

The slow process: A hypothetical cognitive adaptation for distributed cognitive networks

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Abstract

Human cognitive evolution is characterized by two special features that are truly novel in the primate line. The first is the emergence of “mindsharing” cultures that perform cooperative cognitive work, and serve as distributed cognitive networks. The second is the emergence of a brain that is specifically adapted for functioning within those distributed networks, and cannot realize its design potential without them.

This paper proposes a hypothetical neural process at the core of this brain adaptation, called the “slow process”. It enables the human brain to comprehend social events of much longer duration and complexity than those that characterize primate social life. It runs in the background of human cognitive life, with the faster moving sensorimotor interface running in the foreground. Most mammals can integrate events in the shorter time zone that corresponds to working memory. However, very few can comprehend complex events that extend over several hours (for example, a game or conversation) in what may be called the “intermediate” time zone. Adult humans typically live, plan, and imagine their lives in this time range, which seems to exceed the capabilities of our closest relatives, bonobos and chimpanzees.

In summary, human cognition has both an individual and a collective dimension. Individual brains and minds function within cognitive-cultural networks, or CCNs, that store and transmit knowledge. The human brain relies on cultural input even to develop the basic cognitive capacities needed to gain access to that knowledge in the first place. The postulated slow process is a top-down executive capacity that evolved specifically to manage the cultural connection, and handle the cognitive demands imposed by increasingly complex distributed systems.

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1. Introduction

Human evolution is marked by the emergence of a special kind of social-cognitive process, unique to hominids: distributed cognition, performed in mindsharing cultures. Human social groups are more cognitively complex than others, but at the time of our emergence as a species, human social groups were not necessarily larger in population than their predecessors. The increased complexity of their cognitive system was inherent, not so much in group

size, but in the nature of the cooperative, interactive social-cognitive processes that apparently characterized species *Homo* from the outset.

Cooperative cognitive work emerged as groups of archaic hominids became more interactive and interdependent in their cognitive activities and operational rules. This included the transmission of tool-making and tool-using skills by imitation, cooperative hunting and migration, group firetending, and the construction of communal shelters. All these innovations required a degree of interpersonal coordination and communicative skill. The evolutionary trajectory of hominids was one of increasingly shared cognitive work – group decision-making, transmission of skill, sharing of knowledge, and division of

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cognitive labor. This trend led toward complex distributed social systems, which also served as the means to achieve distributed cognitive work. This led eventually to full language and symbolic thought.

In effect, the major evolutionary transformation of early humans was due to the emergence of distributed cognition. The prehistory of human cognition was thus a cultural scenario: Major cognitive change was most evident at the group level, in the improved coordination of effort, by which ancient humans were better able to achieve their cognitive goals.

Although the emergence of mindsharing and distributed cognition may have been the most dramatic change marking human emergence, it remains true that these changes at the group level required corresponding evolutionary changes in the brain itself. Brain and culture were co-evolving in a symbiosis, whereby natural selection was evidently favoring those with more socially adept brains. At the same time, human culture was being transformed into a flexible and powerful storehouse of the information needed to shape the social brain in epigenesis. The evolving hominid brain became increasingly dependent on cultural guidance for its full development, to the point where, in biologically modern humans, the brain cannot realize its design potential outside of culture. In effect, we have brains designed to function optimally in a distributed network, with the network transmitting vital epigenetic information to the developing brain.

The latter was a critical evolutionary step. Human culture defines much about the human brain, especially the so-called “higher order” features of mind that are crucial to sharing mind. The human brain does not acquire language, symbolic skills, or any form of symbolic cognition without the pedagogical guidance of culture. Through its epigenetic impact, culture is a major determinant of how the brain self organizes during development – both in its patterns of connectivity, and in its large-scale functional architecture. And the brain has evolved the sensitivities needed to assimilate the vital information stored in cultural networks.

2. The impact of culture on physical brain development

The most obvious example of culture’s real physical impact on brain development is literacy skill. Literacy is a fairly recent historical change, with no precedent in archaic human cultures; the vast majority of the world’s languages have never developed an indigenous writing system. Yet certain dominant modern cultures are not only literate, but also heavily dependent on mass literacy for much of their cognitive work. Mass literacy is spread only by imposing modifications on the developing nervous systems of large numbers of individuals. These modifications are imposed by “educational” systems: basically, systems of organized group pedagogy whose origins can be traced back to the beginnings of literate culture.

