worth paying so far.

On the other hand, technology is only one way in which evolution must be interpreted as the subordination of human biology to human intelligence rather than *vice versa*. What is more insofar as the tools and machines we build and employ are the products of intelligence and they affect the competitiveness of all the organisms in the human 'niche', technology allows human beings to control much wider swathes of evolution directly, if also unintentionally. By the same token, the technological interventions into our own anatomy made possible by pharmacology, medicine, nanotechnology, genetic engineering and all our undreamt-of future capabilities will eventually enable us to short-circuit the evolutionary *process* itself in the most practical manner possible (Robinson, in press). Given that technology of this order is only a few centuries old - relatively few human accomplishments before the industrial revolution made much impact on the environment at large - one can only wonder at what might be achieved as technology really takes off.

This essay concerns the 'natural history of technology' - the sequence through which tools, tool use, tool-making and their progressively rich and powerful natural, social and 'scientific' context have developed from the earliest organisms to the most advanced intelligence. I prefer the notion of technology to that of tools, because although there is not true technology before intelligence proper, the factors that converge in true technology influence are all but omnipresent and influence a good deal about pre-technological tools. In addition, I define the whole area with which I am concerned very widely, which again reflects the breadth of factors that will eventually coalesce in technology proper. For example, I do not limit myself to tools as classically defined, which typically assume that tools are separated from their substrate, that they are wielded by an agent, and so on. This tends also to exclude the ability to exploit the properties of both natural phenomena (such as eclipses, impending thunderstorms) and social relationship (such as an infant chimpanzee's ability to get its elders do things for it). Disciplinary purists and conceptual splitters may rebel at such an all-embracing definition, but I can only say that it is impossible to say anything useful about technology without noting how and why these dimensions of reality start to intrude on tools and their makers and users.

I suggest that the natural history of technology has passed through three stages, interlinked in such a way that each generates the other, yet in doing so gives birth to something quite new. In the first, 'instinctive' period, such tools as organisms possess are directly part of the organism in the same sense as other external structures such as nests, burrows, and so on. That is, they are functionally part of the organism (or more precisely, of specific forms of activity such as feeding or mating) even though they are structurally separate from its body. At the opposite end of this sequence, 'intelligent' technology consists of equally external structures that are also functionally independent of their creators and users. However, the nature of intelligence means that they are still accessible to any intelligent being - not only to their creators and initial users but also to any intelligent being capable of fathoming what they do and how they work. However, for intelligent technology 'what they do and how they work' aspect of tools is inherent in the tools themselves, rather than being inscribed in the bodies of the organism with the necessary instinct to use them. For example, the possibilities inherent in a hammer or a space craft are available to any intelligence being. This is because being able to use intelligent technology relies solely on their intelligibility to the user - unlike instinctive technology, nothing needs to be 'built into' the use for the tool to be used, and neither are there any tools that are inherently inaccessible to the intelligent user, given only this intelligibility, as there are for non-intelligent organisms. The possibilities inherent in a bird's nest, by contrast, are not recognisable by other (non-intelligent) organisms unless, like a cuckoo or cowbird, they possess the right adaptation to exploit them. In between these two extremes, there stretches out a long era of 'sensorimotor' tools, inhabited by certain birds and mammals. During this phase, a tool's capabilities (e.g., a chimpanzee's hammer stone and anvil) are more or less independent of

any prior *instinctive* 'programming', yet they fall short of strictly intelligent technology because it lacks any insight into the tools themselves beyond their empirical surfaces.

I should emphasise that these are not three discrete types of technology. As their evolutionary distribution indicates, there is a continuum that embraces them all. However, the continuum is by no means smooth. Firstly, once fully established, each transition leads to a massive acceleration in the scope and power of both the tools and the organisms involved; and secondly, the principles on which each type relies are fundamentally different, and unleash a completely new level not only of power but also of ability. All in all, the image of a straightforward evolutionary continuum is as treacherous as one of separate kinds (Robinson, in press).

2. Instinctive tools

There is a strange (and, for present purposes, embarrassing) affinity among tool users of all kinds:

Most laypersons and even candid zoologists sense something unique when watching an animal use a tool. The unmistakable similarity to characteristically human behaviour is compelling. There is an intuitive, sometimes mystical, appreciation of evolutionary continuity that is not elicited even by the most elaborate bird song or the most vigorous canid dominance interaction. (Beck 1980: xi)

The reason why this observation is embarrassing is that it flatly contradicts the main premise of this paper, that there is a qualitative difference between organic tools and intelligent technologies. Worse still, Beck's entirely accurate remarks preface a long and detailed account of tool use in the animal kingdom that extends far into the realms of insects, crabs and other simple creatures. The affinity human beings feel towards other tool users seems to stretch not only to chimpanzees and other primates but also down through a large but haphazard collection of non-human species, many of which are clearly not intelligent in any normal sense of the word. Yet they all use and (to a lesser extent) make tools. This cannot help but create the impression that, if human technology is intimately associated with our intelligence, then intelligence is scattered far and wide throughout the animal kingdom.

Yet this is only an impression, and a false one at that. For once the various forms of tool use are analysed, especially in terms of the demands the tool in question makes on its makers and users, it becomes clear that there are really three clearly different levels of tools involved. The next few sections will try to make clear exactly this tri-partite division means.¹

For present purposes, an 'instinct' can be defined in very general terms: as a structure of activity that is more or less fixedly linked with a particular kind of functioning, and more or less radically separated from other structures. Instincts may be versatile, flexible and sensitive, and may be capable of considerable learning, but there are always deep and insuperable limits to their ability either to be deployed in support of other kinds of functioning or to be organised among themselves into novel (or, *a fortiori*, higher) structures.

Proceeding from this definition, 'instinctive' tool use consists of the incorporation of an extra-somatic element in an organic instinct. As far as the circle of activity that makes up a given instinct is concerned, making use of an extra-somatic element - a twig, a stone, a thorn, even another organism - is simply one more stepping stone on the way to closing the instinctive action as a whole. Within a tool-using instinct, the status and role of the tool is functionally equivalent to that of the parts of the organism's own body or any other organisms that may participate in a collective instinctive activity such as mating. Clearly this does not require a change in the affective structure of activity or imply an objective appreciation of the things and events in terms of which such tools are deployed. This is not least because, from the instinct's own point of view, the tool is not distinguished from the organism's own body or from any other strictly organic element of the activity in question. Hence the ant-lion and worm-lion throwing sand at their prey to hamper its escape have no need of any sense of 'sand' or 'escape' or even 'prey'. Likewise termite fungus gardens, the archer fish's wonderfully theatrical ability to shoot its prey off its perch, and the weaver ants use of their own larvae's silk secretions to glue leaves together (Kummer in Griffin 1982: 113-130).

There is nothing strange or even unusual about this kind of instinctive use of tools. In fact by the standards of adaptive instincts it is rather tame. Very often the other elements to which an instinct binds its organism-host are a much more dynamic and variable than twigs or stones - parasites, symbionts, mates or prey, for example - and in such cases the instinct's effectiveness presup-

poses a far more precise alignment between the participants.² Such activity can also be extraordinarily complex and extended. Why then should it be thought so remarkable when an instinct incorporates an inanimate object? If anything, it is surely easier to imagine the assimilation of such a passive and really rather simple thing as a shell or a stone to an instinctive action, rather than anything as complex and dynamic as another organism.

If this interpretation is correct, then the tendency of decorator crabs to camouflage themselves by fixing shells and sessile organisms to their backs can be understood as simply an active form of instinctive concealment. 'Taking cover' is a perfectly commonplace activity, and one which, when the cover in question stays still, provokes no appeals to intelligence; why then should we be astonished when an instinct appears that 'takes cover' in a rather more active and literal way? Even the fantastic instinct of the *Melia tessellata* crab to brandish live anemones at would-be assailants (the anemones discharge stings on being attacked) is explicable in these terms (Beck 1980: 14-21).

Instinctive tools differ from later forms of technology in being subject to narrow limitations. Unlike 'real' tools (and trails and tokens), the ability to use them is not generalised. On the contrary, it is always extremely narrow, never involves alternative tools, is never extended to other contexts or functions and is always carried out the same way by all members of the species (Byrne 1995: 88). For example, of all of Collias and Collias' (1976: 2-4) long list of examples, in no case does any single species engage in more than one or two. Readers may like ask themselves for which of the functions this list includes human beings have *not* developed a huge variety of structures, or contrast this list's very limited scope with the immense list one could draw up for human beings. Indeed, given the rapidly increasing speed with which technology is now changing, they may like to ask themselves whether such a list could ever be drawn up with any hope of finality. After all, we do not even do what we all have in common in a common way:

No single artefact type is made by all peoples throughout the world. If one were, we would suspect that its manufacture was an instinctive response in man. It might be supposed that particular objects linked to such human physiological processes as eating, excreting, or menstruating occur everywhere, but this is not the case. All peoples do not eat with spoons, and the use of toilet paper, or even a reasonable substitute, is lacking in many societies. Furthermore, although most women around the world wear menstrual pads, even this form is not universal in distribution. In these terms no form of artefact made by humans is comparable to a bird's nest, a prairie dog's burrow, or a beaver's lodge, each of which is made by the members of species with instinct as the primary guide. (Oswalt 1973: 18)

Conversely, if, as Griffin and others have suggested, even instinctive tool use reflects intentional planning (Griffin 1984: 120), then the monomania that the instinctive tool-user's narrowness reveals suggests a species-wide mental disorder of the most remarkable kind. One might just as well say that penguins have strong dress sense.³

Similar arguments can be applied for the various kinds of animal 'architecture' to be found at this level (von Frisch 1974), or its characteristic courtship offerings, display devices, and so on. There is no sense in which instinctive tools, nests or offerings are produced or selected or used as an explicitly constructed means to explicitly recognised end. In other words, they may still be 'tools' in an impoverished sense, but they are not artefacts, for they are not part of any artifice, and it is artifice, not tools *per se*, that qualifies an organism as intelligent. (See Leontyev 1981: 208-217 for a relevant discussion).

In fact, it is striking that, until one reaches the level of mammals and birds, there seems to be no case of tool use that cannot be explained in terms of isolated behavioural adaptations and the re-direction of pre-adapted structures. For example, the caddis larva's curious casing is readily explained in terms of 'the limination, re-arrangement and separation of inherited units in a basic synchronised set of spinning or weaving patterns' and their displacement to new parts of the caddis larva lifecycle (Ross in Collias and Collias 1976: 173ff). It is a perfectly commonplace evolutionary stratagem in other spheres (e.g., Beck 1980: 137-139) and poses no special problems here.

Of course, calling such adaptations 'tools' does have quasi-rational connotations, and perhaps this use of the term should be discontinued. After all, they are only 'tools' in the same sense that a male mantis' offering to a potential mate is a 'love-token', a beehive is the bees' 'home' or the scent trail an ant leaves for its nest mates is an 'itinerary' (Bonner 1980: 128-129). Such terminology is entirely metaphorical, and as such liable to deceive if inadequately theorised. Conversely, the requirements for artifice properly so called are much more extensive than mere instinctive in-

corporation. Nor is learning ability enough for tool use as we normally use the term, with its constructive and even creative connotations: many other propensities and conditions are required for tool use to be possible (See, for example, Beck 1980: 172-173, 190ff, and Chapter 5 in general).

3. Sensorimotor tools

The question the preceding, very conventional account naturally raises is whether the same model can account for tool-using and tool-making in higher animals such as birds, mammals, and above all primates and human beings. As I argue in this section, there seems to be a case for arguing that later forms of tool are better accounted for not by evolution identifying more and more powerful ways of mapping structures onto functions but, on the contrary, by dissociating structures from any specific commitments to any particular functions. On this basis, much more flexible systems and capabilities are created, through which tools and tool-using organisms not only become more versatile but acquire additional layers of sophistication that make it proper to speak not only of tools but also of technology proper.

3.1 The nature of sensorimotor activity

Among birds and some mammals it is clear that much tool use can be accounted for in terms of narrowly 'adapted' instinct, where the structure of activity in question is more or less dedicated to a specific function and cannot be recombined with other structures to create original patterns of activity. Although there has probably never been a time when any widespread pattern of organic activity consisted of a completely rigid connection of a particular structure with a particular function or when that structure was completely divorced from more or less flexible use as part of other functions, the flexibility and scope of these connections has always been narrowly limited not only for insects, fish, amphibians and reptiles but also for many mammals and birds.

At this level at least, instinctive tools share in both the species-universality and the general immutability by which instinct in general has usually been defined. Although not incapable of learning or refinement, radical reorganisation is certainly beyond them. Given that the early phases of evolution are dominated by single-celled creatures, then complicated but not highly structured multicellular organisms and then simply organised central nervous systems, it is likely that early forms of activity of all kinds were highly 'adapted' in this sense (as opposed to the more 'adaptable' forms that have come to predominate in birds and mammals). In such a situation, where the different aspects of an organism's structure and functioning are often only tangentially connected with one another, the assimilation of extra-somatic extensions is perhaps even easier to understand than their acquisition by the more complicated (but not yet intelligent) organisms by which they are succeeded.

