

HOW THE MIND GROWS: A DEVELOPMENTAL PERSPECTIVE
ON THE BIOLOGY OF COGNITION

ABSTRACT. The 'developmental systems' perspective in biology is intended to replace the idea of a genetic program. This new perspective is strongly convergent with recent work in psychology on situated/embodied cognition and on the role of external 'scaffolding' in cognitive development. Cognitive processes, including those which can be explained in evolutionary terms, are not 'inherited' or produced in accordance with an inherited program. Instead, they are constructed in each generation through the interaction of a range of developmental resources. The attractors which emerge during development and explain robust and/or widespread outcomes are themselves constructed during the process. At no stage is there an explanatory stopping point where some resources control or program the rest of the developmental cascade. 'Human nature' is a description of how things generally turn out, not an explanation of why they turn out that way. Finally, we suggest that what is distinctive about human development is its degree of reliance on external scaffolding.

1. INTRODUCTION

In recent years, evolution has moved to centre stage throughout the human sciences. To the traditional topics of sex (Diamond 1997) and language (Pinker 1994) we can now add evolutionary accounts of family dynamics (Sulloway 1996), categorisation (Atran 1990), cheating detection (Cosmides and Tooby 1992), cooperation (Sober and Wilson 1998), conscience (De Waal 1996), art, religion and science (Mithen 1996). New theories of human cognitive evolution have been proposed (Byrne and Whiten 1988; Whiten and Byrne 1997). A strident movement has arisen in psychology and anthropology accusing earlier workers in those disciplines of marginalizing the fact that the mind is a product of evolution (Cosmides et al. 1992).¹

It is in this context that much recent work on rationality and decision making has been located. What would once have been seen as failures of rationality are now likely to be interpreted as good evolutionary design. Gerd Gigerenzer's reinterpretation of the 'base rate fallacy' is a good example. Suppose your insurance company requires you to take an HIV test, which turns out positive. Your doctor informs you that there is a 0.01% chance that the result is a false positive and you are, in fact, not infected.



He also tells you that the prevalence of HIV infection within that group to which you belong (female, heterosexual, no known risk) is also 0.01%. Are you comforted? Most people, as tests have shown, are not. The critical ‘base rate’ data is apparently ignored. The situation changes when the same information is given in ‘natural frequencies’. One woman in 10,000 is expected to have the virus, and her test will be positive. Of the remaining 9,999 women who have the test but do not have the virus, one will also get a positive result. With this information you can easily see that despite your positive result there is a 1 in 2 chance that you do not have HIV. Gigerenzer claims that under the conditions in which your statistical reasoning abilities evolved statistical information would accumulate in the form of natural frequencies. Rather than learning that a rustle in the bushes has a 0.01% false positive rate and that the base rate of rabbits in bushes is 0.01% you would learn that every second rustle in the bushes is a false alarm. Just as the visual system was not designed to work under sodium lighting and hence sees the wrong colours, our statistical reasoning abilities were not designed to work with probabilities and hence commit the ‘fallacy’ (Gigerenzer 1997a, 118–9). There is nothing wrong with our rationality if we use it in the domains for which it was designed.

Along with this increased interest in the evolution of cognition has come a revival of nativism and an extension of nativist claims to new domains. Much attention is currently focused on the suggestion that the evolved regularities in human cognition are so rich and domain specific that they can be conceptualised as innate theories of domains such as grammar, physics, biology and psychology, to name some of the most widely discussed (Carey 1985; Keil 1989; Welman 1990; Gunnar and Maratsos 1992; Welman and Gelman 1992; Pinker 1994). We do not construct these theories on the basis of the evidence available to us, but inherit them from our ancestors. Such claims are commonly expressed in terms of biological ‘constraints’ on the human mind. Minds are constrained to develop in a particular way, and once developed they are constrained to reason in particular ways:

By nature, human minds everywhere are endowed with common sense. They possess universal cognitive dispositions that determine a core of spontaneously formulated representations about the world. The world is basically represented in the same way in every culture. Core concepts and beliefs about the world are easily acquired ... yet they are restricted to certain cognitive domains and are rather fixed. (Atran 1990, 263–4)

Not all advocates of domain specific biological constraints on cognition are so concerned to stress that only one outcome is permitted. Ellen Markman has consistently argued that constraints should be interpreted “as default assumptions – as probabilistic biases that can be overridden” (Markman

1992, 67). But these less rigid constraints still serve to produce widespread conformity to theories grounded in the experience of the evolutionary lineage rather than the individual.

Our aim in this paper is to break the link between the evolutionary perspective on the mind and nativism. It is possible to wholeheartedly endorse the idea that the mind is a product of evolution without accepting the claim that the mind is constrained to develop or to reason in certain, limited ways. The key to separating these two claims is to recognise that what individuals inherit from their ancestors is not a mind, but the ability to develop a mind. The fertilised egg contains neither a 'language acquisition device' nor a knowledge of the basic tenets of folk psychology. These features come into existence as the mind grows. A serious examination of the biological processes underlying such easy terms as 'innateness', 'maturation' and 'normal development' reintroduces the very themes that are usually taken to be excluded by an evolutionary approach to the mind – the critical role of culture in psychological development and the existence of a plethora of alternative outcomes for the developing mind.