The cognitive subroutines that enable a person to become literate consist of chains of deeply automatized

responses to visual symbols. These are hierarchically organized in functional brain architectures that support specific sub-components of reading and writing skills, which are typically learned by prolonged immersion in educational systems that are highly idiosyncratic and culture specific. The algorithms of educational systems are generated and transmitted collectively, formed by the governing ideas of the cultural environment. Literacy training is not easy, takes a considerable amount of time, and is not even close to becoming a species universal skill for biologically modern humans.

Automatization of complex, fast response systems is the key to acquiring literacy skill. Non-automatized responses, such as those of someone who is learning to read a new language, do not allow the reader or writer to concentrate on the meaning of what is written. Automatization of all the stages of literacy training – including word recognition, grammars, vocabulary expansion, and expressive skills, can be achieved only after very extensive practice, to the point of overlearning, in successive stages of competency. During the acquisition phase of such skills, continuous conscious monitoring and corrective feedback are necessary. Once the basic skill has been learned so that the entire procedural system is automatic, conscious monitoring of the basic skill-set is no longer needed, and the response of the system becomes mandatory: that is, the reader cannot avoid responding to a visually presented word as a word. At that point, words and sentences can no longer be treated by the brain merely as a series of lines and contrasts; the meaning literally “pops out” of the marks on the page. Yet no one claims that these popout experiences are innate; they are culturally arbitrary, and learned.

They are also one of the most important interfaces with the distributed systems of culture. And they are instantiated in physical changes to the brain, which have been imposed by means of extensive cultural programming.

The physical reality of the culturally imposed automatic brain systems underlying literacy skill can be seen clearly in certain cases of acquired dyslexia and dysgraphia. In such cases, injury to the brain of a literate person selectively destroys a particular cognitive sub-component of the literacy system, without damaging other closely related brain systems, such as speech and symbolic thought. Literacy-related brain systems thus appear quasi-modular in their organization: they can suffer partial breakdown of certain components, while leaving others intact (Shallice, 1988). For example, one particular lesion might cause a patient to lose the ability to read, while retaining the ability to write, and another patient might suffer the reverse. Specific lesions might even eliminate the ability to read irregularly spelled words, while the patient remains able to read words with regular spelling. These cases point to the existence of specificity of function in acquired brain architectures. This is incontrovertible evidence in support of the direct impact of culture on adult brain functional organization.

There are many other similar examples of cognitive skills that require extensive training, originate in culture,

and depend upon acquired functional brain architectures: for instance, mathematical, musical, artistic, and athletic skills. But literacy skill stands as the clearest evidence that culture can impose radical cognitive re-organization on the brain.

3. Cultures as clusters of distributed cognitive systems

What adaptive forces drove human cultures to invest so heavily in literacy education, and consequently, in the epigenetic re-programming of millions of brains at great cost?

Human cultures are unique in their cognitive nature: ideas and memories can be traded and shared among the members of a group. A useful perspective on this aspect of culture may be taken from computational modeling: culture can be compared in principle to distributed computational networks, in which many computers are interconnected in a network, which acquires properties lacking in the individual computers that constitute it. Membership in the network can make each individual computer look “smarter” than it appeared before joining the network. Specialization and division of labor can be coordinated in a network, and the cognitive power of the coordinated group system can far exceed the reach of any individual. One could perhaps point to the Manhattan Project as the supreme example of what technologically-enhanced cooperative cognitive work (including decision-making) can achieve, when performed in distributed systems made up of specialized, symbolically coordinated components.

Distributed cognition is a useful paradigm in which to view the developing brain. From birth, the rapidly growing human brain is immersed in a massive distributed cognitive network: culture. The network “interface” of the brain to culture is a social one. It usually consists of unwitting “carriers” of the culture: parents, relatives, peers, who convey crucial information about where to direct attention, what to notice, and what to remember. The human infant’s brain seeks such input from the start. One might say that it has evolved a specialized adaptation to search an early connection with cultural-cognitive networks; any serious failure in establishing this social-cognitive connection can result in delayed development, and in some cases, such as autism, in a permanent developmental disability. This early cultural bond is crucial; the human brain has evolved a dependency on culturally stored information for the realization of its design potential.