But there is no reason for adaptedness to predominate indefinitely. On the contrary, there are very familiar patterns in evolution that will provide ample opportunity and pressure not only to refine any prior instincts into extraordinarily well-honed devices for dealing with their respective spheres but also to break them down and shift activity (tool-using and otherwise) away from the narrowly fixed and pre-adapted to the adaptable and flexible. In fact any important environmental factor that is variegated, variable and responsive to the organism's own actions will reward adaptability. For example, both predator-prey relationships (Robinson 2005) and the rich, complex, unpredictable and dynamic environments such as the African savannahs on which human intelligence may have come to fruition (Kingdon 1993; Hockett and Ascher, 1968) are likely to complicate basic biological functions such as feeding, reproduction, defence or seeking shelter beyond the abilities of any plausible pre-adapted instinct. So are the social relationships on which so many theories of the origins of intelligence dwell. And so on.

In such conditions, the basis of successful adaptation will change from mastery of an *empirically* identifiable niche - this kind of terrain, that kind of prey animal, this method of approach, and so on - to establishing control over a *functionally* defined niche. This would be defined not by targets, actions, and so on that can be empirically defined and 'known' in advance but by what our ancestors needed to accomplish, and to accomplish which they were obliged to adopt in a variety of ways that could be suited to a variety of empirical circumstances. In a functionally defined niche, the same result must be achieved independently of the exact empirical conditions in which it is set. In that context, predetermined and fixed forms of adaptedness are likely to hinder at least as much as they help. In that respect, the problem the environment sets the adaptable organism is the re-

verse of that set for the instinctive organism. Any organism that is obliged to deal with a content and context that is too difficult for static, predetermined structures to accommodate will benefit from breaking the fixed links of adapted instincts and enabling itself to assemble content- and context-sensitive processes, methods, tools and techniques.

Thus, as soon as the possibility of such functional recombination and reorganisation arises, the organism's capacity for action and perception expands by the leaps and bounds of a geometrical progression. By the same token, the very freedom with which such restructuring can take place will mean that radically new forms of originality and creativity will start to enter into action and perception, with the result that (as we witness in many higher animals) it becomes literally impossible to define or circumscribe what it is that such an organism might do, since that can only be determined by the combinatorial possibilities that the rise of adaptability makes possible. In other words, the structures and organs with which it is equipped by nature become only the components of a series of virtual or 'functional' organs that are specifically matched to the organism's present situation. At first this 'facultative' approach to its own nature is limited to a heightened versatility in the various forms of perception and behaviour; but as I will argue below, in intelligence this process of functional virtualisation reaches the point where transforms its whole environment into a system of potential organs, including the social and historical world as well as physical nature.

At the same time, one need no longer look for specific functional or even adaptive values to associate with the adaptable organism's abilities. Indeed, if the adaptable style of adaptation shifts the focus of activity from empirical triggers and behaviours to functional outcomes and methods, this can only be undermined by continuing to enforce any specific relationships between structures and functions or between different structures. In other words, the reproductive fitness of such an organism is to be understood not as identifying what this or that particular adaptation is 'for', but by mapping out the extent to which its adaptiveness frees it from any such commitments. For by replacing by adaptedness with adaptability, adaptation moves from being dominated by structures each of which adapts the organism to something in particular to structures that increasingly adapt it to everything in general.

Of course, adaptability is not without cost or risk, which is of course why radical adaptability is not universal. As I have argued elsewhere (Robinson 2005), adaptability is likely to mean reduced response times and a costly infrastructure, and will only pay off where this price is worth paying. And there are plenty of niches where this would be a high-risk strategy, and where adaptability demands too much early experience or offers too few advantages to warrant the investment in slow and error-prone complexity and physiologically expensive neural tissues.

In many species a compromise is evident. To take only a single example, it seems to be the specifically adaptable character of its activity that explains a kitten's playfulness. Being a primarily adaptable creature (at least as far as the kinds of activity - notably hunting - that are anticipated in its play are concerned), the structures through which it acts are largely free from specific motivations and free to combine creatively into complex and innovative sequences. Conversely, the kitten has yet to confine its activity to the specific goals, habits and inhibitions of adulthood. So it plays, not because it has an instinct to do so or because play performs a biological function, but simply because the adaptability of its activity lifts the instinctive direction and constraints on its actions. Like a baby who reaches for the moon simply because it can (and knows no better), a kitten plays because it can, because the opportunity for play arises and because it has no 'reason' not to. However, until its instincts are completely dissolved, the *initial* freedom and flexibility that characterise the kitten is eventually subordinated to late-flowering feline instincts. By virtue of this compromise cats can take advantage of the massive opportunities for early learning and sensitisation adaptability offers them, without risking the openness of a life-long dissolution of all instincts.

On the other hand, insofar as adaptability does pay dividends, it is facilitated, amplified and accelerated by the emergence of the first central nervous systems, which provide the integrated platform and communication and control systems needed to dynamically differentiate pre-existing structures and then coordinate the resulting elements into novel patterns. Both phylogenetically and ontogenetically speaking, this eventually reaches the point where a given structure can both be applied to a large number of different functions and be readily combined with neighbouring structures to create novel patterns of perception and behaviour. Although there seems to be no universally accepted terminology in this area, this implies that the instincts that dominated before have been dissolved in to *reflexes* (Piaget 1971).

This places activity in a situation analogous to that enjoyed by human infants at the start of the development of individual intelligence. During this stage the newborn infant's development focuses on the synthesis of new structures on essentially the same basis as that just described: the progressive refinement and differentiation of various innate reflexes and their coordination, integration and synthesis (both permanent and dynamic) into new, original structures of activity. Leaving aside the question of innate predispositions and constraints on this process, the general logic of a human infant's ontogeny is peculiarly like - indeed, in many respects the acme of - the larger evolutionary process described earlier.

Such analogies are always treacherous if handled carelessly, of course. Species that can be legitimately characterised as predominantly adaptable in this general sense are not, unlike human infants, 'on the way' to intelligence. At the very least the residual weaknesses of adaptable forms of activity mean that most such species will settle for a combination of adaptable and adapted structures. And of course, despite the recent enthusiasm for Darwinian models of development, individual development and evolution change are in many respects fundamentally different - *especially* in intelligent and near-intelligent species. Nevertheless, the resemblance is close enough to justify importing some existing concepts and terminology from the development of intelligence in the individual, and the metaphorical use of this term is surely no worse than the routine use of 'purpose', 'designed for' or even 'function', which is all but universal within evolutionary theory. For this reason, both the patterns of activity and the tools to which the predominance of adaptability over adaptedness lead can be described by the Piagetian term for the human infant's reflexes and development, namely as *sensorimotor* (Piaget 1953, 1955).

3.2 Sensorimotor tools

The most obvious feature of the sensorimotor tool is that it extends the organism's sensory and motor structures. However, it is not this that distinguishes sensorimotor tools from their instinctive counterparts: they too extend their host's sensory and motor abilities in various ways. As Beck put it:

Most animal tool use functions to extend the user's reach, amplify the mechanical force that the user can exert on the environment, enhance the effectiveness of the user's display behaviours, or increase the efficiency with which the user can control fluids. (Beck 1980: 122; see also Vauclair 1996: 60ff)

Nor is it any specific abilities added. Although quite novel, there are few instances of sensorimotor tools that could not be equalled by a strictly instinctive tool. What really marks out the sensorimotor plane is not the tools as such as the sensorimotor organism's *general* ability to *re-organise* its sensory and motor activity as a whole. That is, the sensorimotor organism's ability to wield this tool is not a matter of specific 'programming' for that particular kind of activity, while the ability to wield another tool is the result of a quite different kind of control. Rather, the sensorimotor organism can do this *and* that simply by virtue of the inherent variability of its actions, which can be combined in novel and often quite astonishing ways to create a multiplicity of effects, including a variety of ways of manipulating various items in its environment.

This is also why the range of sensorimotor tools cannot be captured by simply listing them, as instinctive tools can be. If, as has been observed, elephants can scratch themselves with brooms or a chimpanzee can gain ascendancy by banging cans together [\$\$ Goodall], this is by no means because they have an instinct to do any such thing, and neither are such extraordinary actions merely fortuitous extensions of fundamentally instinctive action patterns. It is not biological prescription that accounts for such abilities, but precisely the *lack* of biological prescription. For what has happened with the emergence of the sensorimotor reorganisation of activity is not merely that the organism has acquired a new range of abilities. The reorganisation that a sensorimotor structure of activity portends is much more fundamental than that. For if sensorimotor reflexes are not bound to any particular motive or function, then in a different context, the same reflex might well be applied to a quite different content. Or they might be applied to a familiar situation in quite unprecedented ways.

This amounts to a good deal more than the ability to refine a pre-existing structure by learning or localised differentiation and integration, or by the arithmetic addition of new applications by practice or further evolution. Instead, the sensorimotor organisation of reflexes offer the possibility of a geometric multiplication of abilities, without any further evolution, through the more or less

free recombination of reflexes among themselves and their mobile and spontaneous application to new contents and contexts. Once sensorimotor activity has come into existence, its open, constructive character explains why sensorimotor tools are much less stereotyped and much more readily generalised than their instinctive counterparts. It also explains how they can be so sensitive to content and context and how they can exploit primitive forms of insight or be acquired by virtue of constructive imitation.⁴

Conversely, this liberation of structure from function is not merely an interesting detail of evolution; as far as explaining all non-instinctive tools is concerned - explaining how they are possible and how they work - having a specific motivation or technique would prevent them from existing at all. So, as well as providing a new platform of activity in themselves, the appearance of sensorimotor reflexes also tends to erode the non-sensorimotor structures by which they are surrounded.

This analysis makes it relatively easy to interpret the widespread use of tools by mammals. Unlike the tools of lower animals, there is no need for particular adaptations to particular states, functions, instruments or situations. Indeed, it is hard to imagine how any such activities could be engraved in the sensorimotor organism's biological natures without simultaneously disabling the advantages they gain through adaptability. At the same time, it is unnecessary to look for specifically 'adapted' adaptations. It also explains many non-tool abilities, such as the capuchin monkey's mysterious puzzle-solving abilities (Antinucci 1989) or the chimpanzee's talent for deception (Seymour 1989). In none of these cases is it necessary to postulate a pre-existing urge or template or even *ability* to do such things. One need only assume that the structures of activity through which they are done are freely available for widespread (if not completely general) use, and that they are capable of being combined pretty freely among themselves. Once that is accepted, then to the extent that sensorimotor reflexes predominate over instincts, the organism's activity, tools, talent and potential are *created* by each particular organism and in each new situation, rather than *inherited* through evolution.

In short, unlike instinctive tools, each of which requires its unique adaptive significance, explanation and history, sensorimotor tools presuppose only the ability of the sensorimotor organism to assimilate external elements on the same general lines that it organises its activity as a whole. Far from sensorimotor tools requiring an additional explanation, it would be extraordinary if the adaptability, versatility and freedom of a sensorimotor organism's ability to handle items in its external environment were not broadly equivalent to its general ability to act. At least in the sensorimotor organism, the former is after all only a specific instance of the latter. So, like instinctive tools, the emergence of sensorimotor tool making and tool use pose no special problems, but for completely different reasons.

The impact of sensorimotor reflexes goes far beyond the versatility, sensitivity, spontaneity and dynamism of sensorimotor activity, however. The separation of the structure of reflexive activity from any fixed functioning means that the organism's activity is no longer directly determined by the organism's current state, needs, perspective, and so on. As a result, the infant sensorimotor organism needs extensive care and guidance to make it to adulthood. Which is why, of course, they have an infancy at all. Conversely, the ability of these same structures to organise among themselves means that the structure of sensorimotor activity tends to be governed more by the objective logic of the activity in progress than by the affective condition or innate 'programmes' of the 'host' organism. As a result, the 'locus of control' of a sensorimotor organism's existence is situated more in its environment than in itself. But at the same time, the more completely the various sensorimotor structures are modified and coordinated under the influence of that organism's own unique experience, the more uniquely individual each particular organism becomes. That is why sensorimotor organisms have that remarkable and unprecedented feature, a *personality*.