2. 'BIOLOGICAL CONSTRAINTS' ON COGNITION

The nature of the biological constraints on cognition is a central concern of the 'evolutionary epistemology' that traces its ancestry to Konrad Lorenz, Donald Campbell and Karl Popper (Lorenz 1982/1941; Popper 1973; Campbell 1974/1982). Lorenz's original comparison between evolved features of cognition and the Kantian *a priori* strongly suggests that these features impose limitations – constraints – on what can be cognised. Hence one strand of evolutionary epistemology has stressed the limitations of our evolved rationality in the wider role it is now required to play. There are 'deficiencies of adaptation in human reason' (Riedl 1995). But other strands in the same tradition have recognised a more positive side to the fact that cognition and cognitive development are constrained. Jean Piaget, whose 'genetic epistemology' predated evolutionary epistemology, had already stressed the important principle that any cognitive order must be built on some existing order (Piaget 1971/1967). Rupert Riedl's *Order in Living Systems* (1977) also anticipates much of the later discussion of the role of constraints in evolution. Riedl and other evolutionary epistemologists reject the view that the alternative to unconstrained freedom is constraint in the sense of the reduction of possibilities. Instead, they view constraints as the creation of new possibilities by limitation. Various labels have been applied to constraints viewed in this light, but the phrase 'enabling constraints' seems to have stuck.² The concept of enabling con-

straint embodies the insight that an unstructured cognitive process would be an absurdity. Cognition and cognitive development are as much in need of inherent structure as any other biological process. If the developmental regularities manifest in an organism or the regularities in its adult behavior reflect 'constraints' then the main thing the organism has been constrained from is chaos.

Some contemporary evolutionary epistemologists draw inspiration from dynamical systems theory, a formalism which offers some promise of fulfilling Lorenz's vision of a unified theory of evolutionary adaptation and adaptive cognition. From the perspective of dynamical systems theory the role of constraints is almost entirely creative. What keeps systems from thermodynamic equilibrium are their organisational constraints. These act as a kind of kinetic barrier which sorts the system's components and maintains an energy gradient. In addition to maintaining the system's internal organisation, constraints control the system-environment interaction, allowing the system to "track environmental regularities and relate them to behavioral output" (Christensen 1996, 313). The idea that organisms draw information from the environment is at the heart of adaptationist thinking in biology and has led to numerous comparisons between adaptation and cognition. Christensen and Hooker argue that what is distinctive about cognitive systems is their ability to control system-relevant information by means of new levels of organisational constraints (Christensen and Hooker (forthcoming)). The advent of cognitive systems in evolution is another critical innovation like the advent of cell membranes, one which creates a new internal and quasi-autonomous environment which can more easily be kept within certain critical parameters. The existence of membranes limits the processes that can go on in the cell, but within these limits the system is able to do much more work.

There is a sense in which every model of cognition consists of a set of enabling constraints on cognitive processes. For Descartes the mind is constrained by the natural light of reason, for Hume by the laws of association and for Kant by the categories of the understanding. As well as limiting what the mind can think, these constraints are responsible for the very possibility of thought. What is different about the constraints envisaged by evolutionary epistemology (evolved cognitive structure) is that they do not have an universal or transcendental justification. Instead, they have an empirical, naturalistic justification grounded in our particular history as a species. The new constraints cannot pretend to finality either: like other products of evolution, they have within them the possibility of future development. The uneasiness felt by traditional epistemologists at the idea that cognition is an empirically bounded process is reminiscent

of the unease felt by traditional metaethicists at the idea that human morality is a contingent biological product. Darwin's vision of morality as a species-specific adaptation is still unacceptable in many quarters: if that is what 'morality' is, then it is not morally binding. Likewise, if rationality is the product of a particular, contingent evolutionary history, can it play the normative role required of it?