This dependency applies to the specific content of the knowledge stored in culture, but it applies especially to the process of gaining access to culture in the first place. The first priority of a developing human brain must be to acquire from culture the basic social and attentional tools that it needs to elaborate its cultural connection (Nelson, 1996; Tomasello, 1999). Having done this in early infancy, it will then be in a position to “download” a massive amount of specific cultural content, some of which is procedural, in the form of skill, including language skill, and

some of which is semantic. Without completing that early phase of connection and sharing of mind, much of the information in culture will remain undetectable throughout life. Social-cognitive skills are enabling and empowering, in a capacity sense: they make possible and expand access to information stored in subtle and normally invisible cultural loci.

One of culture’s most important byproducts, technology, has further extended these prototypically human symbolic capacities, by restructuring the distributed cognitive networks of culture, and opening up new possibilities for both representing knowledge, and remembering it. A typical modern cognitive-cultural distributed network links together many human brains with communications technology, images, books, papers, and computers. These kinds of distributed networks perform much of the cognitive work of modern society, from landing aircraft, to predicting the weather and planning educational curricula (Hutchins, 1995). Individuals must be attuned to these networks to function effectively in our society. Decision-making occurs within tight network boundaries.

This raises a major scientific question: what are the specific domains in which the human brain attunes itself to culture? The major interface of the human brain and its cultures is undoubtedly a cognitive one: the uniquely cognitive nature of human cultures can only be explained in terms of a brain–culture symbiosis in the domain of cognition. Cognition can be appropriately singled out as the primary domain in which culture and brain interact. Human cognition constitutes a complex core of sub-capacities and operations, interconnected by means of an equally complex array of algorithms, shaped by cultural forces during development. This applies to both the individual brain, and to the wider distributed systems of culture. The individual is transformed by immersion in a distributed system. In such systems, memory in particular is distributed in many locations, and access paths proliferate.

One property of distributed systems is the division of labor across individuals. In a distributed system, the individual brain no longer has to contain within itself all the skills and information needed for individual survival. Perceiving, remembering, recalling, searching, and attending are managed to a degree from outside, by means of various symbolic media. So are the specific learned algorithms of thought. As the division of cognitive labor in culture becomes more and more specialized, the adaptive task facing a young mind changes, and this has consequences for the deployment of the brain’s resources. In particular, memory storage and retrieval is divided between brains and other media in the complex distributed systems of modern culture, as are many of the algorithms that drive thinking and problem solving. Since this modifies the habitual use patterns involved in cognition, and brain activity and growth directly reflect its habitual use patterns, it is reasonable to postulate that concomitant brain processes, such as synaptic growth and regional localization, are also immediately affected. Unfortunately, although

brain plasticity has been well documented in humans, there is not much direct empirical evidence from brain imaging studies on precisely how habitual, culturally imposed use patterns affect growth and development throughout the life span. We have only begun to collect empirical data on the neuropsychological impact of our close interaction with the external symbolic environment. By collecting more evidence, perhaps we will come to know more exactly how deep immersion in the distributed cognitive networks of culture affects the development of the nervous system.

One way to further refine the questions that need to be answered in this area is to observe brain–culture interaction over long periods. The pattern of emergence of cognitive change and cultural differentiation in human ancestors might prove helpful in conceptualizing how internal cognitive activity, in the brain, is interwoven with cognitive-cultural activity, in distributed networks. In turn, this might enable us to ask more telling questions of the brain.

4. A model of human cognitive and cultural co-evolution

The unique innovation of human beings in prehistory was the evolution of distributed cognition to a new level, indeed, to several new levels that had no precedent in other species. The human brain is adapted to the existence of cognizing, mindsharing cultures that far exceed the individual's ability to store and transmit accumulated knowledge and skill. However, mindsharing cultures could not have emerged by themselves, *de novo*. They are the product of a spiraling interaction between brain evolution and cultural change. The following is a brief review of a specific model of brain–mind–culture co-evolution in hominids (Donald, 1991, 1993, 1995, 2001).

The methodology used to derive this model was inherently interdisciplinary, drawing from many fields that could provide relevant evidence. My basic technique was to test every hypothesis, whether it grew out of one single field of research, or several, against evidence from all other relevant fields of research, and to reject any hypothesis that was incompatible with any solid fact, whatever its origin. This tends to produce robust theories, since accidental convergences from disparate fields of inquiry are highly unlikely to occur, and multiple convergences are even less likely.

