On the emergence of modern humans

Daniele Amati a,b,*, Tim Shallice a,c

a International School for Advanced Studies (SISSA), Via Beirut 2-4, 34014 Trieste, Italy
b Centro Interdisciplinare “B. Segre”, Accademia dei Lincei, Rome, Italy
c Institute of Cognitive Neuroscience, University College, London, UK

Received 10 January 2006; revised 19 March 2006; accepted 1 April 2006

Abstract

The emergence of modern humans with their extraordinary cognitive capacities is ascribed to a novel type of cognitive computational process (sustained non-routine multi-level operations) required for abstract projectuality, held to be the common denominator of the cognitive capacities specific to modern humans. A brain operation (latching) that allows this novel computational process is proposed as well as a physics-inspired mechanism that could explain its rather recent emergence without invoking unlikely genetic or structural changes.

Keywords: Prefrontal cortex; Latching; Paleoanthropology; Human evolution

1. Introduction

One of the major challenges in current science is to understand the emergence of modern humans with their cognitive capacities which in a biological context are extraordinary. How could this have happened in anatomically modern humans, that is, a species which had apparently already evolved to its current genotype or close to it? It is a species in which further major changes in brain structure and
organisation did not occur. Yet this transition in cognitive capacities gave to this single species the potential to transform the natural world. The goal of this paper is to provide a theoretical framework which may help to explain the process of transition by integrating several levels of argument.

In Section 2, we give a brief list of the cognitive capacities that are potentially unique to modern humans; we call them h-capacities. The issue of differentiating such abilities from protocapacities found in earlier humans (other hominins), will be considered in Section 3, together with the different positions that have been taken in paleoanthropology on the time course of the emergence of modern human behaviour. In Section 4, we take the first novel step in proposing that a capacity—abstract projectuality—is the common factor in all h-capacities. The second novel step (see Section 5) is to propose a specific computational process as underlying the cognitive operations that form the basis of abstract projectuality; its key new operational element—which we shall call latching—enables a fluent sequence of non-routine computational processes to occur which can also be protracted in time. We then consider in Sections 6 and 7 how latching might be realised in the brain and how it could have been realised in human prehistory. The third novel step (see Section 8) is to propose a mechanism derived from theoretical physics, which could explain the emergence of latching in a brain as developed as that of Homo sapiens. In Section 9 it is argued that the motor of the process could be an increase in prefrontal cortical connectivity arising from a combination of genetic and epigenetic influences.

2. h-Capacities

Modern humans have a range of cognitive capacities which are unique to them. For many of them it is possible to recognize some degrees of protocapacities in animals and, especially, primates. Assigning protocapacities to hominins is more controversial due to the limited information provided by archeological material. For the present purpose what would be most critical would be to specify them by contrast with the capacities of pre-modern humans such as Homo ergaster, Homo erectus, and Homo neanderthalensis. However, since the cognitive capacities of modern humans are themselves not easy to characterise we begin by simply considering the capacities of modern humans by contrast with other animals, in particular primates. We begin with a brief, incomplete, list to illustrate their diversity:

1. Language. This is obviously the most frequently discussed basic human capacity with a complex underlying structure, which goes far beyond any communication system used by other animals. There is widespread agreement that some form of protolanguage developed relatively early in human evolution (Bickerton, 1991). However, there are major disagreements as to whether there was then a single critical step in attaining a modern language facility such as the acquisition of recursion (Hauser, Chomsky, & Fitch, 2002) or speech (Corballis, 2004) or a whole sequence of critical steps (Jackendoff, 1999).
2. **Tools and instruments.** Modern humans have the ability to use tools and instruments which are designed to realise, amplify, optimise, and extend their natural capacities. This ability goes far beyond that shown in the rudimentary use of tools by monkeys and primates, for instance, in using bones or stones to break nuts or sticks to capture ants (see e.g. McGrew, 1992).

3. **Signs, signals and other homomorphic representations:** Humans have the ability to visually represent aspects of reality for a particular purpose such as indicating something for subsequent use. Thus, a bifurcation or a cross can be used to indicate the correct direction or route, an ability that eventually will develop to provide representations such as plans or maps.

4. **Dynamic concepts.** Humans have the ability to conceive of dynamic entities, to use ideas of forces, or more generally to conceive of causes for events and of the consequences of actions. This allows humans to analyse nature by isolating characteristics, identifying regularities and recognizing relevant causes and effects (see Sperber, Premack, & Premack, 1995). These capacities could be considered as an implementation of what Vygotsky and Luria (1930) called the basic characteristic of humanity: the constant search for a why.

5. **Aesthetic sense.** It enables other capacities to be sublimated for a further function. Poetry and literature are generated from language, painting, sculpture, and plastic arts from schematic representations, music from vocalisation, dance from action and so on.

6. **Metarepresentation.** Humans are capable of using representations not only of directly perceived things but also as a second or higher-level interpretation of “mental, public or abstract” entities (Sperber, 2000).

7. **Algorithmic capacity.** Modern humans have an efficient algorithmic capacity (see Bonatti, 1994). This provides the basis of logical operations, and eventually of arithmetic, geometry, and mathematics.

8. **Categorisation and organisation.** Even traditional societies have complex systems for organising their knowledge, as for instance what they know of the properties of animals and plants (Atran, 1995; Berlin, 1992).

9. **Theory of mind.** A more controversial candidate for an h-capacity is theory-of-mind (Premack & Woodruff, 1978) or mentalising (Morton, 1989). It is known that primates, in particular, are able to perceive the attitudes or intentions of others of their species (Dunbar, 1998; Premack & Woodruff, 1978). Povinelli and Vork (2004) argue that the extra modern human component is the ability to make inferences based on the abstracted mental state of the other, not just on a database of the representations of specific behaviour using their statistical relationships to compute possible actions. On the position of Leslie (1987) this depends on the development of a cognitive process—the ‘expression raiser’ (EXPRAIS)—which makes the human aspects of theory-of-mind derive from metarepresentation, discussed above.

10. **Anticipatory planning.** Human behaviour is often directed towards the attainment of some explicitly represented future state-of-affairs (see Suddendorf & Busby, 2005). This capacity has been called ‘mental time-travel into the future’ (Suddendorf & Corballis, 1997). Humans can also set themselves imagined
goals not closely related to their current situation and current needs (Brinck & Gardenfors, 2003). By contrast, it has been argued that even chimpanzees cannot represent a goal without a means of achieving it (Tomasello & Call, 1997). More generally, Bischof (1978) and Bischof-Kohler (1985) have argued that animals cannot anticipate future needs or drive states, and later evidence is broadly compatible with the position: the ability of chimpanzees to gather stones to take to where they will crack nuts can be interpreted as future satisfaction of a current need (Suddendorf & Busby, 2005). These authors also argue that the capacity develops in relation to theory-of-mind but is not directly dependent on language.

What is critical about even this short list is the variety of specific cognitive processes involved in the different capacities. Any common denominator would need to be abstract. However, is there any reason to associate developments in any of these capacities with the evolution of modern humans per se? It is to this issue that we now turn.