We will not try to settle here the adequacy of a thorough-going naturalism in philosophy. A large, if inconclusive, literature on this topic already exists (Hooker 1995; Callebaut and Stotz 1998; Callebaut and Stotz (in press)). We aim to make a much more limited point. We examine and question the way that biological constraints on cognition are conceived by many of the authors cited in section one. Species-typical features of cognition and of cognitive development are commonly presented using the traditional concept of 'innateness' and its heir the 'genetic program'. This conceptualisation of biological features as hard constraints on cognitive possibility is reinforced by the alternative treatment given by the social sciences to cognitive processes in which no 'universals' have been detected. Here we find an emphasis on the constructed nature of the cognitive and social self, and on the importance of environmental, social and cultural factors in development. The dichotomies of the nature/nurture debate are thus projected into theories of human cognition. In place of this balkanisation of cognition, with its boundary disputes and expansionist manoeuvres, we offer a 'developmentalist' perspective on the biology of cognition. Regularities in cognition and cognitive development result from the interaction of earlier stages of the organism with a wide range of developmental resources. Reliable outcomes are not pre-programmed, but represent attractors of various kinds for the developmental system of the organism. Biological structure takes the form of 'soft constraints' whose primary interest is that they explain how things usually turn out, not that they exclude other outcomes. Furthermore, the existence of these constraints is contingent on many different parameters which set up the typical developmental cascade. Hence the constraints are not only 'soft' in the sense already recognised by authors such as Markman (1992) but in another, deeper sense. Constraints are soft in the first sense because they act probabilistically rather than deterministically. They are soft in the deeper sense because the constraints themselves emerge (and dissolve) as part of the developmental process. Failures to obtain the usual outcome may occur not only because the constraint has been evaded, but because it has been abolished. This perspective is close to that adopted in recent years by a number of developmental psychologists (Thelen and Smith 1994; Elman et al. 1996). We will try to strengthen their case by drawing

on the general case made against ‘program’ accounts of development by ‘developmental systems theory’ (Oyama 1985; Gray 1992; Griffiths and Gray 1994; Oyama 1999).

Representing the same, species-typical features of cognition from a developmentalist viewpoint has several results. Perhaps most importantly, the idea that cognition and cognitive development have biological structure ceases to be linked to the idea that cognition is constrained within certain, pre-specified limits. The link between biological structure and adaptation is also loosened: constraints also emerge spontaneously from the internal dynamics of the processes in question. Finally, the developmentalist approach allows discoveries about the biological structure of cognition to be smoothly integrated into some of the most promising new approaches in cognitive science: theories of situated activity and embodied cognition (Varela et al. 1991; Thelen 1995; Hendriks-Jansen 1996; Clark 1997).

3. THE DEVELOPMENTALIST CRITIQUE OF ‘BIOLOGICAL CONSTRAINTS’

A common response to a species-typical regularity in cognition or cognitive development is to postulate a representation of the regularity which serves as one the causes of its development. This representational role is usually ascribed to some known or postulated DNA sequences whose presence correlates with the developmental outcome in question. The reliable presence of the trait is explained by the fact that there are ‘genes for’ the trait. This strategy is often described as ‘neo-preformationist’ because like the old preformation theory of the embryo it denies that the order manifest in the developed organism actually originates during development. Organisms do not increase in complexity as the result of the operation of physical laws on a nexus of simpler resources (‘epigenesis’). Instead, they are constructed by resources as complex and orderly as themselves: genetic programs or blueprints.

The genetic program approach to development has been criticised by a cluster of innovative ‘developmentalist’ approaches in biology and the philosophy of biology (Schaffner 1998). One of these new approaches is ‘developmental systems theory’ (DST). The developmental system of an organism is the matrix of resources that serve as the actual physical causes of development. DST uses the idea of ‘extended inheritance’ to draw attention to the many causal pathways by which resources come to be deployed at the right locations to play their regular roles in development. Organisms place DNA into a developmental setting that is always highly characteristic of a lineage and commonly owes much of its structure to the

activity of previous generations of that lineage. The zygote itself is a matrix of different inherited structures. Basal bodies and microtubule organising centres, DNA methylation patterns, cytoplasmic polarities, membranes and organelles are all inherited. Changes in these epigenetic elements cause heritable variation in the cellular phenotype and are now widely recognised as ‘epigenetic inheritance systems’ (Jablonka and Lamb 1995; Jablonka and Szathmáry 1995). Developmental systems theory extends inheritance still further. A principled definition of inheritance must include whatever is present in each generation and helps reconstruct the life-cycle. In the fire-ant *Solenopsis invicta*, the morphology of queens and the colony structure differ radically between genetically near-identical lineages of the species. These differences are sustained by stably self-reproducing pheromonal nest cultures (Keller and Ross 1993). Although this case is particularly striking, the phenomenon of organisms constructing the key physical parameters that in turn effect their evolution is ubiquitous (Odling-Smee et al. 1996). The developmental system of the rhesus macaque includes the social interactions necessary for its normal psycho-social and sexual development (Harlow and Harlow 1962; Harlow and Harlow 1969). That of humans includes, centrally, exposure to a human language.

The ‘parity thesis’ of developmental systems theory asserts that, for all their biological importance, genes do not form a special class of ‘master-molecules’ different in kind from any other developmental factor (Griffiths and Knight 1998). Rather than a genetic program passing from one generation to the next and then building an organism, the developmental process – the organism’s life-cycle – reconstructs itself from one generation to the next via numerous interdependent causal pathways. Extended inheritance and the parity thesis imply that evolution is not just change in gene frequencies but change in frequencies of the entire spectrum of developmental resources. For our present purposes the most important consequence of the parity thesis is that we should not single out a particular type of resource as the source of inter-generational stability (e.g., genetic rather than environmental, internal rather than external (Oyama 1998)). All elements of the developmental matrix are reliably recurrent and help explain inter-generational stability. The phrase ‘interactive construction’ nicely sums up the way in which individual resources contribute to development: the effect of each resource depends on its interaction with many others. Genes are interpreted differently in different cells and at different times, as are all other factors which make up the developmental system. Hence whatever the actual structure of the gene or other resource, there is a critical sense in which the rest of the developmental system constructs the information we might be inclined to locate in that resource (Oyama 1985; Oyama 1988;

Neumann-Held 1998). There is no ‘master molecule’. Development, as Kenneth Schaffner has put it, is “an extraordinarily complicated orchestra – and one with no conductor” (Schaffner 1998, 247).