3.3 A typology of sensorimotor tool use

This analysis places any would-be 'natural history of technology' in a paradoxical position. If sensorimotor reflexes are capable of dynamically organising and reorganising activity to any significant extent, or of applying those reorganised patterns of activity to an equally wide range of functional and empirical contingencies, then it will be impossible to catalogue exhaustively the tool-using capabilities to which they give rise. Does that not imply that this would-be natural history now runs into the sand? In certain respects, yes. For example, there will never be a definitive list of sensorimotor tools or their exact uses. We will probably always be taken by surprise by how innovative mammals and birds can be. However, the logic of sensorimotor development as it applies to human

infants, although it cannot be transposed directly to other species, does suggest some interesting hypotheses about the *kinds* of tool use that will emerge in this period. From the instinctive perspective of the previous era, these are entirely novel and relate not so much to the particular tools or the functions they support (the basis of any catalogue of instinctive tools) as the organisation of tool-related activity. In other words, in place of a catalogue of tools it may be possible to create a typology of tool-using *methods*.

There has unfortunately been relatively little research into non-primate tools from this point of view (but see Vauclair 1996: Ch. 4) - certainly not enough to come to many firm conclusions. There is especially little knowledge of how well most non-primates would fare on the Piagetian model of sensorimotor and intelligent capability I am proposing here. As a result, it is difficult to differentiate between instinctive and sensorimotor forms, and I can offer very little empirical support for the following hypotheses as far as most mammals and birds are concerned: as far as they are concerned these are no more than tentative speculations. Primates, however, have provided us with extensive evidence of their cognitive abilities, and Piaget's models have been adopted quite widely by primatologists (Parker and McKinney 1999). We now have quite detailed knowledge of the temporal, spatial, causal awareness of monkeys and apes that would be needed to support sensorimotor tool use and tool-making.

Broadly speaking the primatological literature supports the present hypothesis. Sensorimotor and instinctive tool use cannot be placed together on a single continuum. Not only are the forms of tool and tool use quite different but the social matrices within which tool use is transmitted and acquired both indicate a completely new dimension to tool use at this level and anticipate a crucial dimension of the much more radical transformation of tools that will come with the emergence of fully developed intelligence. For example, the 'use' of other agents (typically caretakers) as 'tools' to achieve one's own objectives is present in primates (Vauclair and Anderson 1994), notably young gorillas (Gomez 1991), chimpanzees (Boesch 1991, 1993; Plooij 1978; de Waal 1983) orang-utans (Bard 1990) and hamadryas baboons. On the other hand, it has not been reliably identified in non-primate mammals or in birds except in plainly instinctive form (Heyes 1994). Indeed, instinctive use of other organisms as 'tools' of one kind or another, as in the case of ants milking aphids or weaver ants using their own young to glue leaves together, are well known but plainly not of the same kind.

On the other hand, the specific limits to which different primates species are subject under various conditions (including their other areas, notably social and numerical cognition) go a long way towards explaining why some species cross the threshold to truly intelligent technology while others remain on the sensorimotor side, but also why there is a natural ambiguity about this situation.

Regarding the specific hints offered by Piaget's model of sensorimotor development, from the point of view of tools the first three sub-stages (summarised in Piaget 1953: 150-152 and 1955: 221-256) are essentially preparatory. During these three periods the infant's native sensorimotor reflexes are successively refined, locally coordinated and then integrated into a more or less well structured system that embraces the sensorimotor reflexes as a whole. As tools are first and foremost means to ends, although the opening sub-stages of sensorimotor activity are essential preliminaries, they do not deliver tools as such. Even the ability to grasp *objects* properly so called - which occurs in the fourth sub-stage of the classic Piagetian scheme - is not quite enough. For only when relationships *between* objects that has been established it is possible to apply one object to another, and so have tool use. Even where the entity to which the tool is applied is, say, part of one's own body (as in the case of the elephant's broom) or to a static substrate (such as the ground) assumes at least an intimation of such a relationship. [I'm not sure that this is necessary or supported by the evidence - for example ...] Before this level of development the infant has already noticed causal relationships, but is not yet able to control one object in order to exploit its causal effects on another object. \$\$

During this [fourth?] sub-stage one should expect to witness the refinement of this highly generalised capability to individual contents and contexts. Or as Piaget puts it, 'the application of known means to new situations' (Piaget 1953: 151). That is, whereas an organism that has reached the first three sub-stages will have a very generalised ability to act in a variety of circumstances, this ability remains limited to the apply a general (perhaps functional) tool type to a general (perhaps structural) situation. It will lack the ability to suit the instrument to the exact content or context of activity. This ability (which, in the human infant, requires only that this tool use be further differentiated and integrated to the point where the infant can respond precisely to the need and opportunity) does appear with the fourth sub-stage of sensorimotor activity.

Also at this new level, the organism demonstrates a new ability to solve problems, with clear implications for how tools are used. 'Given a habitual goal temporarily thwarted by unforeseen obstacles, the problem is to surmount these difficulties: this is what the present behaviour patterns consist of' (Piaget 1953: 151). However, perhaps the most important aspect of this sub-stage is the appearance of objects as Piaget defines them - as. Given the extent to which higher forms of tools and all technology rely on our expectation that things have powers of their own that go far beyond our direct awareness of and control over in them, there could scarcely be a more momentous moment in the entire history of technology, natural or otherwise.

The fifth sub-stage enables the sensorimotor tool user to introduce a yet higher level of refinement into its activity. Although an organism at the previous level of tool use was sensitive enough to fit its tools to the precise, by the time it has reached sub-stage five it is starting to supersede even that level. Now the sensorimotor organism is able to evaluate situations in various ways independently of actually taking any direct action. Typical of this period is the 'experiment in order to see', which generates new approaches through active variation (Piaget 1953: Chapter 5) - a development that not only emphasises the emergence of method behind the direct use of a tool but also points the way to much higher things. For example, I would suspect that an effective termite tool requires this level of sensitivity and elaboration.

The final sub-stage of sensorimotor activity consists of what Piaget described as the 'invention of new means through mental combination' (Piaget 1953: 152). In this period, the internal structure and resources made available by the previous sub-stages of sensorimotor development are sufficient to provide the individual with a map of its environment and its own forms of activity, through which it can 'navigate' things and events in thought (or at least in imagery) without having to engage them in fact. At this point, the human infant is able to, for example, identify alternative routes around a familiar terrain without having experienced them previously. From the point of view of tool use, one would expect the same infant - or any equivalently developed sensorimotor organism - to be able to work on an object from a succession of points of view, and to appreciate the need to apply several different tools when it needs to carry out a complex task. This does not, at the sensorimotor level, involve an explicit knowledge of what the proper procedure for doing this will be or provide an articulated or even particularly effective plan for doing so; but unlike previous sub-stages, at this level the notion of a sustained sequence is at least implicitly present in the action as a whole.

I must emphasise that these are only hypotheses based on a psychological model that has limited application to most organisms, even those capable of significant level of sensorimotor adaptability. In the absence of a human neonate's freedom to develop, it is extremely unlikely that an organism would follow this model exactly - certainly most of our primate cousins do not (Parker and McKinney 1999). It is not even likely that, for most mammals and birds, the stages outlined above would have any unequivocal application. However, treated as a generic model, the above account does refine our notion of tool use, and for any organism that actually verges on genuine intelligence, it will have some direct application.

3.4 The limits of sensorimotor tools

Plainly, sensorimotor tools neither could nor should be explained in terms of the adaptedness of instinct. But neither are they equivalent to intelligent technology. The sensitivity, flexibility, insight and imitation of sensorimotor activity may add up to a profound break with instinct, but the fact that the tools sensorimotor organisms create never do more than organise and re-organise the organism's native sensorimotor abilities still separates them from intelligence proper (Viaud 1960: 39-40, 49-51). Their inability to transcend the empirical plane of the senses and motor activity, of perception and behaviour leaves sensorimotor far short of its insight into non-empirical structures of the kind that higher technologies will embody. As far as we can tell at present, even the most sophisticated chimpanzee or bonobo technology falls short of consciously implementing any causal principal or operational process other than that which can be intuited from their immediate actions.

In other words, it is not that an elephant with a broom could not scratch itself by using its normal sensorimotor capabilities; it simply could not scratch itself *there*. Likewise, a male chimpanzee does not lack the ability to intimidate, but banging cans together does it so much *better*. The change introduced by the sensorimotor level of activity is not in its sensory or motor limits, but in its ability to recognise in very basic ways how external objects can be assimilated to achieve its aims using those very same sensorimotor structures.

Hence the characteristic limits of sensorimotor tools. From the point of view of the tools themselves, sensorimotor tools embody a certain level of sophistication, but their very sensorimotor nature means that there are far greater depths of tools, their construction and use that, under intelligence, will culminate in technology proper, but which they do not penetrate. This limitation is the topic of this section. In the next, the other major shortcoming of sensorimotor tools will be reviewed, namely the lack of insight into the relationships with other organisms within which tool use takes place and which means that tools cannot be integrated into a wider system of social and cultural relationships. Hence the absence of important advances in the organisation of activity such as work and the division of labour.

The classic locus of sensorimotor activity is among primates. Yet the burgeoning primatological literature does little to *explain* the limits of primate tool use, or why it is that, with the exception of the chimpanzee and the bonobo, non-human primates do not generally complete sensorimotor development (Parker and McKinney 1999). In particular, insufficient attention has been paid to the important issue of how the various adapted structures that the sensorimotor organism also inherits interfere with or preclude sensorimotor patterns of activity. This is important because it is debatable whether an organism that is not equipped to develop full intelligence could still be equipped to go through a sequence of stages in tool use that was quite like the above rather orderly series. The evidence seems to suggest that many of the abilities to which sensorimotor reflexes give rise in human infants occur only in impoverished form among most other primates. For example, the classic Piagetian 'circular reactions' are largely missing (Parker and McKinney 1999: pp. \$\$ and Table).

Why that is and what specifically it is that is preventing them from realising the same potential as human beings seems to require some explanation. After all, the developmental process through which human infants pass seems to be more a matter of the logical unfolding of the potential of unconstrained sensorimotor reflexes than of any biologically prescribed process (Robinson 2005), so it is neither anthropomorphism nor teleology to ask why the same does not happen among other sensorimotor organisms. There are various possibilities: for example, a simple lack of neural capacity. However, assuming that any partially sensorimotor organism may (or must) also possess a range of more narrowly adapted predispositions, I would suspect that the latter would constrain and circumscribe their more adaptable neighbours in functional and structural ways that curtail and subvert the 'normal' sensorimotor sequence. Certainly the presence of more than a small number of relatively isolated and peripheral adapted structures would (by definition) be enough to prevent the emergence of intelligence proper, so one should certainly expect that if such structures played a functionally significant role in the life of any otherwise sensorimotor organism, they would at least limit the adaptability and effectiveness of such sensorimotor structures as it did possess.

However, there are also limits to sensorimotor tool use that inhere in sensorimotor structures themselves, which account for the superficiality of sensorimotor tool use directly. For example, there is as yet no clear evidence that any bird or non-human mammal (with the possible exception of some primates - see below) uses tools to control or exploit supra-perceptual or supra-behavioural activities, relationships or sequences. For example, sticks, leaves, stones, and so on may be used for preening, hygiene (Goodall 1986), as seats and for avoiding contact with dirt or with thorns (Alp 1997), for display, for laying bait and digging out and impaling prey, as umbrellas (Ingmanson, in Russon, Bard and Parker 1996) and even for a little impromptu dentistry (McGrew (1992)). However, despite their extraordinary sophistication by comparison with instinctive tool use, the complexity of such actions actually observed has always fallen within the limits of sensorimotor recombination. Conversely, tools are not used to tap and exploit natural sequences or embedded in complex production processes, except where simply triggering such a sequence is enough to achieve the desired results or it is possible to proceed strictly by trial and error. In short, although sensorimotor tools may enable their users to apply or exploit natural principles of one kind or another, their use presupposes no actual insight into those principles on the part of the animal in question.

More specifically, sensorimotor structures lack \$\$

The limited quality of sensorimotor structures is well illustrated by tool use among primates, which is sufficiently ambiguous to maintain a substantial industry among academics. For example, apart from foodstuffs, materials are not deliberately transformed from one state, typically not useful, to another, typically useful, according to a pre-defined procedure or plan. Or at least, we cannot know whether or not otherwise simpler actions are controlled by more sophisticated stratagems: all we can confirm is that we have yet to observe a sequence that would *require* such sophistication. Nor are objects reshaped to take on more useful forms except in ways that are empirically

very straightforward, as when a termiting probe is striped of superfluous matter. Even simple processing techniques such as cutting and slicing seem to be unique to human beings and perhaps their closest cousins, yet they scarcely go beyond the perceptible features of the situation or their direct continuation. Neither cracking eggs nor breaking open shells qualify as intelligent, since they never leave the strictly sensorimotor plane. A non-intelligent organism may be perfectly capable of dropping an egg or a coconut in order to break it open, but without some sense of more abstract transformations, we should not expect even the great apes to build a water wheel or a trip hammer, and still less combine the two into a coconut-processing machine.