There was one additional core postulate driving this model: Brain–culture co-evolution, with cultural-cognitive evolution leading eventually to such innovations as language. If brain and culture co-evolved, the result should have produced a universal architecture of cognition – both on the individual and on the distributed levels – that is evident in all human cultures. Such a structure should endure, even in the modern context, because evolution is conservative, and systems that are working well do not tend to be replaced. The larger architecture of distributed cognitive-cultural systems should be a relatively stable and universal structure. A large-scale cognitive-cultural hierarchy of

mechanisms should form the basis for cognitive activity within the networks that support mindsharing cultures.

A wide review of the evidence suggests that there are three hypothesized “stages” of cultural-cognitive change in hominid evolution, during which the nature of hominid culture gradually shifted from the marginally symbolic, to the proto-symbolic, to the fully symbolic. This process was not conceived solely as a linear, gradualistic series of changes, but rather was characterized by several “punctuations” in an otherwise stable hominid survival strategy. There was an archaic preadaptation about 2 million years ago when *Homo* first emerged, followed by a much more recent cognitive shift, within the past 400,000 years, that was radical and relatively rapid, and culminated in the fully symbolic cultures of biologically modern humans.

The physical evidence favoring this two-stage model came initially from two principal sources, fossils, and material culture. An analysis of the fossil remains of human ancestors reveals two periods where there was a relatively rapid increase in hominid brain size, and a change in body shape toward the modern pattern: The period from approximately –2 Mya to –1.5 Mya, when the species *Homo* first appeared, and a second period from –500 Kya to –150 Kya, when the species *Homo sapiens* first appeared.

Without necessarily conceding that increased brain size or body shape tells us anything in detail about the hominid mind, they do allow for some rough time markers, and a partial reconstruction of their way of life. Such reconstructions suggest that these were periods of significant cognitive challenge, with a concomitant change in the survival strategies of hominids. The material cultural record left behind by hominids agrees with this picture. There were major changes in the cultural record during, and following, these two periods. The changes included changes in such things as toolmaking, firemaking and firetending, diet, hunting skill, migration patterns, and the location and construction of home bases and shelters. Cultural and anatomical changes have not always coincided, and there is much debate about such details as the number of hominid subspecies, but the standard story of hominid emergence has not changed fundamentally during the last two decades.

There are compelling neural and cognitive considerations that greatly enrich this picture. Comparative anatomical evidence is an important clue here. Hominid evolution follows a trajectory from Miocene apes to modern humans. The starting and end points of brain anatomy are well known. Major differences between ape and human anatomy have been subjected to more detailed study, using advanced techniques, during the past decade, and the picture that emerges does not permit as much theoretical leeway as some might assume this field allows.

The cognitive networks that permeate all human cultures evolved in three stages, each of which added a new kind of representational “layer” to human culture, and each of which had its own evolutionary rationale. These networks dominate the brain and mind in epigenesis, and

impose a hierarchical structure on higher, or symbolic, cognition. Such networks might be labeled, for convenience, as “cognitive-cultural networks”, or CCNs. They have a significance influence on the developing brain of the child, through the mediation of parents and community. CCNs co-evolved with changes in various brain structures, and cannot exist without the cerebral apparatus that allows the young brain to assimilate these representational systems. On the other hand, it appears that very little detail is specified in the genes at this level. Increasingly, as a result of human evolution, it is the interaction between a highly plastic genetic potential, and cultural reality on the ground in any given generation, that generates the actual cognitive organization of the individual brain.

Table 1 illustrates the key points of this evolutionary theory of human cognitive origins. It begins in Miocene primates with cognitive capabilities that are assumed to be roughly similar to those of modern apes. These capabilities are labeled as “episodic”. Three successive stages of hominid cognitive evolution are proposed in this scenario, labeled episodic, mimetic, mythic, and theoretic. Note that hominid *cognitive* evolution has here been captured in three *cultural* stages, because the most radical innovation in the hominid line is distributed cognition, culminating in a system of language and symbolic communication that has cultural origins. The scenario is thus: First generate cognizing cultures of a proto-symbolic nature, let these become more complex, until they spontaneously “combust” into systems of symbolic convention, and eventually, into full-fledged language.