3. Hominin development and the origins of h-capacities

Brain volume relative to body weight steadily increased in the homo lineage by a factor of about two from 2 million years ago to the origins of anatomically modern humans (Lewin & Foley, 2004), generally identified with Homo sapiens. By ‘anatomically modern humans’ we refer to humans with modern bipedal locomotion and with short, high rounded skulls, a small face and a chin. Both genetic and paleoanthropological evidence support the idea that such anatomically modern humans evolved in Africa roughly around 160–200 kya, spreading later through the world (Cavalli-Sforza & Feldman, 2003; Ingman, Kaessmann, Paabo, & Gyllensten, 2000; Lewin & Foley, 2004; McDougall, Brown, & Fleagle, 2005; White et al., 2003).

There was however a considerable gap in time before any behavioural consequences of the anatomical change became apparent. There is no sign of symbolism at the appearance of anatomically modern humans (Lindley & Clark, 1990). There is, however, a general consensus that by 50–35 kya in the Upper Paleolithic in Europe and the Late Stone Age in Africa, a range of activities took place which have been characterised as “modern human behaviour;” these include the employment of a range of types of tool technologies, the systematic use of body decorations, such as beads and pendants, the presence of long-distance exchange networks, specialisation of function inside the living area, the invention of improved hunting tools such as spears, bows and arrows and boomerangs, and the design of figurines and representational images (Bar-Yosef, 2002; see also Lewin & Foley, 2004; McBrearty & Brooks, 2000). There are however major differences amongst paleoanthropologists on their view of how cognitive abilities developed over this period, and thus when and where the acquisition of modern human behavioural capacities took place.

Paleoanthropologists may be roughly divided into two schools of thinking. One school proposes that following a gradual development from 200 kya, a rather rapid
change to fully modern human behaviour happened around the transition from Middle to Upper Paleolithic. It used to be widely believed that the arrival of behaviourally modern humans could be dated to between 45 and 35 kya at the beginning of the Upper Paleolithic with an explosion in the complex signs of their presence derived from sites particularly in southwest France and Spain (e.g. Klein, 1992; Mellars, 1998). However, a rival school argued that this position ignored earlier signs of similar activities in Africa. Instead this group proposed a more gradual and slower development over a few tens of thousands of years and possibly from the advent of *Homo sapiens* (Foley, 2005; Henshilwood, D’Errico, Marean, Milo, & Yates, 2001; McBrearty & Brooks, 2000). Thus McBrearty and Brooks took 10 types of behavioural innovation in the Middle Stone Age in Africa, from long-distance exchange to the production of images and dated them from 140 to 50 kya. Moreover, since 2000, the earliest datings of at least two of the ten—the production of images and of beads—have been pushed back to at least 70–75 kya (e.g. Henshilwood et al., 2002, Henshilwood, D’Errico, Vanhaeren, van Niekerk, & Jacobs, 2004).

However, the neo-revolutionary position has not been basically undermined; it may well need only to be refined, as argued for instance by Bar-Yosef (2002), Tattersall (2002) and Klein (see Holden, 2004), for the following reasons:

1. The earlier precursors of modern human signs tended to be much more limited both in their range of characteristics and their geographical isolation. Thus, in Africa, the production of blades, another claimed sign of modern human behaviour, occurs only many millennia after modern human anatomy, except for a few occurrences which are relatively ephemeral and disappear (Foley, 2005). Moreover, African sites which showed early signs of potentially modern behaviour tend to be isolated (Bar-Yosef, 2002, Klein (see Holden, 2004)) and such capacities are not historically stable there but tend to appear and disappear (Deacon & Deacon, 1999).

2. Even if one pushes back individual signs of modern human behaviour “tens of thousands of years” (McBrearty & Brooks, 2000) from 35–45 kya, this still leaves 100,000 years or so with relatively little change by comparison with what occurred later.

3. Without a theory of what constitutes the cognitive underpinnings of “modern human behaviour,” the co-occurrence of many, qualitatively different, such behaviours is more critical than the occurrence of any particular one, such as for instance the use of tools made from bone, now known to have occurred at least 120 kya (Henshilwood et al., 2001). The multiple co-occurrence is unequivocally agreed to occur only in the period 35–45 kya. Moreover, we will argue later in Section 6, based on our own theoretical position, that individual examples of clear-cut modern human behaviour do not occur until or just before this period.

What can one say about the evolutionary development of individual h-capacities? Hominin cognitive development can only be indirectly assessed through the analysis of those few capacities that gave rise to behaviours that left a trace in the paleoanthropological records. The prototypical one is tool technology. These start at the
beginning of the lineage from simple chopping tools made by knocking a few flakes off a small cobble (called mode 1 in a classification originally proposed by Clark, 1968; see also Foley & Lahr, 1997). In the Lower Paleolithic, bifacial flaked hand axes were developed indicating the potential for more extensive conceptualisation and preparation (mode 2). By the Middle Paleolithic our ancestors were able stone flinters using a technique whereby the cores are prepared before the flakes are chipped off; however it is not easy to differentiate the tools into clearly different types (mode 3). In the critical Upper Paleolithic, the technologies do not show a major improvement in stone flinting per se; there is, however, a much greater differentiation and standardization of ‘imposed form’ in the types of tools made (Mellars, 1998), indicating more clearly distinct mental objectives. Moreover, these aspects of so-called mode 4 were often associated with blade production and the presence of bone and composite tools although, as discussed above for bone tools, all aspects of the full package did not always co-occur (see Foley & Lahr, 1997). Mode 4 technologies appeared in Europe and Africa starting around 40 kya. They then spread around the world with the exception of some isolated regions, such as Oceania and parts of South East Asia (Foley & Lahr, 1997) where mode 3 technologies persisted longer.

Considering a second h-capacity, one probable very early sign—the human ability to visually represent aspects of reality—comes from artifacts held to be artificial memory systems, namely objects from the Upper Paleolithic in bone, antler or ivory on which there are sequences of marks (D’Errico et al., 2003). A technological analysis of marks supports the idea that they are memory devices (D’Errico, 1998). Representational images, too, are also found in hominin evolution. Thus recent findings in Southern Africa of hatched lines which have been dated to about 75 kya (Henshilwood et al., 2002) have been interpreted in this way. It is not, however, at all clear what they were intended to represent.