Still less is there any evidence of the systematic use of a diverse toolset, the use of the same tool in many different ways or a truly multi-functional tool of the kind that characterises the simplest human technology:

The premier multipurpose tool is the Australian spear-thrower, or *woomera*. The flat blade of this implement has its spear-throwing edge mounted at one end... On the tip there may be a sharp flint embedded in mastic which can cut, bore or chisel as required. At the other end the hardwood blade or its point may help provide the friction to ignite tinder, as well as serve as a club or rhythm stick; the flat can be used as a small palette or miniature mixing platter. Markings on the spear-thrower can be a personal passport, a recording slate, a 'map' or a message board. (Kingdon 1993: 176-177)

The widely cited case presented by Brewer and McGrew (1990) is impressive but not entirely convincing. The 'tool-set' they describe only emerges as the task advances, and there is nothing in their report to suggest that it is governed by the chimpanzee's prior possession of either a set of functionally differentiated tools selected for the task in hand or any notion of a distinct processing method to which these tools it to be subordinated and that would account for their selection. Likewise for the lack of any instance of a multi-task or multi-phase plan (McGrew 1992: 183, and in Gibson and Ingold, 1993: 158-159. For possible exceptions, see Beck 1980: 74). Physical prowess apart, even the orang-utan who was observed to stack up four boxes to make a tower and then use a stick to reach food was still only operating within the cognitive limits of a (rather bright) sensorimotor infant. Parker (in Chevalier-Skolnikoff and Poirier 1977: 43-112) reviews evidence in another promising primate, the stump-tail macaque, but it too proves to be limited to the sensorimotor level.

Similarly, the famous Japanese macaques among whom various forms of quasi-tool use were said to have spread seem to have been operating on a similarly sensorimotor level. More generally, whether the spread of 'culture' and 'technology' through this group should be accepted at face value has been doubted, not least on the grounds that the spread of cultural innovations is usually rapid, whereas the macaque group took years for all but the most responsive individuals to pick up the original insights (Galef in Bekoff and Jamieson: 1990, vol. I: 74-95).⁵

Not that all our primate cousins are limited to sensorimotor technology, although the relatively limited extent of their intelligence - in Piagetian terms, this sometimes extends into the first, pre-operational stage of intelligence proper, but seldom further (Parker and McKinney 1999) - makes it hard to be very precise about their real abilities. At the moment it is hard to identify what limits their further development - absolute neural capacity and residual neural constraints (Antonucci 1989) are both likely to play a part. Many other factors may also play a role, such as the lack of cultural 'scaffolding' or anything resembling collective representations for tools and tool use. As a result, the sensorimotor organism can no more handle the strictly supra-empirical structure of things and events that truly intelligent activity is able to grasp - typified by a grasp of abstract processes and natural laws, but with many simpler precursors such as simple classifications and series - than a chemical reaction has an anatomy or can die.

Hence the ambiguity of primate tool use. For example, the chimpanzee's use of a rock or a hard root as an anvil provides a tantalising complement to their use of hammer stones, which jointly suggest a complex coordination of action that goes beyond the merely sensorimotor. However, once selected and in place, an anvil is actually a passive element in the action: so long as it is well chosen and properly established, it can be more or less disregarded for the duration for the activity performed on it. So can the wedges used to stabilise these anvils (Matsuzawa in McGrew *et al.* 1997: 196-209). And in any case, the coordination involved in using this particular 'toolkit' is sequential rather than simultaneous - a much simpler proposition. On the other hand, although anvils alone require only a relatively low level of Piaget's pre-operational stage, wedges are not observed in human children until late in that stage (Matsuzawa in Wrangham *et al.* 1994: 351-370). And again, using a substrate in this manner is not to be taken for granted: if it simplifies the hammering, it

complicates the overall process whereby the apes gets from inedible nut to tasty morsel. As Parker and McKinney put it:

Use of a hammer and anvil seems to involve a bifocal coordination, first between the nut and anvil, and then between the nut and hammer in a single interrelational task structure. Use of a wedge to support an anvil adds yet another coordination, suggesting an elaborated coordination. (Parker and McKinney 1999: 55)

Yet using an anvil still does not demand the same insight as combining the actions of multiple tools, and it is not clear that their respective uses of wedges are truly equivalent. As Parker and McKinney go on to note, 'The fact that this behavior seems to be manifested only in late juveniles and adults, and by only a few of them, suggests that this lies near the limit of the cognitive abilities of chimpanzees'.

In short, the marginal nature of much primate intelligence makes it inherently difficult to decide on which side of the line between the sensorimotor and the truly intelligent their technology really lies - if, that is, it is wholly the one or the other.

3.5 Sensorimotor tool-making

As for non-human animals *making* tools, even the most striking cases seldom require the maker to transcend the sensorimotor level, exercise any insight into the more abstract principles and structures that structure and control the world, or go beyond reducing raw material to an already semi-perceptible kernel. A digging stick is created by detaching leaves and small twigs, a hammer is acquired by digging a visible stone out of the soil, and so on. Such tools are more 'naturefacts' (Goudsblom 1992; Ingold in Gibson and Ingold 1993: 429-445) than artefacts: they can be taken more or less straight from nature, without being 'produced' in the sense of being created by a process of structural transformation or assembled out of simpler components to create a whole whose potential functionality is not intuitively obvious in the parts. To take only the most universally cited instance of animal tool-making, it is true that a good termiting probe 'must be sufficiently slender to be inserted, strong enough to prevent collapse during insertion, flexible enough to be snaked through twisting passages, soft enough for the termites to grip, and resilient enough to regain original shape for reuse' (Beck 1980: 86; see also pp.89 and 91), but all these requirements can be met by choosing the right raw material and applying only minor pragmatic modifications. It does not demand that the chimpanzee 'design' the tool, and in this case selecting the right material may easily be accomplished by trial and error (Luria and Vygotsky 1992: 15ff). That is not to say that that is how it is actually done, but the evidence seems to be silent on the latter hypothesis.

More generally, although capable of serving genuinely intelligent purposes, there is little evidence that tools like this are conceived, designed, made or used with any insight beyond directly matching the perceptible features of the tool with the perceptible features of the task. There seem to be extremely few cases, and none that is altogether convincing, of a tool being produced by means of any insight into any structure or relationship that goes beyond what can be observed in the immediate setting in which the tool is made. Even where apes have been observed to produce a usable stone flake, be it by accident or by design (Wright 1972; Savage-Rumbaugh and Lewin 1994), none has yet been seen to make spontaneous use of it (although an orang utan may be trained to open a box by cutting a rope tied around it - Wright, 1972). This is a very far cry from the dawn of the Neolithic, with its finely ground, geometrical tools and methodical creation of durable, functional instruments. (On the subtleties and complexities of lithic tools and tool-making, see Schick and Toth 1993).

There are plenty of other examples of tool-making by non-humans, although again the claim that they express intelligence proper is less compelling than is often thought. The reason for this is often that observers lack a clear model of what constitutes intelligence itself. Of course, there is no reason for others to accept my own neo-Piagetian preferences, but that does not mean that all alternatives carry equal weight, not least because they are generally very equivocal, are supported by far less substantial argument and evidence and, it must be said, their proponents often seem eager to call every least flash of interesting activity intelligent.

For example, it might be thought that making one tool by means of another should qualify as truly intelligent. But this view should be challenged. Although such an accomplishment is plainly beyond almost all non-human species - apart from human beings, only the orang-utan and pygmy chimpanzee have been seen to make one tool by means of another (Schick and Toth 1993: 135-140)

- it still lies well within the scope of sensorimotor activity as a whole, at least insofar as the tools in question can be managed in strictly perceptual and behavioural terms. In other words, such tools are more like a hammer than a machine. Schick and Toth themselves conclude that their subject's abilities were well below those of Oldowan hominids, whereas Wynn and McGrew (1989) take the opposite view; however, neither side has yet shown that they require more than sensorimotor capabilities. It may be extraordinary to observe a bonobo making one tool by means of another, but it is still within the cognitive (if not the manual) capabilities of a human infant.

Given all this, one cannot help but feel that McGrew it is overstating his case when he draws his well known conclusion that 'Given what it is known of chimpanzees' abilities in captivity... they are capable of making and using all the subsistants in [aboriginal] Tasmanian material culture' (McGrew 1992: 144).⁶ Even if this claim were true (and McGrew's own evidence on the use of fire contradicts it), surely what is at issue is not whether the chimpanzee's highest accomplishments are equal to the most primitive known level of human activity, but whether an ape's abilities actually *overlap* significantly with those of any aborigine, and what, if anything, follows from that fact. If - as the evidence suggest, - they don't overlap to any significant degree, then as J.H. Fabre put it:

To disparage man and exalt animals in order to establish a point of contact, followed by a point of union, has been and still is the general tendency of the 'advanced theories' in fashion in our day. Ah, how often are these 'sublime theories', that morbid craze of our time, based upon 'proofs' which, if subjected to the light of experiment, would lead to... ridiculous results.

Fabre was of course speaking as a Catholic, but even the most devout materialist would want to echo his words. Under different circumstances, Tasmanian aborigines could have done anything the readers of these words can do, while a chimp can do practically none of them, starting with reading McGrew's words or understanding his argument. The evidence McGrew cites only shows how little, technologically speaking, human beings can make do with - and even that turns out to be more than any non-human species has yet been observed to do.

3.6 Sensorimotor culture and society

Before analysing the specifically technical character of intelligent technology, it may be worth setting it in the wider context intelligence makes possible. Most accounts of animal technology focus directly on tools and their makers and users. But as far as the wider history of technology is concerned, it is important to recognise that, however fully sensorimotor tools have transformed their instinctive precursors, they still only skim the surface of technology's larger potential. Technology as wielded by fully intelligent beings surely cannot be understood without taking into account a much wider range of structures and functions. In particular, once the social and cultural context of technological development, deployment and use is taken into account, an order of abstraction and complexity emerges that places technology proper far beyond tool-making and tool-using as such (Reynolds in Gibson and Ingold 1993: 407-428⁷). Conversely, despite the liberality with which terms such as 'culture' and 'tradition' are employed by biologists and primatologists, the mechanisms actually involved in making tools and in transmitting and regulating tool use at the sensorimotor level do not qualify as either. In particular, in the absence of supra-empirical rules or relationships (implicit or explicit) to which tool makers and users could be said to adhere, there can be no established or encoded order, recognised or treated as an order, through which each member of a given population could develop skills or attach meaning to its tool-using actions and abilities independently of their personal relationships. There could likewise be neither received or authorised form nor any independent reference point for correct practice. All of these are arguably required for a technology proper⁸.

In what sense then could tool-making and tool use as observed at the sensorimotor level be said to be cultural? The answer is that even in the absence of a structured system that we might realistically call a 'culture', there are forms of activity that can legitimately be termed 'cultural'.⁹

Of course, there is continuity and contagion in the transmission of earlier forms of technology, but the natural resemblance between the practices of organisms who imitate and collaborate with one another is not enough to constitute a culture. The latter may not require a full-blown, articulated sense of, for example, heritage and lineage, but surely some kind of relationship (be it one of continuity or change) between present norms, methods, instruments and products and their

past or future counterparts must surely exist for either a culture or a technology to be said to exist. Empirical resemblances between tools alone do not distinguish between, on the one hand, the genuinely social constructions on which culture and technology proper rest and, on the other, individual organisms learning from one another. The latter may well happen in the same sense that organisms might learn from anything else in their environment: there too one would expect organisms immersed in the same environment to resemble one another, but this would have nothing to do with culture.

That is not to say that there is not a great deal of imitation and social facilitation in sensorimotor species, that learning does not accumulate within a given population, that there is no positive teaching (Boesch 1991; Boesch in Gibson and Ingold 1993: 171-183; for a summary of evidence of teaching, see Byrne 1995: 140ff) or that young primates especially do not benefit from this process. This might constitute cultural activity of a very primitive kind, but even if it does, there does not seem to be any evidence that either learning as such or any other kind of perceptual-behavioural skill has led to the acquisition of anything more advanced than sensorimotor tools. The substance of both culture (meaning, values, norms, and so on) and technology (process, form, established technique, etc.) seem to be completely missing. As Parker observes, none of this requires more than the achievement of sub-stages 4-5 of Piaget's model of sensorimotor development - still well short of intelligence proper (Parker in Chevalier-Skolnikoff and Poirier 1977: 105).⁸ So even in this case, when biologists speak of the dissemination of tools as 'culture' or 'tradition', they are surely either speaking metaphorically or misconstruing the nature of both.

Nor is this at all unexpected: after all, it seems to be difficult even for human observers to pick up the skills needed to make even post-Oldowan tools *purely* on the basis of observation (Corballis 1991: 63): rather greater insight of a strictly intelligent character seems to be necessary to grasp the regularities and spatial order they involve (Wynn 1979, 1981, 2002). Later traditions presuppose a yet higher appreciation and refinement of the mechanisms, processes, skills and alignments of natural forces (Dickson 1990; Schick and Toth 1993). Perhaps that is why there is nothing in the abilities of sensorimotor organisms to explain the *woomera*, let alone Woomera.