The parity thesis is supported by an analysis of ideas of coding and information in genetics and developmental biology. The actual genetic code has no representational resources to specify outcomes other than the primary structure of proteins. Even in that limited domain, differences in other resources lead to different outcomes from the same DNA sequence (Sarkar 1996; Neumann-Held 1998; Griffiths and Neumann-Held 1999). More widely applicable definitions of information fall into two classes, those which obey the parity thesis and make both genes and other developmental resources loci of developmental information and those that ascribe irreducible intentional properties to genes! Rehearsing these arguments in full here would take too long,³ but the key problem for the idea that the developmental program resides in the genome is that the family of notions related to the formal theory of information all define information in terms of causal dependence and covariation. Hence these notions of information apply to all elements of the developmental system, by definition of what it is to be an element.

The implications of developmental systems theory for the sciences of cognition are fairly clear. Fiona Cowie has recently argued that ascriptions of innateness in psychology and allied disciplines have been used to assert either or both of two things: First, ‘innate’ features of cognition and those which are domain specific; second, they are features whose development is not part of the scope of the psychological sciences and which must therefore be taken as given (Cowie 1999). If DST is correct, then the task which is thereby implicitly handed over to the biologists is not to find the ‘genes for’ the trait, but to elucidate the developmental cascade through which the cognitive trait develops. This in turn implies that little of what is commonly inferred from the discovery of a species-typical regularity in cognition genuinely follows. What we actually learn from such a discovery is that organisms typically turn out this way. The claim that they are ‘constrained’ to do so is a speculation about the dynamical structure of the developmental system from which they emerge. At its very weakest, it is the claim that this outcome is an attractor for that system – little more than a restatement of the observed regularity. The stronger claim suggested by the use of the word ‘constraint’ is that the system cannot easily be perturbed from this outcome – a claim that without further evidence is mere speculation. Once we abandon the neo-preformationist conception of the genetic program, there is no general reason to expect evolved traits to be buffered against parameter variations in development. Attractors for

development emerge and dissolve in a time-dependent way as the parameters of the system vary (Thelen 1995). The most we can expect is that evolved traits will be buffered to various degrees against the sorts of fluctuations developing organisms actually had to cope with in evolutionary history. Thus, for example, limb development is buffered against short term fluctuations in nutrition, but is not buffered against thalidomide exposure. Sexual development in the macaque is robust under natural conditions, but is easily perturbed by the experimentalist. In the same way, we should expect evolved cognitive outcomes to be sensitive to perturbations in a wide range of developmental parameters.

4. THE DEVELOPMENTAL BIOLOGY OF COGNITION

Developmental systems theory suggests a more adequate conceptualisation of species-typical regularities in cognition and cognitive development than 'innate' cognitive traits and 'constraints' on cognitive development. Species-typical regularities should be understood as the result of reciprocal interaction between the various elements of the developmental system. The same range of resources is brought together as on innumerable previous occasions in the same lineage of organisms. Many of these resources are the products of earlier stages of the process – 'the organism so far'. Others have been present all along, but take on a new significance in the light of the more developed state of the organism. Still others may arrive at the right time and place because of one of the many causal pathways from parent to offspring. This description gives an impression of extreme delicacy, which probably accounts for the strong intuition that something must be guiding the process, making sure that the right resources are present and compensating if they are not. This intuition should be dispelled by the realisation that complex systems have attractors into which they are drawn from a wide range of parameter settings. The emergent structure of the dynamic process of development substitutes for either the vital forces of Hans Driesch or the genetic programs which replaced them. This insight was probably first clearly expressed in C. H. Waddington's concept of an epigenetic landscape (Waddington 1957).