As far as a third capacity—the aesthetic dimension—is concerned, there are recent sporadic findings from the Middle Paleolithic. Perforated shell beads probably used as ornaments have been found in South Africa and dated to 75 kya (Henshilwood et al., 2004). However, it is in the Upper Paleolithic that the widespread and extraordinary development of art happened. Rock art, including well known cave paintings, are found in several locations in the Old World but mainly in Europe, perhaps surviving due to accidents in history and what is preserved (Lewis-Williams, 2002). They achieve a very high quality of representations and of composition as well as an original use of colour and include motion and apparently perspective (Bradshaw, 2005). By contrast evidence of image-making before 35 kya is “very limited” (Lewin & Foley, 2004). Besides painting, our Upper Paleolithic ancestors also developed other aesthetic artifacts. According to D’Errico et al. (2003) “the first unequivocal material evidence for human musical behaviours”—the Isturitz pipes—can be dated to 36 kya. Considering these three individual h-capacities for which we have direct palaeoanthropological evidence, too, the importance of developments at the time of the Upper Palaeolithic or just before, is also supported. Conversely, this evidence supports the association of the attainment of these h-capacities with the transition to modern human behaviour.
Besides the h-capacities just discussed, which have left material signs, palaeontologists have also discussed other characteristics that they consider provide signatures of modern human behaviour (see e.g. Bar-Yosef, 2002). These include greater control of fire, long-distance procurement and exchange of raw materials, scheduling and seasonality in resource exploitation, structural use of domestic space, and the presence of burials with natural objects (McBrearty & Brooks, 2000). However, several of these characteristics can be also attributed to pre-modern humans, notably to Neanderthals, and they thus should not enter into a more restricted definition of h-capacities.

In line with this modified version of the first school of thought, our aim in the rest of this paper is to attempt to identify a mechanism which could explain the emergence of a very varied set of h-capacities in an already evolved brain. Such a mechanism would not only provide possible causes for the transition, but it would also situate it as following a slower but continuous cognitive development in hominins. The next step in identifying the process responsible for the transition is to propose that a critical stage in the development of all h-capacities is the attainment of a key basic human capacity, so-called “abstract projectuality” which we will now characterize in a more precise way.

4. Abstract projectuality

Other animals also engage in complex actions that lead to satisfaction of a need at some future time. This can even involve predominantly innate structures, as in bees and ants, when conscious choice presumably does not occur. At a higher level, animals may use complex routines to achieve specific goals, for instance, in hunting and mothering. At an even higher level, an animal like a gorilla uses highly complex, well-learned routines to achieve a specific goal, such as eating nettle leaves (Byrne, 2003). We call this type of complex behaviour ‘concrete projectuality.’ The animal is generally aiming to achieve a well-learnt objective; given this motivational context, the behaviour is triggered by specific stimuli or by a memory of a closely related event. In doing so it will operate with a limited number of parameters, representing the position of a prey, characteristics of the terrain, and so on.

Humans by contrast, are able to set objectives which do not stem directly from immediate representations of their current perceptual world and motivational systems but imply instead a representation abstracted from immediate reality. Both the goals and the steps taken to realise them need to be specified on the basis of a limited set of pertinent parameters; they determine an abstract space in which operations and objectives are represented. Pertinence is not ‘natural’ but is determined by the process envisaged (Prieto, 1975). The limited number of parameters—as compared to the infinite number of parameters of reality—allows intentional recursive computation to be produced that can be sustained in time, may branch in a variety of subroutines and may use logical or algorithmic operations. In carrying out the project, which the relevant parameters are may need to be reassessed, and even its objectives redefined. To be effective, such a process of reassessment or redefinition


364
would require an extra level of abstraction in which the elements manipulated are metarepresentations of the elements or processes of the preceding stage.

More specifically, we hold a process requiring *abstract projectuality* to have a number of properties:

1. The process can be protracted—potentially very protracted—in time. Moreover, it can be suspended and continued later.
2. It does not need to be triggered by direct sensory stimuli.
3. Mental effort is usually required in establishing, controlling and implementing projects.
4. It aims to attain goals that may be novel or require the production of new strategies and does not consist merely in reproducing an already well-known procedure. In other words, the procedure required cannot be reduced to what Schank (1982) called a ‘memory organisation packet,’ namely a well-learned, routine program such as that we employ when we to go to work each morning.
5. It involves the potential for fluent non-routine thought.
6. It involves abstraction. In other words, it operates with a limited number of pertinent parameters abstracted from reality.
7. In the course of the process, all characteristics may be modified such as which are the pertinent parameters, the level of abstraction, and the procedures used to attain the objective as well as of the objective itself.

Before considering the relation between ‘abstract projectuality’ and the evolution of modern humans in more detail, we will first consider its possible computational basis. This involves three levels of computation, the final level being specifically critical for abstract projectuality and in particular properties 5–7.

5. Computations

5.1. Basic computational elements

In cognitive science one familiar distinction concerning the cognitive system is that between automatic and controlled processes (Shiffrin & Schneider, 1977). We will use the related and more detailed Supervisory System framework of Norman and Shallice (1986) and Shallice and Burgess (1996) and assume that cognitive computations depend on three types of elements. Using a perspective related to that of Fodor (1983), the first type of element are isolable processing systems (or modules). They are assumed to be processing systems dedicated to a specific type of computational operation unavailable to awareness, such as the construction of a 3-D representation of an object in the higher levels of the visual perceptual system. A related, more complex example could be the production of a spatially transformed representation of key aspects of the scene—how it would appear from a different view. Such ‘modules’ differ from more classical views of modules such as that of Fodor (1983) in having a set of control variables \(c(1), c(2), c(3)\ldots\) which represent alternative types
of transformation (e.g., for the more complex example above—rotation, inversion, expansion etc.) and a set of parameters which relate to specific variables (amount of rotation, the specification of what is to be rotated etc.). The outputs can then be transmitted to other modules, held in buffers or be used to activate action systems.

The second type of element are routine action or thought schemas; we will call them r-operations. For each of these, the presence of a set of triggering conditions, including overlearned goals, leads to the activation of the schema and through that, given it wins the lateral inhibitory competition, its selection; if a schema is selected then a group of modules are in turn selected, and their control variables and parameters are set. They are routinely selected to carry out an overlearned cognitive or motor skill. Thus when making a sandwich, the sight of a loaf in a particular position sets the parameters of the categorical spatial operation module (the second example above) which provides information to action-control systems of how it should be rotated by these systems to allow it to be effectively cut (see Cooper, Schwartz, Yule, & Shallice, 2005 for a formal account of r-operations and the processing systems they control).

Modulating these routine operations is the third type of cognitive element, which we call a ‘supervisory’ operation (s-operation); they modulate the effecting of r-operations from above. An s-operation can have as output either a well-learned combination of r-operations, but with these being produced from a novel set of eliciting stimuli, or a novel combination of r-operations. Each s-operation employs a number \( n_i \) of parameters (discrete or continuous variables) which are a subset of the relevant parameters that enter into the project. Effecting an s-operation is assumed to involve two different types of process. The main one—requiring the use of a subsystem localised in dorsolateral prefrontal cortex—comes into play in non-routine situations; it controls the specific top-down modulatory signals, necessary to select and set the control parameters of appropriate lower-level (routine) schemas (r-operations) which the environment does not trigger sufficiently strongly for them to be directly selected online (Miller & Cohen, 2001; Shallice, 2004; Wallis, Anderson, & Miller, 2001). A secondary type of supervisory process, one that sets the first type in motion (Posner & Di Girolamo, 1998), involves a subsystem localised in the anterior cingulate; it can be thought of as the source of “cognitive effort.” On one perspective (Stuss, Shallice, Alexander, & Picton, 1995) the anterior cingulate is the source of cognitive effort per se; on another (Carter et al., 1998) it is a structure which measures implicit response competition to drive the dorsolateral prefrontal cortex to the same end.