3.7 Are you intelligent? Am I?

All this criticism notwithstanding, it is important to remember that the evidence currently available probably does not do justice to the technological abilities of non-human animals. Like all generalisations about primates - and so, *a fortiori*, about dolphins, whales, parrots and other more remote and less intensively studied species - any conclusions drawn now will probably be eroded, if not actually exploded, over the next few years. Just as we rely on a very narrow and probably unrepresentative sample of stone tools when we try to explain early hominid tools and are forced to make huge intellectual leaps in accounting for them (Davidson and Noble in Gibson and Ingold 1993: 363-388), so research on tool use in non-humans tends to be restricted to a tiny sample of close relatives often living in more or less artificial conditions (Beck 1980: 135ff).

After all, we human beings pride ourselves on our inventiveness, but how often have ethnographers witnessed the invention of new tool or technique by a human being (McGrew 1992: 195; Hobhouse 1915: 297)? How often have you or I thought up anything new enough to qualify us as demonstrably intelligent by the criteria I have suggested here? And how often have non-human organisms been given even a fraction of the experience, scaffolding, training and direction young humans receive as a matter of course (Herman 1986)? Indeed, various researchers (e.g., Byrne 1995; McGrew 1992) have suggested that, like human beings, apes only exhibit their latent ability with tools when it is likely to pay off - which in many cases is unlikely in the wild. On the other hand, the striking difference between the use of tools by wild chimpanzees and by chimpanzees returned to the wild from captivity also suggests that, had they the leisure, opportunity and example, a latent or hard-to-detect intelligence might find expression, even after the scaffolding offered by captivity has been dismantled. So why should we expect such miracles from the few individuals and groups of the few species we have studied so far?

4. Intelligent technology

So hold me, Mom, in your long arms...
 In your automatic arms. Your electronic arms...
 Your petrochemical arms. Your military arms...
 In your arms.

Laurie Anderson, *O Superman (For Massenet)*

While the sensorimotor organism lacks the capacity for further development or its abilities are hedged around with adapted instincts, it will always be limited to the empirical surfaces of things and events. However, once true intelligence has been reached, the scope and insight of this new level of action so far transcends either the instinctive or the sensorimotor that it becomes more of an impediment than a safeguard to retain fixed connections between structures and functions or irreconcilable divorces between structures themselves. This is expressed, not least, by the immense (i.e., the literally immeasurable) difference between instinctive and sensorimotor tools and genuinely intelligent technology.

On the other hand, as soon as progress in adaptability has reached the point where there are no practical limits to how far reflexes can be re-organised, re-integrated and re-synthesised, the next phase comes of its own accord. For by liberating the sensorimotor reflexes from the constraints of fixed adaptedness in general and instinctive action in particular, the road to intelligence is open. This road, which has been mapped out so thoroughly by Piaget (1953, 1955) and his successors and critics (a literature too vast to cite even the highlights), presupposes only the initial presence of sensorimotor reflexes and the absence of any constraints capable of distracting or deflecting the developmental process from its natural and logical conclusion. Just as, once liberated from the constraints of instinct, sensorimotor tools respond to content and context rather than the rules inscribed in the organism's body, so once liberated from any residual instinctive urges and enabled by sufficient capacity, the mutual coordination, integration and synthesis of sensorimotor reflexes among themselves will throw up a radically new level of technology, and indeed of activity in general and activity as a whole.

4.1 The origins of intelligent technology

In the previous section I suggested that the emergence of sensorimotor forms of activity (including sensorimotor tools) was driven by the complexity, dynamism and responsiveness of the environment and the mutual responsiveness of organisms, especially animals. In a word, some niches are simply too difficult to manage through the pre-adapted structures of instinct. However, although the adaptability of sensorimotor structures enables the organism to cope with fast-moving and fast-changing conditions far better than strictly adapted instincts, they cannot exploit these opportunities fully whilst remaining on the sensorimotor plane. There remain many possible 'niches' that extend as far beyond sensorimotor structures as the sensorimotor extends the instinctive. This is the realm that can be commanded only by intelligence.

The limits of sensorimotor are at least two-fold.

Firstly, sensorimotor organisms cannot take into account the supra-empirical properties of relationships between objects. As a result they cannot control the action of tools on their objects and on one another with any precision or regularity, or exploit the non-empirical properties the materials and situations they work with. As intelligence beings we are well aware of the power and the need to group, arrange and generally organise things on non-empirical lines if we are to achieve anything of any depth or complexity. Certainly it is inconceivable that any of the technology (or culture) by which we have so successfully surrounded ourselves over the millennia could have any other basis. As a result, they cannot make the transition from the simple, strictly sensorimotor forms of tool making and tool use to the higher plane occupied by number, series and classifications, by abstract concepts of and relationships in time, space, substance and causation, right up to formal methods such as science and mathematics. And in the absence of such insights, they are incapable of grasping and exploiting the supra-empirical aspects of the objects involved in their activity or the properties of the world at large so on that would lead them to even to precision tools, let alone to machines, to automation of to any of the other technical forms of technology proper.

Secondly, sensorimotor organisms are unable to construct supra-empirical relationships between subjects. That is, they cannot arrange the relationships between tool-using and tool-making organisms that would allow them to organise tool-related activity into the vastly more powerful forms of cooperation that we are familiar with from every level from team-building and planning to work properly so called and the division of labour. Given the role the latter have played not only in the development of technology but in humanity's extraordinary relationship to itself, to its world and to the planet as a whole and every organism on it, the significance of this lack in sensorimotor tools can scarcely be exaggerated.

These are not problems for sensorimotor organisms themselves, of course, any more than the lack of sensorimotor adaptability is a problem for the ant-lion or the archer fish. Not only does their survival prove, from an evolutionary point of view at least, their current adaptive equality (in their niche) to any sensorimotor or intelligent organism, but their very lack of such structures precludes their recognition of any such problem. On the other hand, this is damning with faint praise: there can be little doubt how the ant-lion would fare if human beings really took it into their minds to 'compete' with them.

More generally, the appearance of intelligence signals a whole range of closely connected and entirely fundamental innovations in the nature of tools, tool making and tool use. This suite of transformations is the product of a simple but extraordinary novel and profound process of *reflection*. This process has a dual logic: of reflection on the empirical content and context of action, and reflection on action itself (Piaget 2001). In the former case, the ability of intelligence to focus on objects for their own sake and on their own terms enables it to isolate and connect features, qualities and facets independently of both the object itself but also of any particular the intelligence in question might have in it. In the latter, reflection on the forms and patterns of activity through which intelligence itself acts - its arrangements and groupings and transformations of objects - allows intelligence to establish basic relational concepts such as similarity, group membership, equivalence or simultaneity (Inhelder and Piaget 1964). Taken together and to develop increasingly powerful methods, tools and techniques that culminate (so far) in the full panoply of logical and mathematical structures needed to underpin scientific method and law, and the full range of technological methods, tools and techniques (Inhelder and Piaget 1958; Piaget and Garcia 1989).

From a technological point of view this leads to three radical innovations, even in comparison with sensorimotor tools. *Firstly*, the technical functions of tools can be constantly adapted to the specific but unpredictable conditions in which they are used, in which the principles involved go beyond the empirically observable level of the sensorimotor proper. *Secondly*, their makers and users are able to wield them with a versatility that actively adapts them to these immediate conditions, rather than being inscribed in their native biology. And *thirdly*, the new level of relationship between tool users and makers intelligence creates enables them to organise themselves in ways that qualitatively transform the scope, power and effectiveness of tool use of all kinds.

More generally, the structures through which tools are made and used are increasingly distinguished from the tools themselves. This may include not only techniques for processing particular materials and carrying out particular tasks but also ways of organising the toolkits, processes, techniques, collaborators and resources needed to carry out complicated procedures. This is the beginning of, on the one hand, *work*, as opposed to adaptation, and on the other, *technology*, as opposed to mere tools.

4.2 Creating a Piagetian model of technology

Perhaps the most striking feature of intelligent tools is the literally boundless flexibility and fecundity with which they are created, improved and discarded. Not only is there no list of human tools but there could never be one. The link between this and our capacity for a disinterested perspective on things and events is straightforward and extremely ancient. Even before human beings were capable of much in the way of technology, we were capable of detached observation and appreciation of possibilities that were open to organisms more powerful than themselves.

Large groups of primates, elephants and giant pigs all do great damage to plants in the course of feeding... For prehistoric humans this massive impact of animals on plants would have been a routine experience that that offered the opportunity of revealing food sources otherwise hidden underground, out of reach or broken open by strength no human could emulate. Palm pith, many edible roots and numerous fruit food we have

owed their first discovery to simple scavenging in the wake of elephants, rhinos or giant pigs. Not only the food sources themselves would have been significant, but the context of unearthing, breaking and opening would have provided a ready-made abundance of struts and levers to assist effective scavenging... Whether known or not, the object's material usefulness and its properties as a food or fabric become open to assessment. (Kingdon 1993: 53)

At the opposite end of the scale, the lessons to be drawn from rope-like creepers, natural snags, gums and even spiders' webs were duly learned (Kingdon 1993: 180-194). 'One ingenious Aboriginal technique is to train a living liana around a prepared axe or adze head and leave it to become embedded before "harvesting" the naturally hafted tool' (Kingdon 1993: 180). Likewise for fire, which seems to have been actively husbanded long before *Homo sapiens* was capable of creating it independently (Kingdon 1993: 55ff). All these cases rely on powers of objective observation that are lacking in non-intelligent organisms, and indeed *must* be lacking prior to intelligence, for they presuppose the ability to apprehend and appreciate things and events independently of any functional interest in them. The ability to perform objective comparisons between discrete objects or to anticipate the powers and effects of an innovation require comparably intelligent capabilities.

Conversely, one has only to note the sheer number, power, variety, originality and prevalence of the tools at intelligence's disposal to see the difference between intelligent and sensorimotor technology, let alone intelligence and instinct. And even more convincing than such a quantitative calculus (which could never go very far beyond a catalogue of inventions), a logical analysis of the sequence of intelligent technologies reveals that tools themselves represent only the first stage in a succession of technological revolutions, each of which ushers in a qualitatively new relationship between intelligence and its environment, to the point where our technologies promise (or in present circumstances perhaps one should say, threaten) to transform our entire planet.

Broadly speaking, these stages parallel the stages of cognitive development associated with Piaget theory. I should immediately emphasise that this means neither that technology is a function of individual cognition nor that one could measure either cognitive or technological advance by the other. Rather, although Piaget's ideas are normally associated with the psychological plane, his 'genetic epistemology' is more correctly regarded as a general theory of action. It identifies structures, stages and developmental processes for all forms of activity, including not only the epistemic achievements of the individual but also all other forms of activity. Piaget himself developed his model outside the psychological and epistemological areas only in very limited ways (e.g., Piaget and Garcia 1989; Piaget 1974, 1995), but it is clear from both the underlying reasoning and his own general statements that he intended it to serve a far wider purpose.

Although Piagetians have generally focused on development psychology and educational issues, this much wider application of Piaget's theory has been recognised by a few theorists. This has led to the formation of Piagetian models of action in areas as diverse as architecture (Radding and Clark 1992), religious thought (Barnes 2000; Fowler 1981), the development of scientific concepts (Caprona *et al.* 1983), art (Gablik 1977), moral values (Hallpike 2005), up to and including the structures that regulate the largest scale social and historical systems of action (Robinson 2004). All these examples have cognitive elements, but the supra-psychological dimensions are crucial to each case.

So one should not assume that, because a large-scale historical process such as the development of tools and technology is being analysed in terms of what is superficially a theory of individual cognition, that I am claiming that, for example, the pervasive use of a relatively primitive *technology* indicates that its makers and users are restricted to a relatively primitive *cognitive* level. That would be to succumb to an elementary fundamental fallacy, which may be loosely termed the 'theory of primitive mentality' (e.g., Lévy-Bruhl 1965). Far from collapsing the different aspects of such a complex phenomenon, Piaget's model requires one to analyse each of its elements be analysed on its own terms, in its own right and for its own sake, and that one draw no conclusions until all levels and facets of technology are set in a complex historical dialectic of individual cognition, social systems and technology. Otherwise it would be quite inexplicable why, for example, whereas the greatest technical genius may be obliged to live (more or less) within the technological possibilities set by the society they inhabit, the child of an advanced technological civilisation can perform miracles when equipped with a very modest computer.

