Layers in the Fabric of Mind: A Critical Review of Cognitive Ontogeny

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Introduction

Cognitive science, particularly in the last three decades has witnessed several creative moments and innovative proposals on the nature of mind, naturalized epistemology, cognitive development, biological roots of cognition, and an attempt to understand what it is to be distinctively human, scientific, theoretical, and socio-cultural. Encouraging leads to the underlying biological roots of cognition also came from neuro-physiological investigations as well as theoretical biology. Cognitive architectures based on information processing approaches are gaining strength and becoming popular and getting somewhat closer to being accepted as the received view on the subject.

This multi-disciplinary discourse, along the way, not only reenacted several traditional philosophical positions, but also exhibited considerable innovation in rephrasing the traditional questions seemingly guided by a huge corpus of scientific findings from AI, physiology and pathology, and ingenious experiments on cognitive agents (both non-human and human subjects, including infants in cribs). While taking note of the developments, I wish to identify some conceptual and foundational problems in the dominant trends of the current cognitive science, and describe a picture of ontogenic layers that seems to represent the human cognitive phenomena. Given this vast multi-disciplinary canvas, a single essay cannot do justice in critically reviewing the area. I will therefore focus here on what I consider the most fundamental issue that has a bearing on the foundations of not only cognitive science, but also science education. As an epistemologist, I will dwell on issues closer to naturalized epistemology and architecture of mind than on empirical cognitive psychology.

The fundamental cognitive transition

The focus in this essay is on metasystem transitions[1]: from biologically rooted procedural knowledge to socially rooted declarative knowledge. Another fundamental transition, from folklore to science, will be alluded to while drawing the picture of the layers in the fabric of mind towards the end.

Why is the transition from procedural knowledge to declarative knowledge important? In the current literature, sensory-motor intelligence is mostly assimilated into what is generally known as *procedural knowledge*, as against *declarative knowledge* (Mandler, 2004). During cognitive development a child undergoes the transition from a modular, unconscious, non-verbal stage to non-modular, conscious, conceptual and verbal declarative knowledge. Since we do not begin with a display of verbal declarative knowledge at birth, but develop it eventually, even nativists

[1] The term "metasystem transition" coined by Valentin Turchin of the Principia Cybernetica Project (Turchin, 1977), whose focus is to study the major evolutionary transitions from microcosmic systems to the most complex social systems.

must account for this transition, though, strictly speaking, they are not developmentalists in their temperament. The problem, therefore, is as fundamental as the transition from non-living matter to living matter.

Piaget's model of cognitive development aptly identifies this problem as the focus of the transition from the first stage to the second. He mentions that sensory-motor operations provide the early *schemes* for developing the corresponding concepts (*schemas*) associated to the schemes (Piaget, 1970). In his model, cognitive agents act on objects, and this action is essential for learning. In this sense each subject *constructs* by acting on experience. Piaget made a strict connection between motor competence and conceptual competence. Though he underestimated infants' cognitive abilities, and considered the sensory-motor stage pre-conceptual, his studies continue to be relevant till date, for his identification of the problem is arguably correct. Subsequent studies on infants showed that such a stage may not be more than a few months after birth, while nativists argued that conceptual knowledge and consciousness are innate (Carey and Gelman, 1991). In a recent work, Jean Mandler, based on the work of several other researchers, provides an account of how wrong Piaget was, in assuming that infants during the first stage do not have declarative knowledge. Mandler argues, that both sensory-motor competence and conceptual competence develop almost at the same time and this happens very early, as early as six months after birth (Mandler, 2004).