This proposal will seem unfamiliar to many cognitive neuroscientists, but the “stages” of human cognitive-cultural evolution should not seem too unfamiliar, because they were established on rigorous cognitive criteria: Each putative stage involved a novel form of memory representation, and a new style of cognitive governance at the top of the distributed cognitive system that was, quite literally, governing. Each new stage – mimetic, mythic, and theoretic – marked the genesis of a new medium, or domain, of memory representation in the distributed system, or CCN, and in the individual brain. The latter effect was

an epigenetic change due to “deep enculturation”. Each CCN domain postulated in this model has a complex internal hierarchical structure that is dictated by the properties of the shared memory systems available to hominids at that stage. The superordinate descriptive labels – episodic, mimetic, mythic, and theoretic, capture the top, or governing, level of representation within each domain.

One additional point: This is a “cascade” model inasmuch as it assumes a conservative process that retains previous gains. As hominids moved through this sequence of cognitive adaptations, they retained each previous adaptation, and it continued to perform its original cognitive work perfectly well. New levels of representation evolved to perform a different kind of cognitive work for the species. Mimetic cognition incorporated, and extended, prior gains at the episodic level; and mythic, or narrative-based, cognition, was scaffolded on top of a mimetic, or gestural, mode of thought and communication. The final step, the so-called theoretic stage, evolved slowly out of the classic mythic–mimetic thought strategies of traditional human cultural networks, retaining the latter within it. It was a combined product of extensive experience with sophisticated literacy skill and symbolic technology, resulting in the institutionalized application of analytic thought strategies to government, science, and education.

The first two hominid transitions – from episodic to mimetic, and from mimetic to mythic, were mediated largely by neuro-biological change, while the third transition, to the theoretic mode, was heavily dependent on changes in external, non-biological, or artificial, memory technology. The fully modern mind retains all of these cognitive structures, both in the individual, and in the distributed networks that govern cognitive activity in modern humans.

Each of these stages was marked by complex modifications in hominid survival strategies that undoubtedly involved many different changes in skeletal anatomy, brain anatomy, emotional responsivity, intelligence, memory, social organization, reproductive strategies, and temperament, among many other factors. Cognitive evolution could not have taken place in a vacuum, and major changes in cognition undoubtedly had implications for

Table 1
Three stages in the emergence of human CCNs, starting with the “episodic” cognitive-cultural style of primates

Stage	Species/period	Novel forms of representation	Manifest change	Cognitive governance
Episodic	Primate	Complex episodic event-perceptions	Improved self-awareness and event-sensitivity	Episodic and reactive; limited voluntary expressive morphology
Mimetic (first transition)	Early hominids, peaking in <i>Homo erectus</i> ; 4 M–0.4 Mya	Nonverbal action-modelling	Revolution in skill, gesture (including vocal), nonverbal communication, shared attention	Mimetic; increased variability of custom, cultural “archetypes”
Mythic (second transition)	Sapient humans, peaking in <i>H. sapiens</i> ; 0.5 Mya–present	Linguistic modelling	High-speed phonology, oral language, oral social record	Lexical invention, narrative thought, mythic framework of governance
Theoretic (third transition)	Recent sapient cultures	Extensive external symbolization, both verbal and nonverbal	Formalisms, large-scale theoretic artifacts and massive external memory storage	Institutionalized paradigmatic thought and invention

many survival-related variables, including diet, intraspecific and interspecific aggression, heat dissipation, metabolic energy, disease resistance, physical size, sexual dimorphism, and so on. The cognitive stages listed above were derived in that very wide theoretical context. But the prime driving force behind these changes was a cognitive one.

The reasons for labeling the primate cultures of the Miocene epoch as “episodic” have been spelled out in various previous publications (Donald, 1991, 1993, 2001). The theory begins with the assumption that the early hominid brain, like its primate, and most probably australopithecine, predecessors, lacked language or any capacity for generating explicit symbolic representation in the wild. The archaic hominid brain, like most others in the primate line, shared the same basic design features that humans share with all primate brains. This means that the earliest predecessors of hominids would have been very clever social animals, with a remarkable ability to understand complex social relationships, but limited expressive skill. In other words, they could understand social episodes and scenarios, but had no way of expressing this knowledge to one another.

The cognitive capacity that supports episodic intelligence is best described as “event-representation”. Events are the “atoms” of episodic cognition (Nelson, 1986). Social life consists of events, clustered in episodes; these define alliances, troupe membership, and power relationships. By this definition, primates have excellent event-representations, or ERs. They can remember specific events in an episodic manner; that is, they remember vivid details that are specific to a particular episode. For instance, after a fight with a rival, they remember the principal agents, outcomes, and future social implications of the fight. That kind of vivid, detailed event-memory in humans is usually called episodic memory, and it is anchored in concrete events. For this reason, the cognitive and cultural style of primates might be labeled “episodic”.