4.3 Tools, machines and automation

So tools are by no means the last word in intelligent technology. They are not even its most characteristic or important form. Although the most ubiquitous, they are also the most simple, basic, limited and primitive, requiring no more than the ability to grasp and manage objects on the empirical plane of perceptual and behavioural activity. It is true that this already includes a structured world of structured objects (these being the products of sensorimotor development), but at the very start of the pre-operational stage there is no explicit understanding of what exactly what objects are, how they relate to one another, how they constitute a world, how all this relates to my own actions and experience, and so on. On the contrary, action at this level is still limited to perceptual and behavioural surfaces.

However, no sooner is pre-operational action under way than the corresponding forms of technology start to develop in new and radical ways. The basic developmental process during the pre-operational stage is this: actions are carried out (by individuals, socially, and so on) that affect the world; it is noticed both how these affect objects and how the actions are themselves structured; the recognition of these results under a variety of conditions and in a variety of circumstances allows knowledge of both objects and of activity to be coordinated, integrated and synthesised; and as a result, subsequent actions are better informed and more sophisticated. More specifically, during the pre-operational period objects are increasingly thoroughly classified along various dimensions of sameness and difference, and seriated according various kinds of transitive asymmetric relationships of more and less.

Likewise for technology: just as the elaboration of the most basic form of pre-operational intelligence leads to the abstraction of elementary supra-empirical relationships, eventually internalised in the form of 'concrete operational' methods of structuring activity, so the use, refinement and coordination of simple tools leads more and more sophisticated methods of tool-making and tool use, including ways of grasping and solving some of the many non-empirical problems involved in designing, making, selecting, coordinating and using tools. Eventually this leads to the formation of a qualitatively new kind of technological *object* that organise the functioning of a multiplicity of tool-like component into a continual process defined by predetermined sequences. In short, just as cognition develops from the pre-operational to the concrete operational, so technology passes from tools to *machines*.

The upshot of this development could scarcely be more radical or important. By continuing to the point where intelligent methods, skills, procedures and techniques are objectified in artefacts that are capable of executing technical processes on their own authority, so to speak, not only is a new level reached on the individual and social planes but the corresponding artefacts themselves exercise a level of control that was previously the prerogative of individuals. With that, machinery is born (Marx 1954: Chapter 15).

The main difference between a machine and a tool is that a machine's reach extends beyond discrete acts controlled through its user's constant empirical regulation to the machine's own direct and autonomous organisation and control of successive actions on and relationships between objects. As Diderot put it in the *Encyclopédie*, a machine 'is one single and prolonged act of reason, of which the manufactured article is the logical conclusion'. Or perhaps a little more pragmatically: 'Now sort these and now select that, now load this, this and this, now apply heat there, now measure this and repeat until the measure is right, now cut it just so, now smooth that part there, now join these, now insert those, and if this hole is too small, turn that handle there.' The machine's design and construction enable a complex of objects - raw materials, data, settings, interim products, the machine's own internal processing and measurement toolkit, and so on - to enter into relationships with one another that previously came about only through the actions of the user. Thus the machine embraces not only a greater span of time and space but also organises complex sequences of cause and effect. In short, machines embody a *process*, rather than merely placing instruments at the disposal of the true producer, namely its operator. So the machine evolves as the technological counterpart of Piaget's pre-operational reasoning, and comes to maturity as the technological counterpart of Piaget's concrete operations.

Of course, this mechanical rationality is still imposed from without. The rationale, character and use of the machine all lie with its owners, designers, makers and users. But this is by no means a dead end, for as soon as we begin to reflect on, refine, optimise and update the processes our machines embody, the activities for which they are used, the products they make and the new relationships in which the coordination of any related machines results, we start to grasp, objectify and

re-internalise the yet higher structures through which we develop them still further. With that, we start to grasp not only how these particular machines work but also our machines as a group and as a whole, and even machines in general and machinery in the abstract. But this abstraction of the formal principles, methods, skills and techniques for designing, building and operating machinery is enough to instigate, articulation and refine our technology on a yet higher plane, which Piaget called 'formal operations'.

Formal operational technology presupposes that we can now *objectify* in machines themselves these newly recognised structures in the form of a new level of strictly formal (e.g., mathematical) designs and controls - a process that sees the progressive transformation of the creators, makers and maintainers of our machinery from mechanics to engineers. On the other hand, we start being able to connect the nature and quality of the products we expect our machines to produce directly to the design and control of the processes the machines carry out. In short, formal operational structure allows us to build into machines themselves both models of the purposes they are supposed to serve and the algorithms for the function and operation of machines, all regulated by internal systems of parameters, options, measurements and control. With that we arrive at *automation*.

The link between this new stage in the history of technology and the development of intelligence in general is again straightforward. From elementary feedback and feed-forward to computing systems that mechanise logic and mathematics themselves, automation extends our technology beyond the basic machine's pragmatically interconnected *relationships* to include the ability to make formal judgements for themselves. For this to be achieved, the processes that are embodied in and through machines must have matured far enough for complete *systems* of relationships (which is to say, relationships between relationships) to be formalised and the inner logic of the production process to be abstracted, formalised and embodied in that technology. But that is only to say that the development of a formally structured technology demands the same things as scientific method, formal operational cognition, formal social systems such as bureaucracies or due process (Robinson 2004), and so on.

In practical terms, automation means that one must be able to integrate all the machines and other systems that are needed to achieve a predefined purpose, integrate all the data-gathering and decision-making procedures required to control the process, and so on. Not only must each link in the chain be forged, all interfaces aligned, every possible option and alternative built in, the requisite data and raw materials accurately graded and fed in, each step rigorously (though not necessarily rigidly) controlled, and all results exactly verified and validated; in addition, the possibility of failure must itself be considered, defined and its proper identification, evaluation and disposition likewise incorporated in the system.

This would be an unimaginable achievement, were it not for the fact that we take it for granted every day. Or perhaps we take it for granted because it is unnecessary to imagine it - a more likely conclusion, given that probably no one is capable of imagining more than a few tiny slivers of the automated industrial behemoth to which we have collectively (and inadvertently) given birth. On the other hand, the basic form of this immense paradise *cum* labyrinth *cum* wilderness is one with which all the readers of these words are intimately acquainted - which explains how we can take it for granted, of course. After all, not only is automation merely the natural consequence of organising machines into yet higher mechanisms, of carrying mechanisation to its logical, natural and historical conclusion, but the logic it embodies is first cousin to the logic of the formal thought in which the reader is engaged at this very moment.

But even the formalisation of structure and function carried out by automation's revolutionary synthesis of reason and mechanism is of limited significance and potential. For a formally automated system is incapable of spontaneous insight into, and therefore criticism and control of, itself. It is true that there may be a degree of self-regulation, even a kind of pseudo-development whereby the process is itself processed through yet higher regulatory controls. But this is neither insight nor development properly so called, for these higher layers of regulation are themselves entirely pre-determined. That is, they are entirely *unintelligent*. No matter how many layers of automation are laid on top of one another, no matter how extensive the recursions or intensive the iterations, their outer limits and their deepest foundations are set by the owners, designers, builders and operators of the device, not by the device itself. Unlike intelligence, automation alone is incapable of advancing beyond its own parameters, which are as fixed as the periodic table. It is still only the instrument of the intelligence that creates and directs it rather than intelligent in its own right.

4.4 Artificial intelligence \$\$\$

I hope that the chasm separating the shallowest intelligent technology from its most complex instinctive predecessor is now obvious. Its objectivity - the fact that intelligent technology not only *has* objective consequences far beyond the subject's ability to anticipate, control and perhaps even imagine them but is created specifically *for the sake* of those objective consequences - places it far beyond any no-intelligent structure, including even the sensorimotor tool-user. Its objectivity also brings other unprecedented attributes. For example, the specifically rational structure it possessed by virtue of its embodiment of previously subjective skills, techniques, and so on, makes it potentially available to all other intelligent beings. Conversely, its growing capacity for self-direction and self-control makes it into an increasingly independent player in the dialectic of praxis as a whole, while its technological synthesis of intelligence with physical, chemical and biological structures imbues technology with unprecedented new powers as much as it subordinates the physical, the chemical and the biological to technology's makers' original purposes.

Of course, much the same could be said of any organic structure: is not every adaptation the embodiment of some such refinement? However, unlike organic structures, intelligence is perfectly capable of grasping and making use of any new, higher, latent structure its activity generates, not only without having to have it built into its body or its brain but also objectively - which is to say, for the structure in question's own sake and on its own terms. To give a very trivial example, we are capable not only of using levers or lenses in all manner of practical ways, and of studying how to achieve better, faster, cheaper effects of all kinds, but we do this not by focusing on our own advantage. On the contrary, we achieve the best results by ignoring the specifics of what are trying to achieve and studying leverage or optics for their own sakes. Furthermore, intelligence can organise and propagate its knowledge in ways that enable it, through logical and mathematical tools, to derive from each such insight infinitely many new implications, possibilities and contradictions - an unimaginable achievement for any organism that is still hampered by the least touch of adaptedness and instinctive constraint.

Consequently, not only can no organism that is incapable of objectivity possess technology but there can be no biological basis to technology among technology-bearing organisms - no specialised technological organs, drives, capacities, nor any natural artefacts. That would prejudice and limit the organism in question to a point of view that was restricted to its own states and to 'natural' connections that drove its activity, rather than objective considerations as to the nature of and relationships between things, events and the objects that might be interposed to control them.

If our capacity for objectivity gave us technology, the objectivity of our technology has its own implications. An artefact's independence of its maker is *essential* to both technical and cultural artefacts. Whether it be in the form of the spoken word (which requires little more in the way of extra-intelligent resources than vocal control over sound) or accessible embodiments of the forces of nature of the kind we find in tools and machines (which may require extensive power over a huge range of physical, chemical, biological and rational structures), artefacts are only possible because they do indeed synthesise the intelligent with the non-intelligent. Yet it is not our artefacts that create the abyss between biology and intelligence. Intelligent beings are not different from life at large because we have language and tools and they do not. That would be to put the cart before the horse. Rather, we have language and tools and all the rest because we are intelligent, and where other organisms lack them it is because they aren't. Just as matter did not come alive by learning to breathe but rather breathes because of the totality of relationships which make it live, so intelligence did not supersede biology because it learned to speak or use tools. They are integral to intelligence, but they do not, by themselves, define it.

That is why intelligence is so infinitely fruitful. Intelligence is not the sum or product of language and social organisation and technology and all the rest. If it were, if these forces and structures were adaptations out of which intelligence is composed, it is hard to see how we could be continually transcending the limits of any given technology, social system, and so on, in a manner that is completely unlike the history of the genuinely biological structures on which our activity relies. As far as I can tell, there has been no significant change in the biological structure or function of the eye in the last million years, but through culture and technology, *vision* has been completely transformed.

That is also why it is only when intelligence as a whole comes to its final fruition that technology and culture will reach theirs. Hence the lack, in all the above review of technology and culture, of any reference to artificial intelligence. Likewise, artificial intelligence is by no means only

the last word in artefacts, even though it stands at the head of both cultural and technical series. For the basic requirements and expressions of a true artificial intelligence, considered as a form of true intelligence, are no more and no less than those of intelligence as a whole.

That is why a true artificial intelligence cannot be created by increasing the performance, scope or functionality of tools or machines or even automated systems. Neither can it be created through the accumulation and automation of more and more allegedly intelligent skills and techniques - to repeat, we possess such faculties because they follow from our intelligence rather than *vice versa*. Rather, the creation of a genuine artificial intelligence relies on somehow replicating the necessary parts of the development of *natural* intelligence. That is, an artificial intelligence must be grown, not built, and must grow from the artificial intelligence's own point of view. That is, it must grow *up*, like - indeed, *as* - a person, not a flower. An artificial intelligence can no more be built or grown from seed than a natural intelligence. On the contrary, the development of intelligence of any kind must be based on a full ontogenetic dimension, regardless of its provenance, through which the intelligence in question has its own objects to construct, its own world to make and make sense of, its own certainties to reach and transcend. So intelligence may be induced and taught and encouraged and facilitated, but not manufactured or sown or programmed.

How then can artificial intelligence be said to stand at the apex of all cultural and technical artefacts? Surely the massive accumulation of technology and culture is the very antithesis of the emptiness of the sensorimotor reflex from which natural intelligence begins? The answer lies in the fact that the history of culture and technology is the history not only of power and knowledge but also of the elimination of *conditions* on power and knowledge. By its accumulation and synthesis of positive attainments, intelligence also abstracts from, and so negates, any particular perspective or premise. In the terminology of the social sciences, the development of technology and culture leads not to Weber's 'iron cage of rationality' but to a world system capable of comprehend anything - as ever, with intelligence - for its own sake, in its own right and on its own terms. Or in the terminology of a quite different world-view, it leads neither to increased attachment to the world or to increased detachment from it, but to the non-attachment that is attached and detached as circumstances demand.