Schematically speaking, an r-operation is one that, given an appropriate motivational state, can be triggered by overlearned environmental stimuli (or a short-term memory of them) and/or a higher-level r-operation or by an s-operation (see Cooper & Shallice, 2000). r-Operations can also give rise to an action or, through lower-level r-operations a cascade of related actions. An s-operation, by contrast, arises given a non-routine combination of a goal and a particular environment. It is designed to produce more adequate behaviour, which can result from prior pre-planning, by problem-solving or most basically by a direct constraint-satisfaction procedure (Shallice & Burgess, 1996). Effecting an s-operation corresponds phenomenologically to the carrying out of a strategy or working according to a rule (Dehaene & Changeux, 1991).
It is typically necessary whenever the controlling system is required to abstract from the environmental situation and from the history of its own previous attempts to attain the same goal (Shallice & Burgess, 1996). Thus such a supervisory operation contains the kernel of the potential to carry out meta-level operations. To give a concrete example, in a game of chess, for instance, an s-operation will be required in responding to a non-routine combination of threats (see Saariluoma, 1995 for a relevant deep theoretical discussion using a different but compatible conceptual framework). In addition it will be required for higher-level operations which do not reduce to a routine computation of moves within a playing strategy as, for instance, whether to exchange pieces into an end game (strategic or tactical planning of the player). For a discussion of the content of s-operations and how they can be interpretable within a symbolic representative framework (see Perner, 2003).

The operation of a single s-operation, or of disconnected sets of s-operations, together with the r-operations to which they give rise we will call a type I process. It comes into play as a result of the motivational and cognitive activation of a goal, which for a type I computation already needs to be well learned, given the environmental and motivational situations. Type I s-operations have an output which can be quite complex, corresponding to those of certain types produced by higher mammals which have prefrontal cortex. Such actions are determined by a strategy, which can be replaced later by another, but only if a relevant change in the environment should occur. The hunting behaviour of lions would be an example of behaviour realised by type I functioning.

It should be noted that the arguments to come later concerning more complex computational processes are not entirely dependent on the particular computational framework developed so far. Certain other conceptual frameworks could be employed, particularly those based on production systems (Newell & Simon, 1972), such as the ACT-R theory of Anderson et al. (2004). On this approach, certain operations depend upon the existence of representations in a particular higher-level control buffer—the ‘goal buffer’ in the ACT-R case. An s-operation would correspond to operations in this framework where the representations in the buffer themselves arise from the execution of a previous production. Within an AI production system framework a lower bound of the number of relevant parameters for the operation would be the number of active elements involved in the working memory states at input and output to the operation (e.g. Duncan, 2001).

Let us now add a new type of process, a prospective memory, that can store interim products or potential outputs of an s-operation, which cannot be immediately realised while other operations are taking place. The stored memory may then be reactivated when other later stimuli occur. For this to be possible a procedure is required for setting up a specific operation to occur at an open-ended time later when particular environmental contingencies occur. Thus when an early human has seen a stone suitable to be made into a flint, the stone may be picked up even if it will be some time before flinting can occur. This use of a prospective memory to defer completion of an s-operation to a later, more appropriate, time allows the setting up and realising of intentions. To be more concrete, to fully effect an s-operation, specific r-operations will be needed which themselves may require particular environmental
situations. If the requirements for the subsequent r-operation are not currently available, then a goal needs to be generated which is open-ended (open-ended goal-setting). This will have the effect that if and when the appropriate environmental contingencies occur and the r-operations can be realised, then the previously suspended s-operation is completed. Afterwards the original operation can be re-under-taken successfully. Such processes may be available to animals other than Homo sapiens having frontopolar cortex, including apes and hominids (see Byrne, 1998 for relevant discussion). If in addition, the goals are open-ended, not restricted to a specific situation but more abstractly defined, then supervisory operations would acquire a limited capacity to tackle what the AI theorist, Newell (1990) called ‘im-passes.’ With what we will call type II computational processes, it is then possible to organise non-routine processes over extended periods of time.

5.2. Latching and sustained multi-level processing

We now introduce an essential further process, we shall call latching; this process produces a continuing sequence of s-operations. We will introduce latching by means of an example that is derived from a neuropsychological test that one of us helped to develop. We will then characterise its properties and analyse the overall process that repeated latchings allow.

The test—the Hayling test (Burgess & Shallice, 1996)—aimed to investigate in the verbal realm certain of the key set-switching processes involved in a well-known non-verbal test-, Wisconsin Card-Sorting (Milner, 1963). The Hayling test assessed whether patients can avoid producing a strongly elicited verbal continuation. Subjects have to complete a series of sentence frames such as ‘The ship sank very close to the...’ with a word that is unrelated to any of the words in the sentence or to its natural completion. What was surprisingly found was that normal subjects frequently and rapidly learn to avoid the inherent difficulty of the task, that of inhibiting the natural completion e.g. coast, by using the strategy of thinking of a possible response before the sentence is produced. For instance, a commonly used strategy is to select an object in the room, and then simply to check when the sentence frame is presented that the word thought of does not by chance relate to the sentence frame. If it does the operation is repeated. Fifty percent of 12-year-old children can achieve this type of strategy in a few trials (Shallice et al., 2002); adult patients with prefrontal lesions tend to have a great difficulty in so doing (Burgess & Shallice, 1996).

Fig. 1 illustrates how latching operates in this specific situation. It represents the processes involved in responding to the last sentence frame (j) before the strategy is developed and to the subsequent sentence (j + 1) in which it is developed; for simplicity it is assumed that the full strategy is developed in one trial. Up to the jth sentence the subject hears the sentence frame. r-Operations R1 are then used to comprehend the sentence and make available information {b} on the set of ‘forbidden’ words to later processes. Then the subject attempts to generate words (a), but because of the influence of the sentence frame, most words produced clash with the requirements of the task. This strategy is represented in the figure by S1 with each attempt (a) being compared with forbidden words {b}, in a checking process labelled C which returns
the words to S1 marked as unsuitable or suitable. Occasionally a word (say, $a_3$) is produced which satisfies the checking process and is then reported using $r$-operations $R_2$. Overall, from the subject's perspective, S1 is unsatisfactory, being highly effortful and error-prone. After a number of such trials a new strategy, S2, described above, is produced, latched from S1; it results in a satisfactory output as realised again by $R_2$.

**Fig. 2** represents this processes of latching in the specific example. To improve, the subject must first generalise that the words that tend naturally to come to mind are in conflict with the task requirements. Then, the subject must create the abstract goal ($G$) to avoid this situation; $G$ is an example of an open-ended goal-setting operation of the type discussed in Section 5.1, with the addition that its satisfaction can involve a new $s$-operation; it is a necessary ingredient of latching. Then the subject must
realise that a word must be produced independently of the sentence frame, most naturally by doing so before they hear the sentence frame (TP1). He or she must also create a concrete method for doing this such as using the names of objects in the room (see Shallice & Burgess, 1996) (TP2). Finally he or she must realise that a somewhat more complex concrete procedure (S2), which becomes the final effective strategy, is necessary: the word produced must be checked against the sentence frame and if necessary the operation TP2 repeated. The final strategy, S2, is then kept in a prospective memory, P, to be used for processing subsequent sentence frames.