A similar understanding of development has been arrived at independently in the cognitive science community via at least two routes: via the application of dynamical systems theory to cognitive development (Thelen and Smith 1994; Elman et al. 1996) and via 'situated' or 'embodied' models of cognition itself. Esther Thelen sums up her dynamical systems approach to child development as follows:

behavior and cognition, and their changes during ontogeny, are not represented anywhere in the system beforehand either as dedicated structures, or symbols in the brain, or as codes in the genes. Rather, thought and behavior are “softly assembled” as dynamical patterns of activity that arise as a function of the intended task at hand and an individual’s “intrinsic dynamics” [by which is meant] the preferred states of the system given its current architecture and previous history of activity. (Thelen 1995, 76)

Thelen has described the emergence of effective reaching and grasping in 3–4 month old infants in this new framework (Thelen 1995). The undirected movements which precede the emergence of the new behaviour are modelled as the chaotic behaviour of a simple physical system of joints and muscles periodically excited under the influence of the infants general state of arousal. Thelen describes the course of development in two individuals, one highly active and one relatively quiescent. The former flailed his arms wildly in the period before reaching emerged and converted this flailing into vigorous but well-directed reaching. In contrast, reaching in the second child required the initiation of more vigorous movements than previously observed. As well as following different development trajectories to the same outcome, the two infants had to tune different system parameters in order to reach it. The regular emergence of coordinated reaching at this stage is explained, not by an instructive cause, but by the interaction of existing activity patterns with an interest in the objects to be grasped, creating an attractor to which the system will move from several prior states. Naturally, this increased interest in objects, must itself emerge from the interaction of an earlier state of the child with other elements of the developmental system. Calling it ‘innate’ or announcing that it ‘matures’ is simply issuing a promissory note against future developmental psychology and biology. A possible account will be discussed in a moment.

Other studies by Thelen and her co-workers reinforce some of these themes. Rather than new behaviours emerging because a representation of them is activated, they emerge from the previous dynamical state of the system as one of its parameters varies. This can be demonstrated in ‘microgenesis’ experiments which bring about the emergence of a new behaviour before its normal period of ‘maturation’ by manipulating some parameter of the system. Coordinated stepping in infants results from the interaction of motor patterns present from earliest infancy but suppressed during an intermediate period by the weight of their limbs. When the available muscular force catches up with the weight of the limbs the old pattern results in the ‘spontaneous’ emergence of effective behavior. However, this and other aspects of walking can be brought out earlier in development by removing simple physical constraints (Thelen and Ulrich 1991).

The second source of convergence on the developmentalist perspective on cognition has been by way of ‘situated’ or ‘embodied’ models of

cognition itself. Intelligent behaviour can be supported by the simplest of internal mechanisms if these mechanisms can take advantage of regularities in the environment with which they will normally interact, including, importantly, the bodies through which they will interact. This perspective has produced a number of successes in 'situated robotics'. Authors such as Horst Hendriks-Jansen and Andy Clark have suggested that the lessons of situated robotics can be extended to sophisticated human cognition (Hendriks-Jansen 1996; Clark 1997). Our cognitive processes assume and exploit the presence of a highly structured environment, including languages and other systems of representation. With the aid of this external scaffolding, we can accomplish tasks beyond the capacity of the 'naked brain'. Hendriks-Jansen describes how the existence of intentional behavior in the mother may 'scaffold' the development of intentional behavior in the infant. This work, incidentally, throws some light on the antecedents of the development of reaching and grasping discussed above. The studies summarised by Hendriks-Jansen suggest that around four months the infant, whose gaze has previously been strongly directed onto the mother's face, begins to look away. Although the infant's gaze is not in fact directed at anything, it is interpreted by the mother as an interest in various objects. At this point:

The infant may perform a primitive reach-and-grasp gesture in the direction of the object; the mother will interpret this as an attempt to take hold of the object and intervene to complete the infant's action. She thereby incorporates the infant's rudimentary activity patterns into an action that is about an object. The mother provides the supporting framework or scaffolding in which the activity pattern acquires intentional significance. (Hendriks-Jansen 1996, 273)

This scenario describes a possible origin for the increased interest in objects which played a role in the explanation of coordinated reaching given above. Once again, however, a certain existing state of the system is taken as given. We can say that the infant 'innately' starts to look about or that this behaviour 'matures' at around four months. Once again, there is a temptation to take these terms as denoting some sort of explanatory category, whereas in reality they are devoid of any scientific content and constitute a promissory note against future developmental biology. If the new behaviour is caused by elevated production of some gene product in some brain region, for example, this in turn will have resulted from an interaction between those cells and other elements of the developmental system. Development is interactive emergence all the way down.

In this section we have described two approaches in cognitive science that lead to a developmentalist perspective on the organism: the application of dynamical systems theory to child development and theories of embod-

ied cognition. It will have become clear that the two are closely linked. They are also highly convergent on the developmentalist perspective that has emerged from the work of Susan Oyama and which was discussed in the last section. In the next section we consider how these new approaches might interact with the recent, biologically inspired work on rationality and decision making mentioned in section one.

5. BIOLOGICAL APPROACHES TO RATIONALITY

Traditional approaches to the study of rationality shared Leibniz's dream of an universal calculus consisting of formal axioms and rules of choice which apply independently of the topic about which decisions are to be made and the context in which the decision process occurs. It was the economist Herbert Simon (1957; 1987) who first systematically questioned this ideal of content and context independent rationality. He coined the term 'bounded rationality' to describe the procedures humans actually use when they have to formulate and solve complex problems. Simon argued that both natural selection and the self-interest of individuals making their way in the world would favor 'satisficing' instead of 'optimizing' behavior. Satisficing, and bounded rationality more generally, should not be understood as simply optimisation under constraints. That would leave the traditional approach to rationality untouched and merely introduce a secondary study of how rationality can be approximated by agents with limited resources. The original intention behind the ideas of satisficing and bounded rationality was more radical: it was to challenge the idea that decision problems and their optimal solutions can be defined without reference to the content of the decision and the context in which it occurs.