It that respect the development of intelligence does indeed culminate in an emptiness equivalent of the sensorimotor neonate, although the wealth embodied in that emptiness is the complete antithesis of the newborn's naiveté - as, given its place at the head of intelligence as a whole, one would expect. However, all this can only come about when intelligence and the universe itself are on the verge of losing their separate identities, for the core expression and fundamental imperative of artificial intelligence is not that human beings should *create* intelligent artefacts, but that natural intelligence become *identical* with its artefacts, and human nature finally internalise its own artificiality. This is partly because any genuine intelligence we might create of our own volition and through our own means will have to be treated as the same as ourselves; but much more importantly, the creation of artificial intelligence will abolish absolutely not only the difference but also the distinction between reason and its maker.

4.5 The levels of intelligent technology

The corollary of this is important for understanding the complex interplay between the different levels of intelligent technology, which is quite different from its predecessors in this (as in so many other) respect. In brief, a simple item of strictly intelligence technology could well be devised by a relatively undeveloped individual, such as a human child. However, the cognitive limitations of childhood preclude the development of more sophisticated technology,

Dialectic of individual and social development

4.6 Technology and culture

Goals and their supporting objectives, targets, and values and the related web of supporting significations, meanings, and so on. Means-end relationships.

At the social level, this includes the division of labour.

Science.

5. Conclusions

We should remember that in its games the chimpanzee used a stick without any compelling practical necessity, as an object of play and that this stick, as an object of play, began to serve in a variety of roles: as a pole which it would climb, or, as a spoon, enabling it to eat, or as a shovel for digging up roots; lastly the animal used the tool as a 'general purpose tool', in Köhler's expression, by means of which it would touch objects beyond its reach, or those it did not want to touch with its hands for one reason or another, such as dirt on its body, or lizards, mice, electrically charged wires, and so forth.

Alexander Luria and Lev Vygotsky (1992: 21)

5.1 Tickets vs wings

One of the most pernicious but also widespread illusions about human beings is the assumption that, however human beings may transform their world and themselves, the 'real' kernel of human nature will always lie in our nature as organisms - in how our brains work, in how our bodies are laid out, in what our genes supposedly program us to do, in the force of whole swathes of supposed 'predispositions', in the limits our biology imposes on our capacity and predisposition to learn, and so on. Whatever reservations may be entered about human flexibility, versatility, plasticity and general 'specialness', there remains a final, fatal identification of biology with destiny.

One key expression of this is the way in which the terms 'natural' and 'artificial' are almost universally treated as antonyms. Hence innumerable fantasies of the 'If only I could fly' variety: it is clear that the problem is perceived as being a lack of wings, not a lack of tickets. So when it is pointed out that the Wright brothers granted that particular wish more than a century ago, the invariable response is that flying by artificial means, not being a talent with which we are endowed by birth, is somehow cheating. Indeed, there seems to be a tacit assumption in many quarters (not least among biologists) that the non-biological aspects of human nature are only secondary, if not epiphenomenal or even illusory, addenda to 'real' human nature.

But there is an immense difference between something being ours by birth and being ours by birthright. As intelligent beings, our heritage does not depend exclusively on our heredity. On the contrary, our biology becomes less and less a determinant of our relationship to the world as human intelligence matures. While human *biology* knows nothing of lift-drag coefficients, navigation beacons and departure lounges, there is surely nothing more natural than that human *beings* should. The artificial nature of human flight makes no difference, not least because it is its artificiality that makes it human.

I hope that the significance of this point is obvious. Our artefacts already extend far beyond any limits that might be set by any 'biological kernel' of human nature - what biological process or system could possibly account for the creation of space flight, global banking systems, nuclear power or the internet in any but the most vacuous terms? Indeed, because of our artifices, there seem to be *no* limits either to what we can discern about the world about us or to what we can do in it, other than the limits set by the objective properties of the world itself. As organisms, we cannot fly, but our machines can; we cannot detect quasars or quarks with the naked eye, but our machines can; and as naked human beings our impact on the world would be negligible, but for better or worse, the impact of our technology seems to extend up to and beyond all preceding levels of environment change.

But more than changing the scope of our relationship to our natural environment, the artefacts through which we do these things can only be made or operated effectively because our intelligence represents a radical advance over any previous form of organic structure or function. Where non-intelligent organisms can be said to operate according to what might be called the logic of affect - i.e., according to the nature and structure of their current states, drives, instincts, and so on - a technology of the kind that human beings have created is only possible because we are able to

adopt a specifically *objective* attitude and approach to things and events. However strong or weak a model of objectivity one assumes, all human technology seems to assume the ability to look at things and events from a 'point of view' that is independent of one's current biological function or interest, situation or state.

There cannot be any doubt that we may be able to trace some of the *motives* for making and using artefacts of all kinds to factors such as the strictly organic aspects of biological hunger or the need every complex organism feels for a degree of physical security. Nevertheless, if we allow that the need to slake one's thirst or take cover is wholly biological - by no means a self-evident proposition - such motives do not explain the ability to apprehend, let alone master, either the *objective* logic of technological devices on the one hand or the *objective* physical, chemical and organic properties of the world technology both assumes and accesses. One might as well argue that, because all biological activity has a chemical basis, we should seek a chemical formula for natural selection. Or as George Gaylord Simpson put it, 'Some... who accepted the (indeed almost obvious) validity of those contrasts nevertheless used to insist that all that was needed to transform animal... into human... was the transfer of function from the affective to the objective... As Ernst Cassirer pointed out long since, the transfer so lightly assumed is exactly the problem' (Simpson 1969).

Thus, the rules that govern a machine or an industrial process or a whole industry or the global economy know nothing and operate wholly independent of the processes and mechanisms that govern biology, human or otherwise. Yet we are able to understand and manipulate them almost regardless of the biological state we are in at any given moment. We are able to approach and relate to the functions technology supports (human and non-human) and the materials, processes and mechanisms out of which it grows and through which it operates in their own right, on their own terms and - independently of what we may have designed it for - for their own sake. Which is to say, objectively. Misleading metaphors and analogies apart, there is no counterpart to adaptation or physiology in the workings of machines or car plants or telecommunications systems or economic planning, or, consequently, in the structures human beings must develop in order to create or control them. However weakly we interpret this requirement, it cannot be gainsaid without also gain-saying the very possibility of the technology by which we have surround ourselves. We could not hope to have any technology beyond the very simplest tools if we were not able to transcend the biological propensities and constraints to which most recent biological models of human nature would reduce us.

In short, far from being *second* nature to human beings, artifice is as vital to any intelligent being as breathing. In fact, artifice is *more* essentially a part of what makes us human, for although it is not hard to imagine that the human race will one day dispense with the respiratory system it was bequeathed by evolution, it is surely inconceivable that we will ever cease to pursue - and realise - the wildest flights of fancy. And given how reluctant our biology has always been to fulfil our dreams, we *will* have to resort to artifice to realise them.

If, on the other hand, we decline to prefer intelligence to biology, the paradoxes can only continue to pile up. For example, those who assert that aeroplanes are not part of 'human nature' are usually quite ready to accept that speech is a natural (if very remarkable) activity. But if speech is natural, are reading and writing *unnatural*? And if reading and writing are allowed, what about pens and paper? And books, and printing presses and newspapers and global communications systems beside which the most huge and complicated leviathan of the air is as a mouse trap to the Maginot Line? Or if that is too abrupt a leap, is covering my head with my hand when it rains artificial? What about using some natural object such as a large leaf? Or a large leaf with a stick through it to make it more manageable? But if that is natural, then why aren't an umbrella or machines for making umbrellas or a barometer or a weather ship or weather control or a life-sized replica of Jupiter's Great Red Spot? Of course, these things would not be natural to a lily or a sheep or even an orang utan, but they surely are perfectly natural to human beings, if only because human beings have already created most of them.

And then, as soon as the slightest contrivance is allowed though the portals of 'human nature', what artifice can be excluded? Ultimately, so far are artifice and nature from being irreconcilable that, for human beings, they are one and the same. Far from being opposites, as far as human beings are concerned they are synonymous. Indeed, if we include culture as well as technology, in soon becomes clear that human nature not only *permits* artifice, it actually *consists exclusively* of artifice. Even if the artifice in question is used to feed a 'natural' appetite, consists solely of arranging natural objects to suit ourselves or, as so often happens, is so taken for granted that it is

regarded as itself 'natural', its artificiality could not be either more necessary to it or more obvious.

5.2 Technology and culture

Before drawing any conclusions from this momentous process, I would like to emphasise that, however conspicuous it may be, technology itself is seldom the prime mover in technological advance. It is convenient to treat it in isolation, as though tool use were a discrete or atomic function, but in reality technology is a system of means that economic, political and other social processes exploit and deploy, and only to a relatively small degree an independent force in its own right. The isolated genius who creates the steam engine, the submarine or the calculating engine in a historical (especially economic) context that is incapable of supporting or making use of it will earn a footnote, but the invention itself is no more than a curio. Even in the simplest of societies, team work will amplify our individual powers to at least as much as tools, and in any case team work is often the precondition of some tools, such as large fishing nets, being used at all.

However, this is no place for a general analysis of the relationship between, on the one hand, technology and culture and, on the other, the social processes of specialisation and exchange, the division of labour, work, and economic relationships generally. Yet it is still worth noting that, by being placed in its proper social and historical setting, it is easy to see that making and using tools are only minor steps in wider processes that have long been subjected to thorough analysis by social scientists, but remain unanalysed (indeed, unacknowledged) by biologists. In fact, it is hard to see how the realities of technology could ever be visible to biologists, given the extent to which it relies on forms of subjectivity, objectivity and worldliness that are also invisible to any possible biology. The mere fact that, for intelligence, making, choosing and using even the simplest tool all presuppose the ability to appraise the objective characteristics of task at hand, the means at its disposal and the ends at which the intelligence in question is aiming renders the simplest facts of intelligent technology completely unintelligible to any normal biological approach.

Not that technology lacks biological consequences. From the very start of human evolution, the creation of basic tools, shelter, clothing, communications and fire have helped transform the niches *Homo sapiens* was capable of penetrating, the organisations in which it lived and even its bodily forms. By comparison with our immediate ancestors, our skeletons are lightweight and fragile, with many of the bony buttresses and ridges long since gone, not least because we have found technological means to replace strength and endurance by co-opting nature's own powers and finding means to hold the harsher elements of our environment at bay.

It must be added that the analysis of the natural history of technology presented in this chapter simplifies the development of technology drastically. For example, even though no tool does more than extend and enhance sensorimotor capacities such as movement and vision, or at most the perceptual and behavioural leverage offered by moving pictures or a bicycle, many important tools remain unimagined by, and indeed unimaginable to, an intelligence that has only just gained control over its own sensorimotor apparatus. Hammers and other implements which can be taken almost directly from nature may be universal, but it is only at later stages, when more sophisticated kinds of artefact have been developed, that more sophisticated tools appear, even where they perform an equivalent function. A hammer stone, a steam hammer and a linear accelerator all perform the same abstract function, but they are the products of qualitatively different levels of intelligence. Conversely, the structural complexity built into a tool may be out of all proportion to the functional simplicity of the role it performs. *What* a tool does it may be directly perceptible, but *how* it does it is often quite a different matter, especially in an industrial society. So a small child can grasp *what* as structurally complex yet functionally simple a device as a clock or a telescope is *for*, but the same child may be completely unable to grasp how either works or really understand the more profound uses to which they may be put.

Of course, some of the most powerful pieces of technology are based on precisely the reverse relationship: the *simulation* of higher level functionality by structures that, in themselves, are only capable of a much lower level of functioning. Here the computer provides the ideal example: although it can simulate logical and mathematical operations with a facility, speed and power of which the greatest *savant* could only dream, no computer has yet performed a real logical or mathematical act. Nor, pending the arrival of artificial intelligence proper, as they likely to. Within the domain for which it is programmed, a computer can look astonishing intelligent, but in itself it

is exactly as intelligent as a gatepost. Intelligence resides in contemporary computers only in the same sense that Saturn resides in a computer that is modelling its orbit.

I began this paper by arguing that intelligence represents a fundamental advance over instinctive forms of biology, and I hope it is now clear that how weak the link between the two sides really is, even if the transition is mediated by a long sensorimotor era. Pre- and non-intelligent structures determine what it means to be intelligent and how we reason only in the sense that gravity determines how we walk. That is, they provide an external condition, demanding that we do something about this locomotion business, affording us the opportunity to go from here to there, creating the external conditions, and so on. However, the naturalness of walking does not mean that it is not equally natural that it be completely superseded - in the case of walking, by skis and horses and wheels and flight, and in the case of the organic substrate of natural intelligence, by whatever means other than our present biology we devise to achieve that end. Already we have walked under other gravities; soon we shall reason with other biologies; ultimately we must respect only the logics of matter and reason as such - which, I suspect, will turn out to be one and the same.