We introduce here the concept of transitional procedures (TP), namely potential operations which may themselves not be viable, as they are building blocks for the later effective strategy; they are therefore not necessarily available to be reactivated through prospective memory in future. The empirical evidence does not enable one to determine the ordering of each of the TP suboperations; thus it is conceivable that the presence of a salient object in the room could lead to TP2 directly following G for a particular subject and only then lead to TP1. However, each of the operations is non-routine, and critically, the processes that succeed S1 must occur in a fluent sequence to be effective. The intermediate steps must remain in a form of working memory; they need never become stabilised in a procedural or semantic memory before the next non-routine step is taken. On the current framework, the whole process in which strategy S1 gives rise to strategy S2, is what we call latching (generalising a concept developed by Treves (2005) in a model of syntactic production (see also Kropff & Treves, in press)).

We have discussed a specific example, but in general, latching is held to come in different forms. An s-operation can directly give rise just to a single other s-operation, namely propagation, as in the example. Alternatively an s-operation can give rise to a second s-operation and at the same time leave a prospective memory; this we call branching. Finally the elicitation of an s-operation may depend on the output of another s-operation and a prospective memory of the output of an earlier s-operation, namely coalescence. As discussed in the example, latching can include the generation of temporary open-ended goals and of transitional procedures, and typically takes only a short period of time, comparable to the duration of working memory. In a later section we provide a possible mechanism for latching. Any process involving latching we call a type III computation. If it involves a succession of latchings,
especially when branching and coalescence are involved, then this will allow a complex computational structure.

We will now show that type III computations give rise to the properties required for abstract projectuality, as discussed in Section 4. Like all computations that involve s-operations their purpose is to allow the confronting of novelty (property 4), and they require effort (property 3). A succession of s-operations and the use of prospective memory allows the processes to be protracted—indeed potentially very protracted—in time (property 1). More specifically, while in a type II computation, the specific goal-setting requires long-term memory processes, so that the elicitation of supervisory operations remains staccato, with each separated in time from any preceding s-operation. In a type II computation, a redefinition of the goal and the occurrence of a potential solution can occur close together in time. Type III computations would thus allow the potential for fluent non-routine thought (property 5) (see Mithen, 1996). Moreover, since one s-operation directly elicits another, it does not need to be triggered by direct sensory stimuli (property 2).

The standard human capacity of modifying or adapting the current strategy to pursue a goal is allowed by type III computations. Thus the successor s-operation will often involve a different set of relevant parameters from the preceding s-operation (property 7). So, operation TP1 in the example given above relates to the ordering of two abstract items in a sequence. Yet the output of operation TP2 relates to objects in a room; therefore the parameters involved in TP2 must relate to the representation of objects in the visual scene, and have a quite different set of dimensions. Similarly the level of abstraction can change. Thus in the example shown in Fig. 2, the output of TP1 is an ordering of abstract states. This is concretely realised for some subjects by a procedure (TP2) based on visual perception and naming as illustrated in Fig. 2. The former is more abstract than the latter. While the concrete example given does not include modification of the overall goal, it clearly includes subgoal generation and modification of the overall goal could occur if such an operation leads to a related goal which is assessed to be more attractive.

Of the properties of abstract projectuality, this leaves the relation between latching and property 6 to be elucidated, namely why abstraction should be required. To justify that one needs to consider the working memory which s-operations use. Consider again the example shown in Fig. 2. The critical step is that realised in operation TP1 which can be summarised as effecting:

\[
\text{Time Order}(e, f) \rightarrow \text{Time Order}(f, e)
\]

The two variables, \(e\) (the sentence frame) and \(f\) (the putative solution word), need to be represented only as tokens in a discrete single-dimension space. Thus the process can be a very low-dimensional one.

Now, selection of s-operations must require a working memory. Assume, following Duncan (2001) in his theorising on dorsolateral prefrontal cortex, that the working memory used is analogous in its contents to that for the AI program SOAR (Newell, 1990), in which all relevant variables and operations are stored. Then for the sequence to be effected by latching S1 \(\rightarrow\) S2, the working memory would need to contain representations of the meaning of the sentence frame, of the episodic
memory records of the processing of previous sentences, of the meaning of the task instructions and of the perceptual lay-out of the room. If these representations were not stored in the working memory then it would not be possible for them to be called upon by the s-operations that require them. Thus, if an additional operation must also be carried out using the working memory, such as the temporal inversion one represented by the formula above, then it must make low storage demands or the working memory would be overloaded. This implies that the representation needs to have few features and be of low dimensionality, namely be abstract (see Jones, 1985). Indeed given the different types of material that have to be simultaneously stored in the working memory, then all will probably need to employ reduced descriptions of lower dimensionality rather than their full concrete form; that is, there would need to be more abstract representations than those available to the perceptual system. This then corresponds to property 6 of abstract projectuality.

Type III computations allow the potential for a complex intertwining of s-operations and prospective memories, as must exist in any really complex human project. The organisation of such a structure cannot be given by local latching operations alone without representations that correspond to more global properties of the whole structure. Thus to handle efficiently the alternatives that the capacity for latching provides—as humans are able to do—metarepresentations of sets of type III computations would be required on a hierarchy of abstract levels of operation.

In this section we have argued that type III computations possess all the properties assigned to abstract projectuality in Section 3. They allow the potential for fluent, non-routine, abstract thought which is required for most problem-solving and chains of induction or deduction. They can be realised in language, but also in non-verbal realms such as painting, tool construction of game-playing and indeed would be required in all h-capacities. Thus latching would represent in our view the basic new computational element that allows sustained non-routine multi-level operations, giving rise to the emergence of modern humans.

6. From type III computations to the paleoanthropological evidence

How would the properties of type III computations relate to the paleoanthropological evidence discussed in Section 3? As discussed there, stone tools have an origin much older than the Upper Palaeolithic. From the perspective of Mellars (1998), it is problematic to categorise or classify Middle Palaeolithic stone tools into clearly separate “types” (but see Marks, Hietala, & Williams, 2001, for a contrary view) or discrete morphological forms. Upper Palaeolithic tools, by contrast, show a much more sharply defined standardization into a larger set of different tools (see Lewin & Foley, 2004). This transition can occur through a type III insightful computation driven by a clear idea of how to fulfil specific tool objective. Thus an axe needs to become more than a cutting stone with a handle. The relation among the weight of the stone, the length of the handle and their relative positioning needs to be optimised with respect to how to prolong the arm into a hard cutting device using muscular strength.
However, a long sequence of type I and type II computations would also seem a possibility. Practiced flint makers could by a set of type I computations realise that flints differ in their effectiveness for cutting. They would then by further type I operations be able to understand that flat surfaces and narrow edges would be more effective. They would form a type II intention to realise this in practice, and then by a mixture of type I steps followed by later creation of type II subgoals, possibly aided by connectionist learning of the input–output mappings of each new production step, they would eventually arrive at an overlearned blade construction procedure. This procedure requires that each new stage is a small improvement on what went before. Moreover, the design progresses could progress by one step a generation or less, so that all but one step was routine for the designer of the next.