Gigerenzer (1996; 1997b) has a vision of rationality which shares this radical intention: "Content has not yet assumed a life for its own. For the most part, it is seen only as a disturbing factor that sometimes facilitates and sometimes hinders formal rational reasoning" (Gigerenzer 1996, 331). Gigerenzer's criticisms of the content free-approach are backed up by real and thought experiments intended to show that stating a problem in a social context does more than facilitate or hinder the application of content and context independent rules. In many cases the problem cannot even be formulated outside the specific social situation. Suppose, for example, that you are invited to dinner and there is only one piece of cake left. You would like to eat it, and if there were an additional piece of cake left you certainly would eat it. But there is only one piece and you are a polite woman, so you do not eat it. This behavior violates the formal rule of internal consistency of choice. Choosing x from the set $\{x, y\}$ but choosing

y from the set $\{x, y, z\}$ is regarded as irrational in decision theory. But we can hardly count someone irrational simply for following the accepted standards of good behavior. Of course, we can redescribe the case so that the choice fits the rule, but this only underlines how unhelpful the rule is in characterising what it is to be rational. It is the social situation in this case which defines the alternatives with respect to which we can ask if the choices are consistent.

The idea that cognition should be judged against standards suited to the specific situations which cognitive processes evolved to cope with is central to contemporary evolutionary psychology (Barkow et al. 1992). But to accept bounded rationality is one thing, to accept a vision of the human mind still working as it did in its Pleistocene prehistory, equipped with a multitude of inborn, content-rich, and mutually independent modules – a vision that we might call ‘limited rationality’ – is quite another. In the light of the discussion in sections two, three and four it is important to detach the idea of bounded rationality from the idea that the mind is limited in its abilities to performing only the cognitive operations that it performed in the evolutionary past. The evolutionary psychology movement views the mind as a collection of highly specialized mental modules (the ‘Swiss army knife’ model of the mind). But although there are powerful arguments for the existence of such modules, there is also evidence against the ‘strong modularity thesis’ (Gigerenzer 1997b, 274) that all mental processes are modularised and that these modules function largely independently from one another. A crucial feature of humans is that they can and very often do conflate functions and domains, a propensity which can be exemplified by the ubiquitous use of anthropomorphic thinking or the extrapolation of social categories into the non-social realm. For Mithen “it is the human passion for analogy and metaphor which provides the greatest challenges to Cosmides and Tooby’s view of the mind” (Mithen 1997, 50).

Taking a developmental perspective on evolved cognitive traits allows us to do justice to both bodies of evidence: evidence of the apparent modular nature of cognition and evidence of our ability to transcend modularity. Mithen (1997, 51–5) summarises the evidence from the study of child development which seems to support the idea that children possess intuitive knowledge organised into separate domains. Most famously, children acquire language with a facility that seems to defy possibility for domain-general learning mechanisms. Very young children are able to attribute mental states to other people and do so in characteristic ways that have been labelled the ‘child’s theory of mind’. Children also have an intuitive understanding of the natural world, with characteristic patterns of reasoning for living versus non-living things. This intuitive knowledge “appears

to derive from a cognitive foundation of innate content-rich mental modules. Such modules appear to be universally shared by all humans". For all these domains "one can imagine strong selective pressures for the evolution" of the relevant faculties (Mithen 1997, 54). But domain-specific modules cannot be the whole story. Children learn with equal facility to apply the evolutionary rules of one domain to another, so as to apply categories of psychology, biology and language to play with their inert physical toys, for example. For several decades now, adult biologists have reliably learnt to reject the essentialist approach to species which they developed as children and to understand species relationships on an analogy with family relationships. The solution of this paradox is to understand modularisation as a product of development. Like the characteristic patterns of limb movement described in section four, characteristic patterns of reasoning represent basins of attraction for the developing mind, basins that can dissolve again as development continues: "Developing minds [show] the rise and fall of a Swiss-army-knife mentality" (Mithen 1997, 55). Though it may be true that the mind of early hominids stopped growing at some stage of modularity, in modern humans development extends the phase of the modularisation in which the mind works in separated cognitive domains to a stage 'beyond modularity' (Karmiloff-Smith 1992). According to Karmiloff-Smith, the 'representational redescription' of the knowledge embodied in one modular cognitive mechanism by another allows the application of existing skills to new purposes (Karmiloff-Smith 1992, 701). In the terms of the discussion in section two, theories such as Mithen's and Karmiloff-Smith's are recognising the role of the biological structure of cognition as a set of 'enabling constraints' which make possible further and more sophisticated cognitive achievements. The possession of separate faculties makes it possible to build connections between them, mapping from one domain into the other, creating analogies, metaphors, and thereby new activities and solutions on old problems. This capacity of the modern human minds, which Mithen calls 'cognitive fluidity' or the 'flexible mind', seems to be the source of the human capacity to innovate. Our rationality is bounded, in the sense that it is constituted by a specific set of evolved resources, but this does not mean that we are restricted to performing the particular cognitive operations in virtue of which these resources evolved.