The episodic mind-set of primates is non-symbolic or pre-symbolic in its expressive or representational style. There is no evidence that primates think or communicate in symbols in their natural state. The episodic mind is concrete, analogical, episode-bound, and anchored firmly in the perceived present. It acts largely within the span of working memory, using perceived similarities between situations (and distinctions between them) as a means of choosing appropriate behavior.

Hominids, who shared an ancestor with chimpanzees about 6 million years ago, evolved beyond this mind-set at some point in their emergence. If we assume a Miocene starting point for hominids that was very close to the cognitive capacities of modern apes (A), and use biologically modern humans as the end point (B), the theoretical exercise becomes one of identifying the most probable sequence of events – neural, cognitive, and cultural – leading from A to B. The three transitions outlined in Table 1 constitute a coherent theory of the nature and approximate time course of the path from A to B.

5. Implications for theories of temporal integration in the social brain

The highly social and interactive nature of human cognition has not yet been fully investigated in brain research. There are some major innovations underway in the direction of studying the “social brain”, but for the most part, these consist of demonstrations of emotional connections with society. The transactional and distributed nature of social cognition itself is more difficult to study. But it must be studied, because social cognition and its consequence, mindsharing cultures, are key to understanding the unique nature of the human mind.

The emergence of a complex interactive social-cognitive system represented a significant shift away from primate social life, and undoubtedly presented a major cognitive challenge for the evolving hominid brain. Perhaps the most significant challenge was in mastering the temporal dimension of social perception. Human social life unfolds in long, complex, multimodal, and interactive episodes and scenarios which establish such things as social structure, hierarchy, custom, group intentionality, and ultimately, sophisticated interactive behaviors such as gesture, pedagogy, skilled rehearsal, and social cooperation. The mastery of such lengthy episodic experiences required the evolutionary improvement of a pre-existing primate capacity for temporal integration. Although we cannot say with certainty when it began, it seems certain that basic evolutionary improvements in human temporal integration were in place by 2–2.5 million years ago, when the distinctive distributed cognitive strategy of human society had begun to bear fruit in the form of cooperative hunting with stone tools.

The magnitude of this change can be seen in the limitations of even the most accomplished and socially intelligent of enculturated primates, when it comes to coping with the social complexity demanded by successful group cooperative work. Kanzi and Panbanisha, Savage-Rumbaugh’s star bonobos (Savage-Rumbaugh et al., 1993), can master many practical uses of tools and symbols, including even simple videogames, and can understand speech sounds and elementary grammars much better than was thought possible a mere decade ago. But they are extraordinarily limited in their ability to follow, let alone master, such vital human social skills as multi-agent communication, multi-agent games, complex tools, and the complex nonverbal conventions that we know as social gestures.

Why is this? Some have suggested that these are “wild animals” whose instinctual responses cannot be suppressed. Yet they do successfully suppress many of their natural response tendencies, compared with their wild-reared conspecifics. Others have argued that they lack a special “language acquisition device”, or that they lack certain metacognitive skills, such as a capacity for perspective taking or “theory of mind”, a hypothetical (and undoubtedly complex) capacity for understanding the minds of others. However, we have no good model of either of these

postulated mechanisms, or even any convincing evidence that they exist as coherent brain sub-systems.

Underneath these kinds of surface capabilities, there is the more fundamental cognitive challenge that these enculturated apes apparently cannot match: The comprehension of extended human social scenarios that engage several agents in complex interaction. Apes are excellent perceivers of social events, up to a certain level of complexity. But human social interactions exceed that capacity, and hominid evolution has evidently extended primate event-perceptual capabilities. Clearly, human beings are very good at perceiving their own social complexities. The popularity of manufactured entertainments, such as plays, novels, and films that endlessly re-work various social scenarios testifies to our obsession with complex social plots and narratives.

What is the cognitive element, missing in primates, that has enabled human beings to master so complex a social life? One possibility is that apes lack a capacity for the wide temporal integration that is necessary to cope with the intricate plots and sub-plots of human life. The continuous integration of new events into old scenarios, so common in human social cognition, allows the mind to oversee short-term events and episodes from a deeper background vantage point, while bracketing the fast moving events in the foreground, and placing them in an accurate context. The standard model of cognition is very much dominated by the study of the sensorimotor foreground: processes such as perception, short-term memory, working memory, and attention, are normally studied as reactions to what is immediately present at the sensory surface. Little is known of the mechanisms that enable the longer-term integration of such events into longer ongoing social scenarios.