The hand axe involves optimising three main variables. But consider the so-called Isturitz pipes of which about 20 specimens exist from the Upper Palaeolithic. In a detailed analysis, D’Errico et al. (2003) argue that they were played by insertion into the mouth probably with the addition of a vibrating reed. They argue for the necessity of a further set of critical details in the development of the pipes, including use of a standard raw material—vulture ulna—of the bevelling of the finger holes, of clockwise rotation of the holes by 5–15° from the pipe’s axis, which in some mouth positions allows a pressure-seal to be maintained with less effort, and in some of the presence of two pairs of finger holes. Given the complex relations between the characteristics of the finished object, the skill of the player and the sound achieved it becomes less plausible to see the history of its production as merely the incremental adjustment of a fairly inflexible program instead of requiring one or more stages where fluent insightful thought restructures the achievement of a set of complex goals.

Another example of moving between different domains of thought is given by Lewin and Foley (2004). They discuss Solutrean laurel leaf blades produced so thin that they would no longer be useful for their basic purpose. Instead it is suggested that they are designed for a ritual purpose or to demonstrate the effectiveness of the craftsmen’s ability (Foley et al., in press). This shows the designer’s ability to move from one domain of operations—tool construction—to another, a social one. This ability to conceive of an object within the contexts of two separate goals transcends type II operations; indeed the inability to move between conceiving of something within two different conceptual frameworks has been argued by Goel and Grafman (2000) to be a prefrontal characteristic.

Or take cave painting itself. Even Picasso is reported as being astounded by the technical mastery required to produce some of the Lascaux cave paintings (Beltran, 1999). In cave paintings salient parts tend to be exaggerated by comparison with their real size (Lewis-Williams, 2002), so in no sense is the product just that of copying off an image. Instead, producing such a painting must involve a series of complex choices in which the artist realises different parts of a complex whole involving colour and representations of movement and perspective (Bradshaw, 2005; Chauvet, Deschamps, & Hillaire, 1996), and in which each new part must be related to other parts taking into account both the structure of the rock (see, e.g. Lewis-Williams, 2002), only visible from barely adequate illumination, and the emotional and aesthetic impact of what could be produced. Moreover, the individual figures may be
placed aesthetically as part of a complex arrangement (Delporte, 1995). Again, the overall goal has to be realised by a complex set of non-routine fluent choices, moving between different cognitive domains. Type I and II operations alone would be insufficient.

7. The brain bases of different types of computation

Are the computational assumptions made so far empirically plausible given what is known from cognitive neuroscience? In particular, is there support for the distinctions made between type I, type II and type III computations and between those and ones just involving r-operations. If one conceives of coping with novelty as requiring a set of Supervisory System subprocesses, three have been held to be critically involved in type II and III computations—novel strategy generation, the setting up and realising of prospective memories and open-ended goal-setting. In addition, checking operations are required in the processes leading up to open-ended goal-setting but are not critically involved in latching per se. As we shall discuss, part of the evidence for the existence of specific mechanisms underlying such processes is that they localise specifically in the brain.

s-Operations, the core element of type I computations, which are already present in higher mammals, require the dorsolateral prefrontal cortex. That this region is involved in top-down strategic modulation of lower-level structures is shown in many studies. These involve cellular recording in the behaving animal (e.g. Wallis & Miller, 2003), lesion studies in animals (Petrides, 1994), functional imaging (e.g. Frith, 2000; Rowe, Toni, Josephs, Frackowiak, & Passingham, 2000). Neuropsychological evidence also shows that the same structures are involved in novel strategy generation in type III (e.g. Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Reverberi, Lavaroni, Gigli, Skrap, & Shallice, 2005). Moreover, in humans the left dorsolateral prefrontal cortex is more important for these processes than is the right (Fletcher & Henson, 2001; Shallice, 2004).

The systems involved in prospective memory (the setting up, holding and realising of intentions), the key elements of type II processes, are present in a more restricted range of animals. Two very different lines of evidence suggest that prospective memory depends upon the lateral frontopolar region, in so-called Brodmann area 10 (BA 10), which has been little studied in animals. First, patients with lesions in this region do not carry out long-term projects. Lesions in BA10 lead to an inability to set up, hold or realise intentions (Burgess, Veitch, de Lacy, & Shallice, 2000; Shallice & Burgess, 1991 (see also Shallice, 2004)). Second, imaging studies show that activation of structures in the lateral part of BA10 occurs when an active prospective memory is being held, i.e. information which may itself initiate a future s-operation, and is not just a passive episodic memory trace on which a future s-operation may be carried out (Burgess, Quayle, & Frith, 2001; Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999; Koechlin, Ody, & Kouneicher, 2003). A recent model—that of Koechlin et al. (2003)—suggests that lateral BA10 directly modulates top-down dorsolateral prefrontal cortex as required on our approach. A third subprocess essential for
latching—open-ended goal generation—has also been held to involve prefrontal cortex (Duncan, 1986) but less is known about its more specific localisation.

It should be noted that other structures used in r-operations have also evolved from the ape to the modern human brain. The first law of the organisation of the cortex is that its many different regions each carry out qualitatively very different functions despite no gross differences in morphology. In the monkey and even the ape there is some lateralisation of function (see e.g. Poremba et al., 2004) but it is not that major. In the human, not only are many language functions at least partially lateralised but so is the high-level organisation of action production (De Renzi & Lucchelli, 1988; Liepmann, 1908), certain prefrontal functions (Fletcher & Henson, 2001; Shallice, 2004) and even perceptual ones (Warrington & Taylor, 1978). The new computational possibilities opened up by this gross reorganisation of the cortex due to lateralisation allows many systems to be present in the human brain but not in the ape. Examples would include other aspects of language processing in addition to syntax: a specialised system (in what is normally assumed to be Wernicke’s region) for categorising phonological inputs as familiar learned words, a posterior perisylvian system for holding phonological information to enable new word-forms to be imitated and transmission routes from input phonological to semantic systems (Scott & Johnsrude, 2003), an acoustic-to-articulatory transfer process (Hickok & Poeppel, 2004; Wise et al., 2001) and yet other processes in speech production (Corballis, 2004).