If

5.3 Beyond technology

If the argument offered here is correct, then it is necessary to ask how far this argument can be driven. If the basis of tools at their various levels is a sequence of disjunctions between the instinctive, the sensorimotor and the intelligent in general rather than specifically tool- or technology-related capabilities (i.e., they are created and controlled by particular adaptations, modules, and so on) then the same argument will apply to all other forms of activity. For example, one must expect the various levels of cultural activity to follow a similar logic, not to mention social or symbolic patterns.

Notes

¹ For an analogous account of object permanence, see Etienne (1984).

² Maynard Smith and Szathmáry (1995) analyse these relations in similar terms.

³ However, Griffin is in illustrious company: Darwin himself remarked that 'When we behold a male bird elaborately displaying his graceful plumes or splendid colours before the female... it is impossible to doubt that she admires the beauty of her male partner' (Darwin 1901: 140).

⁴ For the complexities of imitation and related kinds of transmission, see Beck (1980: 162ff) and Byrne (1995: Chapters 5 and 6). Bonner (1980), Crook (1980), Griffin (1981, 1984), and Walker (1983) provide further examples. For a history of the distinction between 'true' and merely biological imitation, see Galef in Zentall and Galef (1988).

⁵ See Natale and Antinucci in Antinucci (1989) for an assessment of the Japanese macaque's general cognitive capacity; and Byrne (1995: 55ff) for a further critique. McGrew (1992: 194-195) reports a more convincing instance among chimpanzees.

⁶ Hewes (1994) proposes the Mrabi and Tasaday peoples as possessors of technologies yet more simple than the Tasmanians. However, not even these cases refute my point.

⁷ The Marxist view is much more comprehensive - see, for example, Marx and Engels (1968: 71-93) or Leontyev (1981: 207-24).

⁸ For a sceptical review of both the evidence for and alleged mechanisms of tradition in animals, see Galef in Bekoff and Jamieson (1990, vol. I, pp. 74-95).

References

- Aiello, L.C. and Wheeler, P. (1995). The expensive-tissue hypothesis: The brain and the digestive system in human and primate evolution. *Current Anthropology*, 36, 199-221.
- Alp, R. (1997). 'Stepping stones' and 'seat-sticks': new types of tools used by wild chimpanzees (*Pan troglodytes*) in Sierra Leone. *American Journal of Primatology*, 41 (1): 45-52.

- Antinucci, F. (ed.) (1989). *Cognitive Structure and Development in Non-Human Primates*. London: Lawrence Erlbaum.
- Bard, K.A. (1990). 'Social tool use' by free-ranging orangutans: A Piagetian and developmental perspective on the manipulation of an inanimate object. In Parker and Gibson (1990: 356-378).
- Barnes, M.H. (2000). *Stages of Thought. The Co-Evolution of Religious Thought and Science*. Oxford University Press: New York.
- Beck, B.B. (1980). *Animal Tool Behaviour: The Use and Manufacture of Tools by Animals*. New York: Garland STPM Press.
- Bekoff, M. and Jamieson, D. (eds) (1990). *Interpretation and Explanation in the Study of Animal Behaviour*, vols. I and II. Oxford: Westview Press.
- Boesch, C. (1991). Teaching among wild chimpanzees. *Animal Behaviour*, 41: 530-532.
- Boesch, C. (1993). Aspects of transmission of tool-use in wild chimpanzees. In Gibson and Ingold (1993: 171-193).
- Bonner, J.T. (1980). *The Evolution of Culture in Animals*. Princeton: Princeton University Press.
- Brewer, S.M. and McGrew, W.C. (1990). Chimpanzee use of a tool-set to get honey. *Folia Primatologica*, 54: 100-104.
- Byrne, R.W. (1995). *The Thinking Ape: Evolutionary Origins of Intelligence*. Oxford: Oxford University Press.
- Caprona, D. de, Ducret, J.-J., Rod, O., Rosat, M.-C. and Wells, A. (1983). *History of Science and Psychogenesis*. Geneva: Fondation Archives Jean Piaget.
- Chevalier-Skolnikoff, S. and Poirier, F.E. (1977). *Primate Bio-Social Development: Biological, Social and Ecological Determinants*. New York: Garland.
- Collias, N. and Collias, E. (eds) (1976). *External Construction by Animals*. Stroudsburg, Pa. Dowden, Hutchinson and Ross, Inc.
- Corballis, M.C. (1991). *The Lopsided Ape. Evolution of the Generative Mind*. Oxford: Oxford University Press.
- Crook, J.H. (1980). *The Evolution of Human Consciousness*. Oxford: Oxford University Press.
- Darwin, C. (1901). *The Descent of Man and Selection in Relation to Sex*. London: John Murray.
- Dennett, D.C. (1991). *Consciousness Explained*. Boston: Little, Brown.
- Dickson, D.B. (1990). *The Dawn of Belief: Religion in the Upper Paleolithic of Southwestern Europe*. Tucson: University of Arizona Press.
- Etienne, A.S. (1984). The meaning of object permanence at different zoological levels. *Human Development*, 27: 309-320.
- Fowler, J.W. (1981). *Stages of faith: The Psychology of Human Development and the Quest for Meaning*. San Francisco: Harper & Row.
- von Frisch, K. (1974). *Animal Architecture*. New York: Harcourt Brace Jovanovich.
- Gablik, S. (1977). *Progress in Art*. Rizzoli: New York.
- Gibson, K.R. and Ingold, T. (1993). *Tools, Language and Cognition in Human Evolution*. Cambridge: Cambridge University Press.
- Gomez, J.C. (1991). Visual behaviour as a window for reading the mind of others in primates. In Whiten (1991: 195-207).
- Goodall (1986). *Chimpanzees of the Gombe*. Cambridge, Mass.: Harvard University Press.
- Goudsblom, J. (1992). *Fire and Civilisation*. London: Penguin.
- Griffin, D.R. (1981). *The Question of Animal Awareness: Evolutionary Continuity of Mental Experience* (revised and enlarged edition). Los Altos: William Kaufmann, Inc.
- Griffin, D.R. (ed.) (1982). *Animal Mind - Human Mind*. New York: Springer-Verlag.
- Griffin, D.R. (1984). *Animal Thinking*. London: Harvard University Press.
- Hallpike, C.R. (2004). *The Evolution of Moral Understanding*. Prometheus Research Group: www.prometheus.org.uk.
- Herman, L. M. (1986). Cognition and language competencies of bottlenosed dolphins. In Schusterman, Thomas and Wood (1986: 221-251).
- Hewes, G.W. (1994). The baseline for comparing human and nonhuman behavior. In Quiatt and Itani (1994: 59-

93).

- Heyes, C.M. (1994). Social learning in animals: categories and mechanisms. *Biological Review*, 69: 207-231.
- Hobhouse, L.T. (1915). *Mind in Evolution*. London: Macmillan.
- Hockett, C.F., and Ascher, R. (1968). The human revolution. In Montagu (1968 : 20-49).
- Inhelder, B. and Piaget, J. (1958). *The Growth of Logical Thinking from Childhood to Adolescence*. London: Routledge and Kegan Paul.
- Inhelder, B. and Piaget, J. (1964). *The Early Growth of Logic in the Child: Classification and Seriation*. London: Routledge and Kegan Paul.
- Kingdon, J. (1993). *Self-Made Man. Human Evolution from Eden to Extinction?* New York: John Wiley and Sons, Inc.
- Leontyev, A.N. (1981). *Problems in the Development of the Mind*. Moscow: Progress Publishers.
- Lévy-Bruhl, L. (1965). *The 'Soul' of the Primitive*. London: Unwin.
- Lock, A. (ed.) (1978). *Action, Gesture and Symbol. The Emergence of Language*, London: Academic Press.
- Luria, A.R. and Vygotsky, L.S. (1992). *Ape, Primitive Man and Child*. Orlando: Paul M. Deutsch Press, Inc.
- Marx, K. (1954). *Capital*, I. London: Lawrence and Wishart.
- Marx, K. and Engels, F. (1968). *Selected Works*. London: Lawrence and Wishart.
- Maynard Smith, J. and Szathmáry, E. (1995). *The Major Transitions in Evolution*. Oxford: W.H. Freeman.
- McGrew, W.C. (1992). *Chimpanzee Material Culture: Implications for Human Evolution*. Cambridge: Cambridge University Press.
- McGrew, W.C., Marchant, L.F., and Nishida, T. (eds) (1997). *Great Ape Societies*. Cambridge: Cambridge University Press.
- Montagu, M.F.A. (ed.) *Culture: Man's Adaptive Dimension*. New York: Oxford University Press.
- Oswalt W.H. (1973). *Habitat and Technology: The Evolution of Hunting*. New York: Holt, Rinehart and Winston, Inc.
- Parker, S.T. and Gibson, K.R. (1990). *Language and Intelligence in Monkeys and Apes*. Cambridge: Cambridge University Press.
- Parker, S.T. and McKinney, M.L. (1999). *Origins of Intelligence: The Evolution of Cognitive Development in Monkeys, Apes and Humans*. Baltimore: Johns Hopkins University Press.
- Piaget, J. (1955). *The Child's Construction of Reality*. London: Routledge and Kegan Paul.
- Piaget, J. (1971). *Biology and Knowledge*. Edinburgh: Edinburgh University Press.
- Piaget, J. (1953). *The Origins of Intelligence in Children*. London: Routledge and Kegan Paul.
- Piaget, J. (1974). *The Place of the Sciences of Man in the System of Sciences*. New York: Harper and Row, Publishers.
- Piaget, J. (1995). *Sociological Studies*. London: Routledge.
- Piaget, J. (2001). *Studies in Reflecting Abstraction*. Hove: Psychology Press.
- Piaget, J. and Garcia, R. (1989). *Psychogenesis and the History of Science*. New York: Columbia University Press.
- Plooi, F.X. (1978). Some basic traits of language in wild chimpanzees? In Lock (1978: 111-131).
- Quiatt, D. and Itani, J. (eds) (1994). *Hominid Culture in Primate Perspective*. Niwot, Colorado: University of Colorado Press.
- Radding, C.M., and Clark, W.W. (1985). *Medieval Architecture, Medieval Learning: Builders and Masters in the Age of Romanesque and Gothic*. New Haven: Yale University Press.
- Robinson, R.J. (2004). *The History of Human Reason*. Prometheus Research Group: www.prometheus.org.uk.
- Robinson, R.J. (2005). *The Birth of Reason*. Prometheus Research Group: www.prometheus.org.uk.
- Robinson, R.J. (in press). Wallace revisited. Does intelligence evolve?
- Russon, A.E., Bard, K.A. and Parker, S.T. (1996). *Reaching into Thought: The Minds of the Great Apes*. Cambridge: Cambridge University Press.
- Savage-Rumbaugh, S., and Lewin, R. (1994). *Kanzi: The Ape at the Brink of the Human Mind*. New York: Wiley.

- Schick, K.D. and Toth, N. (1993). *Making Silent Stones Speak*. London: Weidenfeld and Nicolson.
- Schusterman, R.J., Thomas, J., and Wood, F.G. (eds) *Dolphin cognition and behavior: A comparative approach*, 221-251. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Simpson, G.G. (1969). *Biology and Man*. New York: Harcourt Brace Jovanovich.
- Viaud, G. (1960). *Intelligence*. London: Arrow Books.
- Vauclair, J. (1996). *Animal Cognition: An Introduction to Modern Comparative Psychology*. London: Harvard University Press.
- Vauclair J., and Anderson, J.R. (1994). Object manipulation, tool use and the social context in human and non-human primates. *Techniques and Cultures*, B24: 121-126.
- Waal, F.B.M. de (1983). *Chimpanzee Politics. Power and Sex Among Apes*. New York: Harper and Row.
- Walker, S. (1983). *Animal Thought*. London: Routledge and Kegan Paul.
- Whiten, A. (ed.), *Natural Theories of Mind: Evolution, Development and Simulation of Everyday Mindreading*, Oxford: Basil Blackwell.
- Wrangham, R., McGrew, W.C., Waal, F.B.M. de, Heltne, P., and Marquardt, L.A. (eds). *Chimpanzee Culture*. Cambridge, MA: Harvard University Press.
- Wright, R.V.S. (1972). Imitative learning of a flaked-tool technology - the case of an orangutan. *Mankind* 8: 296-306.
- Wynn, T. (1979). The intelligence of later Acheulean hominids. *Man* (ns), 14: 371-391.
- Wynn, T. (1981). The intelligence of Oldowan hominids. *Journal of Human Evolution*, 10: 529-541.
- Wynn, T. (2002). Archaeology and cognitive evolution. *Behavioral And Brain Sciences*. 25: 3: 389-438.
- Wynn, T. and McGrew, W. (1989). An ape's view of the Oldowan. *Man* (ns), 24: 383-398.
- Zentall, T.R. and Galef, B. (eds) (1988). *Social Learning. Psychological and Biological Perspectives*. London: Lawrence.

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