In reality, human social life, and many other aspects of human mental life in a more general sense, is lived in a slower, wider time frame or “intermediate time zone”, within which many events and episodes are grasped and understood in terms of their implications for social relationships and future behavior. The capacity to achieve temporal integration on this scale seems to be absent in apes. Human brain researchers should therefore be looking for a “slow process” in the brain that is uniquely human, and can operate over long time frames, such as many hours, while maintaining a long-standing bias, noting the place of every intervening event that occurs in the sensorimotor domain, and retaining long-term control over thought and behavior.

6. The slow process: a hypothetical neural entity

In effect, the hypothesized “slow process” is a vastly extended working memory system that serves as the overseer of human mental life, and is the deepest layer of the mind. This is the intermediate-term governor of human mental life, the deep background process that shapes our cognitive agendas over the longer run, while maintaining oversight over the foreground of mental activity that

occurs closer to the sensory surface. While its application in cognition is wide, its prime function is to enable the mind to comprehend and navigate the multifaceted social-cognitive world that human beings inhabit.

The existence of this capability presents a challenge to neuroscience, because there is no known neural process that can remain active for such long periods, and tolerate so many interruptions at the sensorimotor interface, while continuing to update its temporary “world view” with new information. The slow process can track intricate events over long periods, yet it can also guide moment-to-moment thought and behavior, providing the contextual framework for forecasting and planning social action. The slow process involves memory; in fact, it is a form of extended working memory.

Half a century ago, Hebb (1949, 1963) proposed that there were only two kinds of memory record in the nervous system. One of these, short-term memory (STM) traces (later re-labeled as working memory, or WM), which I call ST-WM traces, are electro-chemical in origin, and constitute the active focus of activity in the brain at any given moment. The other kind of trace, or long-term memory (LTM), consists of structural changes, mostly in the form of altered synaptic connections. The former, ST-WM, are active, bound neural traces, more or less co-extensive with awareness, that correspond essentially to “the feeling of what happens” (Damasio, 1999); that is, the stream of consciousness. The LTM records are normally inactive, and amount to a dead storage mechanism, not unlike, in principle, to the dead memory records of, say, books or DVDs, inasmuch as they do not play a role in mental life unless activated. LTM traces are only effective in behavior when they are primed, and are more influential when retrieved into awareness, and converted into a fully activated trace in ST-WM.

In its basic form, this model has remained largely unchallenged and unaltered, except for some hotly debated details, such as whether some bound traces are too short to be classified as ST-WM. Hebb’s criterion for the existence of ST-WM was the delayed response, which cannot be demonstrated in many species that are undoubtedly capable of binding simple stimuli. Thus, a very short bound trace is different: a briefer neural trace that lacks a ST-WM mechanism to give it life beyond the immediate presence of stimulation from the environment. Simple binding and ST-WM thus exist in two different temporal ranges, with the second capable of sustaining its activity for many seconds, autonomously of external stimulation.

Neither the paradigms of binding studies nor those of ST-WM studies hint at the existence of a class of active neural traces that can last for hours on end, governing decisions and maintaining the general direction of behavior and thought. Yet this class of trace must exist, given the overwhelming evidence of autonomous sustained imagination, thought, and planning in human social life. There must necessarily be a third kind of neural process that corresponds in its time parameters to a broader period of

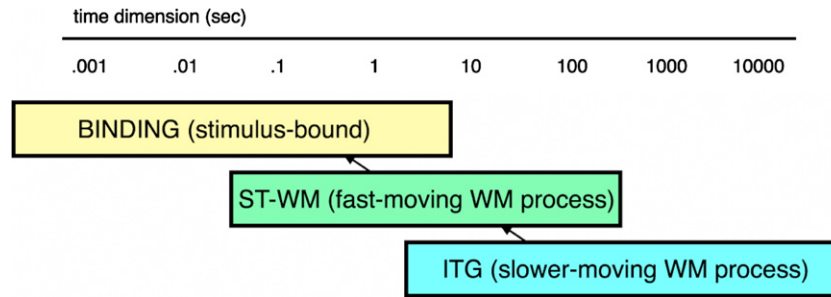


Fig. 1. Approximate temporal ranges of the stable neural traces that support perceptual binding, short-term working memory (ST-WM), and intermediate-term governance (ITG). The neural mechanisms supporting these three temporal ranges appear to be distinct from one another. ITG is very highly evolved in humans. It is a necessary precondition for mastering the complexities of human cognitive-cultural networks.

temporal integration. This kind of trace cannot be as ephemeral as instantaneous binding or ST-WM; nor can it be as static as a permanent structural synaptic change. I have called this kind of longer neural trace “intermediate-term governance”, or ITG.