The 'embodied mind' perspective offers some further, complementary perspectives on rationality. Clark (1997) argues that our rationality is the result of the combination of individual cognitive profiles and a wide range of external scaffolding. Public language plays a paramount role in constituting human rationality by supporting individual thought and coordinating

social interaction and communication. This leads to a variety of different choice situations from ‘highly scaffolded choice’ as one extreme to ‘weakly constrained individual cogitation’ as the other (Clark 1997, 181–2). Ironically, predictions made by traditional rational choice theories work best in highly scaffolded situations which leave less room for the operation of individual psychological features such as beliefs and desires. These social-institutional scaffolding structures in which individuals are embedded “have themselves evolved and prospered (in the case where economic theory works) by promoting the selection of collective actions that do indeed maximize returns relative to a fixed set of goals” (Clark 1997, 1982). Individual psychological profiles are not that simple and predictable, since behavior to maximize personal returns is influenced by politeness, shyness, and all kinds of personal and contextual influences.

6. ON HUMAN NATURE

In this paper we have described a number of convergent bodies of scientific work which undermine the idea that the inherited biological structure of cognition takes the form of hard constraints. In the last section we applied some of these ideas to the specific topic of rationality. To many evolutionary psychologists these claims will suggest that we are representatives of the ‘standard social science model’ with its default assumption of infinite cognitive malleability (Cosmides et al. 1992). In this final section we will try to explain why this is not the case, and what conception of ‘human nature’ we take to be viable in light of the way that the mind grows.

The traditional conception of human nature is problematic at every level. First, the very idea of ‘the nature of a thing’ has been substantially re-thought in the recent literature on kindhood and category formation. Second, ‘human nature’ is meant to be the essence of the species *homo sapiens*. Yet there is a broad consensus in biology and philosophy of biology that species are not natural kinds and do not have essences! Finally, human nature is traditionally conceived as a set of developmental outcomes that cannot be changed by changing the environment, or to change which would produce something deformed – a ‘monster’ in the original meaning of that word. Clearly the entire thrust of this paper goes against this traditional conception of human nature. But despite these many difficulties, it is still possible to salvage something of human nature.

The second difficulty, the rejection of essentialism in systematics, is perhaps the easiest to deal with. There is a broad consensus that species are united by common ancestry and not because all members of the species share some set of properties or participate in an overlapping cluster of

properties (Ghiselin 1974; Hull 1976; Sober 1994/1980). This is usually taken to imply that taxa have no essences and that they are not natural kinds. Species are historical entities like nations or corporations. However, another response to the historical or phylogenetic view of species has been to rethink what is meant by 'natural kind' and 'essence'. This has been a major spur to the recent work on 'the nature of nature' to which we have already alluded.

Recent discussion of the nature of natural kinds has two sources: discoveries about how we conceptualise nature (Keil 1989; Lakoff and Johnson 1999) and theories of how nature itself is ordered (Wagner 1996; Wilson 1999). The questions at issue are, first, how do people form useful categories and, second, what it is about the world that makes these categories useful? Many of the recent findings about the biological structure of cognition mentioned in section one have stemmed from research on this first question. It seems that children have, in all sorts of ways, a head start in constructing useful categories. Philosophical work on the second, related, question has shown that it is possible to base 'natural kinds' on any of a number of sources of order in nature. Natural kinds are categories that have some value for induction and explanation because of some causal process enforcing similarity between instances of the category. Darwinian species, defined by common ancestry, can be natural kinds because heredity ensures that individuals with a common ancestry will resemble one another. Thus we can allow that species have none of their intrinsic properties essentially, only their ancestry, while still expecting to find reasonably reliable generalisations about the 'nature' of a species (Griffiths 1999). The reliability of species categories is reinforced by a number of other biological processes, such as interbreeding in sexual species and the fact that developmental mechanisms are shared by common descent. It is in this sense that we can talk of 'human nature' – something that is characteristic of human beings because all humans are descended from a common ancestral population and are constructed by similar developmental systems.

Having taken a position on the nature of natures in general, and the natures of species in particular, we are left asking what is distinctive about the nature of the human species in particular. Human development is, not uniquely but certainly outstandingly, reliant on external scaffolding. This scaffolding is commonly referred to as culture. Part of the rationale of the traditional idea of human nature was to isolate features that do not depend on culture. These 'biological' features represent our true nature – the naked ape stripped of its cultural clothes. It seems to us that this traditional project is as misguided as seeking to investigate the true nature of an ant

by removing the distorting influence of the nest! Human beings and their cultures have co-evolved as surely as ants and hives or dogs and packs. Human nature must inevitably be a product of a developmental matrix which includes a great deal of cultural scaffolding.