Systems involved in specific types of r-operations which are found in humans and not in apes are unlikely to be limited to language. Thus specific systems have evolved for skilled actions involving use of tools or other artefacts—as in cutting meat with a table knife, or even with a flint (Johnson-Frey, 2004). At least two and possibly three different types of processes are involved. One underpins what is called “naive physics” and more specifically the processes which encapsulate our knowledge of the local mechanical and geometrical interactions between the body and elementary tools in use. We know from the study of apraxia that a critical set of these systems are localised in the left parietal cortex; patients with lesions there have great difficulty in selecting physically appropriate novel tools (Goldenberg & Hagmann, 1998). A second is the facility required to implement the subroutine organisation of the schemas controlling motor skills such as those involved in tool use, where the representations of the tools and their parts need to be considered as “arguments” at one level of the schema hierarchy (Rumiati, Zanini, Vorano, & Shallice, 2001; Schwartz, Reed, Montgomery, Palmer, & Mayer, 1991). Nor are the specific lower-level systems that are newly evolved in humans likely to be limited to language and tool use. Consider those involved in appreciation of music, which Peretz (2001) has argued involve a specialised modularly organised system.

All these systems for specific types of r-operations would have evolved with the increase in the size of the cortex during the couple of million years of hominid evolution. Together with single-shot Type I non-latched s-operations and later Type II potential they could give rise to the development of cognitive protocapacities. Some of these, such as flint knapping and early tool technologies, are recognisable on palaeontological grounds. Others, like possible protolanguages can only be speculatively inferred.
Could these later systems which facilitate particular types of r-operations be present only in modern human? The fact that each such system is only required in a subset of our cognitive capacities makes this implausible. It would require that a set of unrelated processes in different parts of the brain evolved together in a very short time. It is more plausible that our basic functional architecture, along with lateralization of function, was already present in earlier humans such as *Homo erectus* despite their lack of modern human cognitive capacities.

To summarize, we have identified brain structures which are most relevant for operations central to type I and II processes. We have not identified, however, any new brain system for creating latching and therefore for type III computations, the hypothetical basis of modern human projectuality. This is in accordance with the belief of anthropologists that no qualitative change in the brain of anatomically modern humans occurred in the transition to fully modern behaviour (Tattersall, 2002). How might the transition have occurred?

8. The transition

We have identified in latching between s-operations the basic mechanism that gives rise (at the psychological level) to the indefinitely sustained character of fluent multilevel cognitive operations required by abstract projectuality and thus, from this prospective, to the emergence of human cognitive capacities. This requires that a novel process comes into operation which does not entail the appearance of a new brain structure and yet could have occurred in a short period apparently unrelated to speciation.

One attractive possibility is that latching could be the result of a phase transition in a *Homo sapiens* brain already prepared in the long process of hominid evolution by having the complex circuitry characterised by type II computational capacity. The complex circuitry must already involve a large set of connections within and between the brain structures just discussed. A large increase in the number of synapses in the brain in the later stages of the evolutionary chain has recently been observed and we shall discuss this later in some detail. In the proposed mechanism that we conjecture, it is a limited continuous increase in the (albeit complex) connectivity that gives rise to the sudden appearance of a new possibility—latching in this case—that produces new long-range correlations (type III processes) as typical in phase transitions.

This conjecture is supported by a simplified physical model, which allows both analytic studies and computational simulations. This has been proposed and analysed in a parallel paper by Treves (2005): it uses, as a simplification of an attractor neural network, a (Potts) model having a very large number of units each having a number of different states (say a variety of colours). If the number of connections (connectivity) between units is large (despite their still being relatively sparse), a large number of attractors (memories)—different excitation patterns corresponding to different inputs—may be stored. A particular input gives rise to its excitation pattern (make the system fall into an attractor) that subsequently decays with an exponential function—characterised by an attenuation time—leaving the system ready to
respond to a new input with its corresponding excitation pattern. The analysis of the model in question shows that if the connectivity increases beyond a critical value, “latching” appears: before it decays far, the excitation pattern created by an input stimulus gives rise to a new pattern that then gives rise to a third one, and so on. Overall attenuation is lost: the exponential decay of a single pattern is suddenly transformed into a slowly decreasing chain of excitation patterns, even in the absence of further stimuli.

The model which suggests the phase transition is based on a simplification of attractor neural networks. Properties of dorsolateral prefrontal cortex, a key structure for s-operations, have already been modelled effectively using attractor networks (Gutkin, Laing, Colby, Chow, & Ermentrout, 2001; Gutkin & Smith, 2000) although no attempt has been made to simulate latching properties in models of this structure. By itself the Treves model does not show that the series of excitation patterns can realise a rational sequence of fluent s-operations. However, it does demonstrate that a transition from non-fluent to fluent output could correspond to a phase transition. Thus it indicates that latching could reproduce property 5 of abstract projectuality.

The phase transition conjecture has so far found theoretical support in that the latching concept—discussed in Section 5.2—emerges from a specific connectionist model. Is there also evidence to support the hypothesis of an increase in brain connectivity which we have argued is theoretically critical for latching to occur? Also, if so, how does it relate to the structures held to be involved in type I and type II computational processes that we suggested to be found in our predecessors? These issues are considered in the section that follows.

9. Brain connectivity and the transition to latching

What material changes could underlie the transition to latching? The complex circuitry of mammalian neocortex is the consequence of a highly coordinated process involving, successively, the generation and differentiation of neurons, axon navigations and branchings that constitute the topographical charts of the different cortical areas and, finally, the establishment of synaptic contacts (Bourgeois, 2001). The first two processes are genetically determined and controlled by a large variety of genes even if subject to neuro-modulatory effects. The number of claimed cortical areas (as well as their specializations) increases considerably in evolution. Thus in one approach they are estimated to go from 21 for rats, to around 40 for cats, to 72 for macaques and up to around 200 for man (Bourgeois, 1997). Moreover, the active synaptogenesis period expands in animal phylogenesis; even in the primary visual cortex it increases from 14 post-conception days in rats, to 30 in cats, 136 in macaques and 470 in humans. In this period as well as in a subsequent one, in which the density of synapses in cortical tissue does not increase on average (a period that in humans extends up to puberty (Huttenlocher & Dabholkar, 1997)), the neuro-synaptic network is very plastic allowing basic sensorial, motor and cognitive learning to occur which is specific to the individual. This long plastic period allows epigenetic
influences to become more relevant for the synapto-architecture. Moreover, the proportion of brain volume that consists of long-distance “white matter” connections is much increased in humans. Thus in a small insectivore white matter is less than 10% of the volume of the neocortex, but in humans it is 42% of the combined volume (Frahm, Stephan, & Stephan, 1982).

These are general considerations concerning the cortex as a whole. What can one say of the regions we have considered to be specifically concerned with s-operations and prospective memory, i.e. the dorsolateral prefrontal cortex and the lateral frontopolar cortex (BA 10) as discussed in an earlier section? The active synaptogenesis process lasts for much longer in prefrontal cortex than in, say, visual cortex. Thus the lateral prefrontal cortex (along with the temporal–occipital junction, potentially critical in tool use) is the major brain region to show growth between the adolescent and the adult (Sowell, Thompson, Tessner, & Toga, 2001). Moreover, this is occurring with a reduction in grey matter, suggesting increased proportions of white matter connections. Turning to the fronto-polar cortex (BA 10), Semendeferi, Armstrong, Schleicher, Zilles, and Van Hoesen (2001) have shown that this area is proportionally much larger in the human than in the ape. They also show that in humans the proportion of cell bodies in this region is relatively less compared with the ape. They therefore infer that white matter connectivity of individual pyramidal cells in this region is much increased in the human.