In its field of influence and time parameters, ITG corresponds more or less to the “supervisory system” postulated by *Shallice (1988)* and others, and identified especially with the prefrontal cortex. We have no good neural model of the activation or localization of such a long-lasting process. Researchers have identified many more transmitters and modulators than were known in Hebb’s era, and there are many potential candidates for a slow neural process with some of the properties needed to explain the existence of ITG. However, none of them seems a feasible candidate for the maintenance of something as complex and subtle as a very slow moving social scenario or mental plan, running in the deep background, enduring for many hours, and influencing a whole succession of actions and changes of strategy.

Human social life involves intricate strategic planning, with many moves and counter-moves, and online adjustments and updates. The same applies to most social games, such as chess or soccer, which are designed to engage the ITG systems of the brain for long periods, toward some competitive end. The game may be interrupted by any number of trivial or subsidiary events, but the basic operating context imposed by the game will continue to dominate until it is complete. It is that deep background, the governing context, that I am describing here.

Hebb’s model, modified in many details, has been widely applied in theories of attention, perception, and memory. Theories of attention and perception are still concerned with the formation and filtering of the short-term active trace. Theories of neural binding are concerned with both attention and perception in the shorter term (*Singer, 1994; Crick and Koch, 1995*). Researchers are also actively examining how the ST-WM system, aided by attention, can capture several bound neural traces that occur slightly apart in time, and integrate them into a single bound event-representation (*Rodriguez et al., 1999; Miltner et al., 1999*). In this sense, theories of binding are basic to theories of ST-WM traces as well as short-term binding.

But, for the moment, neither binding nor ST-WM theories can deal with an active slow process such as ITG.

This theoretical challenge is summarized in a wide temporal framework in *Fig. 1*, which illustrates three levels of temporal integration achieved by the human central nervous system. The first operates in the very short time range, from fractions of a second, to a few seconds at the most; that is, traditionally defined, short-term, and local binding. The second operates in the ST-WM range of few seconds or tens of seconds, and can integrate bound material from any modality into an active trace that exists for a few minutes at most. Unlike very short-term binding, it seems to be very limited in capacity, and closely tied to selective attention. The neural mechanisms of these two kinds of temporal integration appear to be somewhat distinct from one another. Moreover, the two mechanisms seem to have evolved at different times, in different species. Elementary binding evolved earlier, and appears to occur in many species. On the available behavioral evidence on delayed response, ST-WM capacity occurs in much fewer species, and appeared later in the evolutionary record (*Donald, 2001, pp. 184–195*).

There are theoretical gaps between theories of mechanism for these three temporal ranges of neural integration. The current evidence on short-term electrical traces does not provide any feasible mechanism for stable, long-lasting active traces in human beings, despite the fact that they obviously exist. Longer lasting neural activity (ITG) sets the ground rules and semantic foci to direct and control complex interactive social scenarios, such as conversations that last for many hours, and organized games of various kinds. It predominates in human life. It can be lost selectively in cases of damage to the prefrontal cortex in particular (*Stuss and Benson, 1986*). Yet, we have no good candidate for a theoretical mechanism for the trace aspects of ITG.

In summary, there is good reason to predict the eventual discovery of a slow temporal domain of brain activity, longer in duration than any existing demonstration of bound neuro-electric activity, and stable across many interruptions at the level of short-term binding and ST-WM activity. Such a mechanism must be able to maintain a stable bias in a specified neural network, for a long enough time, in the waking brain to account for human social cognition. It must also be able to maintain its activity through

many interruptions in the faster moving working memory foreground of cognition, standing in the deep background, and overseeing the traditional architecture that forms the core of most information-processing models of the brain.

From a review of human cultural and cognitive evolution, there is good reason to expect that this mechanism, whatever it may prove to be, is at the very heart of human social and cultural life, and close to the core of human nature.

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