Theories of embodied and situated cognition suggest that the individual representational system is part of a larger representational environment which extends far beyond the skin. Cognitive processes actually involve as components that are more traditionally conceived as the expressions of thought and the objects of thought. Situated cognition takes place within complex social structures which 'scaffold' the individual by means of artifactual, linguistic and institutional devices. When applied to cognitive development these approaches suggest that culture makes humans as much as the reverse. In order to assimilate these ideas about cognition we must abandon a still popular picture of the relationship between biological and cultural evolution. There was no process of 'human biological evolution' which produced the 'anatomically modern human' and which was followed by a process of 'cultural evolution' (Ingold 1995). Human beings have had a culture since before they were human. That is, modern humans owe a good part of their capacity to develop cognitive powers to the successful replication of earlier developmental systems which included a range of social and cultural resources. Humans are born into intentional surrounding as part of a lineage which has co-evolved with environments in which intentionality and representation exist in other subjects and in objects and the context-of-use of these objects (Sinha 1989; Ingold 1991).

These extra-individual developmental and psychological processes which allow the human organism to construct its personality from a range of social and cognitive resources can be seen as a key to the distinctive nature of humans. Human evolution has given rise to a new stage of development: childhood (Furth 1987). The evolution of infancy created a niche for the interactive emergence of specific human cognitive capacities, a niche created by the appearance of artefacts as representations of social norms. Attempts to model this process of interactive emergence have consistently had the same character: they involve the successive creation and dissolution of what can be viewed either as 'constraints' dictating the character of cognition at one phase of development or as attractors explaining the occurrence of that phase. Piaget described this process of building and breaking constraints as increasing 'equilibration'. The growth of knowledge proceeds by 'accommodation' to and 'assimilation' of new knowledge, the two cognitive mechanism of 'adaptation', and by the subsequent organisation and integration of this knowledge into internal cognitive structure. In addition, the organism increases its capacity

for future adaptation by improving the mechanisms and rules by which it organises its knowledge (Piaget 1971/1967; Hooker 1995). For example, when a child plays for the first time with a rattle it has no internal category for objects-to-make-noise and it assimilates the rattle to its internal scheme for objects-to-suckle. By so doing it detects the proper function of the object, which increases its enjoyment and motivates the child to accommodate its internal scheme for objects to this new category. The other form of change, an increase in adaptive capacity, occurs when the child learns to separate ends from means, as in separating rattling from the rattle, and can apply its scheme for rattling to other objects. In her contemporary model of cognitive development, Thelen has used the idea of a time-dependent epigenetic landscape to understand a similar process of feedback. The path of development is dictated by the emergent dynamics of the system, but this dynamic structure changes over time and partly in response to the developing system's effects on its own parameters. The child's activity, driven and 'constrained' by the structure of its nervous system at that time, is also providing the feedback that modifies that structure and leads to the emergence of behaviours 'forbidden' by the old dynamics.

We have suggested that an important part of human nature is a distinctive developmental phase which exploits cultural scaffolding to change the dynamics of the cognitive system in a way that opens up new cognitive possibilities. This does not sit easily with the idea that our biological inheritance consists of a set of adaptations to a specific ancestral lifestyle, and within whose limitations we must learn to live. We suspect that this other image of 'human nature' requires two presuppositions with which we fundamentally disagree. The first is a neo-preformationist model of development which obscures the need to explain how developmental outcomes are actually constructed. The second is a dualistic account of human biology and human culture in which the first evolved without the other and hence can develop without it. In contrast to this picture we suggest that the stability in human development which is revealed in pan-cultural traits and in developmental outcomes that resist deliberate attempts to modify them is a dynamic stability. It results from the emergence of attractors during development. No doubt many of these attractors are entrenched, in the sense that they are linked to other elements of the dynamics and cannot be modified in isolation. The attractors are also likely to depend on parameters of the cultural scaffolding. Hence possibilities for individual psychological modification will be intertwined with collective, cultural change. So 'human nature' is far from infinitely malleable. But we will need to understand development much better before we can hope to understand which features are entrenched and in what manner. In the meantime, evidence of con-

straints, entrenchment, and boundedness should not be misrepresented as absolute limitations on human possibility. The extent and nature of these limitations cannot be determined by observing how minds typically turn out, only by understanding how the mind grows.

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NOTES

- ¹ For an overview of all these developments, see Davies (1999).
- ² Donna Haraway has been credited with inventing this term (Burian and Richardson 1990; see also Christensen and Hooker (forthcoming); Juarrero 1998).
- ³ For an introduction to the debate over genetic information, see Sterelny and Griffiths (1999). For recent discussions see Sarkar (1996), Sarkar (1997), Godfrey-Smith (in press), Kitcher (in press).
- ⁴ Author's names are in alphabetical order.

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