Thus regions which for other reasons are relevant for the computations underlying abstract projectuality are indeed ones where there is good evidence of major increases of connectivity between the ape and human and, as important, this also occurs relatively late in child development. This implies that extra-somatic influences could add to the genetic ones in enabling the critical connectivity to be reached; those that add efficiently would tend to become strongly incorporated into the developmental process due to the extraordinary cognitive advantage they provide to communities which adopt them. Their acquisition gives a scent of sinless Lamarckianism! Naturally the time scale of the transition at the global level (its degree of suddenness) appears to be related to the spread of social influences.

A paradigmatic example is child raising: human piloting of the development of their offspring goes far beyond care, orienting of instinctive tendencies or learning by imitation, as present in animals. The complex human parent–filial relationship provides many types of stimulation to a child’s development and transmits a subtle but strong combination of ethical, moral, cognitive and behavioural codes (Csibra & Gergely, 2006; Moreno, 2002).

The role of extrasomatic influences on connectivity fits well with the timing of human emergence. Human groups first showed extensive signs of becoming sedentary in the Middle Stone Age, when major population expansion also occurs (Ingman et al., 2000; Lewin & Foley, 2004; Rogers & Harpending, 1992). This would allow longer and more systematic child rearing. On the above argument this would lead to greater connectivity in key brain structures and so greater possibility for the development of abstract projectuality.

It should be pointed out that the existence of a mechanism to produce the transition to latching does not imply the exclusion of other concomitant circumstances,
epigenetic or even genetic, that may have influenced connectivity. It has, for instance, been recently found that a genetic variant of microcephalin—a gene that influences brain development and size—arose around 37 kya and spread under strong positive selection (Evans et al., 2005). This could represent a genetic factor contributing to brain plasticity through an allele being positively selected, when greater connectivity became critically important due to the potential transition to latching.

10. Conclusion

The argument presented in this paper operates on five levels. First, we claim that human emergence depends upon a new capacity—abstract projectuality—instrumental to all the extraordinary cognitive capacities that characterise modern humans. Second, this depends upon the development of qualitatively new types of brain computational capabilities (we call latching), and in particular the potential for branching and coalescing, that are basic for the possibility of sub-routine structure of novel operations and give rise (at the cognitive level) to the capacity for sustained multi-level operations. Third, we claim that this evolutionary development depends on processing in particular parts of the prefrontal cortex. Fourth, a continuous increase in relevant neural parameters, in particular connectivity, may have produced a phase transition giving rise to latching without qualitative changes in the underlying functional architecture. Finally, we argue that the change in connectivity is itself subject to epigenetic influences, including socialisation and child raising.

Theorists have produced somewhat related speculations on each of these levels. At the first level many cognitive scientists assume that language—or at least some aspect of language processing—was the original modern human capacity and that the abstract organization and the communication systems it allows generated the other h-capacities. In our framework, all h-capacities have a common causal root—the processing aspects of abstract projectuality defined in Section 4. The existence of a novel mode of processing is not however equivalent to its concrete realisation in the social context of early modern humans. Undoubtedly, the powerful communication between individuals that language allows could have played a major role in the epidemic of new h-capacities that occurred. From an alternative point of view, Sperber (2000) has argued that the ability to produce metarepresentations was a precursor to modern language abilities rather than being dependent upon them. We recognised in Section 5.2 the key role of metarepresentations in the multiple level structure that can arise from the type III computational processes resulting from latching. Again at the first level, it has also been argued in the literature on human thought processes that there are two types of intelligence—intelligence A and intelligence B—and that human emergence depends upon the evolution of intelligence B (Stanovich & West, 2003). Intelligence B could correspond to the product of type III computations. Even more closely, Mithen (1996) has argued with considerable paleoanthropological evidence that ‘cognitive fluidity’ is the critical step, again clearly analogous to the product of type III computations.
Our second level arguments about a novel computational capacity—that for sustained multi-level operations allowed by latching—has a resemblance to that of Hauser et al., 2002. They see the basic human capacity as (potentially infinite) recursion, the ability of an operation to “call” another operation of the same type. They have argued that this is required in the evolution of a number of critically human skills, including but not limited to language. Moreover, the way that the products of two s-operations can coalesce in the operation of another has considerable similarities with the basic “minimalist” concept of *merge* in modern linguistics.

If one turns to the third level, the relevant brain mechanism, Semendeferi et al. (2001) argue that the fronto-polar cortex is a crucial structure for human emergence. At level 4 Coolidge and Wynn (2005) have speculated that increase in the capacity of Baddeley and Hitch’s (1974) executive working memory, itself related to the Supervisory System concept (see Baddeley, 1986), lies at the basis of the transition to modern human thought. Besides speculations on mutations (Coolidge & Wynn, 2005; Corballis, 2004), the only theorist who to our knowledge proposes micro-level changes that may underlie human emergence is Bourgeois (1997). He proposed a heterochronic epigenetic hypothesis of a strong evolutionary increase in the number and duration of synaptic molecular interactions in humans, which would slow down synaptogenesis and thus give time to establish recursive processes that would allow more interactions between neurons. The goal underlying this hypothesis is similar to the current one. However, the postulated mechanism is quite different. He conjectures time delay at the molecular neuro-synaptic level to allow more temporally protracted higher-level operations. In our case there is no drastic difference to be invoked at the micro level: recursive and time sustained brain operations are generated by a transition in the global behaviour of cortical circuits (corresponding to a reduction in attenuation) without their having a specific molecular or structural origin. Nature is full of drastic and rather sudden macro-changes without sudden drastic micro-changes. Moreover, the phase transition view has the character of suddenness (on the evolutionary scale) and coherence in different characteristics that human emergence suggests.

The language of phase transitions of physics may be unusual to scientists more accustomed to continuous transformation processes. Evolutionary biologists are however familiar with rather rapid and unforeseen transformations in organs or structures that were prepared by natural selection for a different function. This is called exaptation, a concept that has indeed been invoked for human emergence (Tattersall, 2002). The transition we propose may indeed be considered as a concrete mechanism for exaptation. It should be noticed that without a mechanism to show how a new function arises from a structure prepared for other reasons exaptation may itself appear to be magic.

At the fifth level the argument that the neural changes are dependent upon processes that occur well after birth and are affected by many cultural and child-rearing factors is a widely held view. That the strong evolutionary increase in brain connectivity from rats to hominids becomes a crescendo due to epigenetic influences, and so opens to the environment the genetic envelope is an idea strongly advocated by Changeux (1983).
The crucial novelty of our position is to assign to a new computational process (sustained non-routine multi-level operations) the emergence of all typically human cognitive properties. Proposing, furthermore, a brain operation (latching) that allowed the novel computational process, together with a mechanism that may use the conjunction of genetic and extrasomatic (social) influences to explain the rather recent emergence of latching without invoking unlikely structural changes.

Acknowledgement

We thank John Morton for his extensive and insightful comments on an earlier version of this paper.

References