Karmiloff-Smith in *Beyond Modularity* describes her theory of *representational redescription*, where she tries to reconcile Fodor's nativist model (Fodor, 1983) with Piaget's developmental model (Piaget, 1968). During the process of representational redescription, *implicit* procedural knowledge transforms into *explicit* declarative conceptual knowledge by a process of re-encoding (Karmiloff-Smith, 1995). In *Origins of the Modern Mind*, Merlin Donald narrates with detailed substantiation the evolution of modern humans from Apes. He convincingly demonstrates the transition from the more primitive procedural to *episodic* memory, which in turn, over several thousand years, transitions into more recent and peculiarly human *externalized* memory, with the intermediary mimetic and mythical stages (Donald, 1991). Though Donald is not talking about ontogeny, but phylogeny, the order of the transitions provides important clues to the possible ways a child might develop into an externalized social being.[2] Peter Gärdenfors in his recent work *How Homo became Sapiens* agrees with Donald and adds further weight to the *externalization* hypothesis, underlining how a process of detachment could help in the transition, as well as in characterizing human cognition (Gärdenfors, 2003). Keeping in view Vygotsky's emphasis on the role of the social character of the human mind (Vygotsky, 1978), and Wittgenstein's strong argument against private language, and in support of the essentially social nature of language and thought (Wittgenstein, 1953), leads us to expect very strong social and culturally rooted accounts of the human mind. We may not be able to accept these apparently incompatible views, unless we can reconcile them by employing a sound conceptual base. In this essay I move towards such a reconciliation. If developmental psychologists' are correct in stating that during early ontogeny implicit knowledge metamorphoses into explicit knowledge, Wittgenstein's argument of impossibility of private language comes into trouble. Though Wittgenstein's arguments were intended against the empiricist epistemology, the same argument can be cast against developmentalists.

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[2] No strict recapitulation of phylogeny in ontogeny is really possible, particularly due to the force of enculturation process as soon as the baby is born.

While it is possible to discern subtle differences between the various positions mentioned above, what comes home is that, to understand the nature of human cognition, it is important to understand the relation between the hardwired, implicit, inaccessible, procedural knowledge rooted in *neuro-sensory motor mechanisms* on the one hand and explicit, verbal, symbolic, accessible, public, conceptual, declarative knowledge rooted in *socio-cultural mechanisms* on the other. Even though a nativist like Fodor did not believe in the developmental view of cognition, he correctly identified that the harder problem is to understand the relation between the modular and the non-modular components of the mind (Fodor, 1983; Fodor, 2000).

It is important to note that I am making an over generalization when I am clustering a large set of descriptions of the phase before and after the transition, in the above passage. Such a grouping is not strictly justifiable. We may discern subtle differences among them. The clustered description however will help us to broadly confine to the domain of discourse that is the focus of this essay.

The engaging problem therefore is either to understand the functional *relation* between modular and non-modular aspects of mind, as a nativist would like us to say, or the *transition* from procedural knowledge to declarative knowledge, as developmentalists would want us to say. I tend more towards the developmentalists, though I hope to see a reconciliation, as Karmiloff-Smith did, and to grapple with the transition problem. Either way, it is clear that this is a non-trivial problem in cognitive science, and a solution to this problem will have serious implications in understanding human cognition.

In what follows, I will identify the conceptual problems with the influential modularity model of mind. We shall see that one of the essential characters of modules, namely informational encapsulation, is not only inessential, it ties a knot at a crucial place blocking the solution to the problem of understanding the formation of concepts from percepts (nodes of procedural knowledge). Subsequently I propose that concept formation takes place by *modulation of modules* leading to cross-representations, which were otherwise precluded by encapsulation. It must be noted that the argument is not against modular architecture, but against a variety of an architecture that prevents interaction among modules. This is followed by a brief argument demonstrating that a module without modularization, i.e. without developmental history, is impossible. Finally the emerging picture of cognitive development is drawn in the form of the layers in the fabric of mind, with a brief statement of the possible implications.

Modularity

Jean Piaget's theory of cognitive development is today considered to be a domain general account. His theory proposed a general mechanism in the form of *assimilation* and *accommodation* of experience based on genetically endowed potential schemes. For every cognitive task—perception, concept formation, arithmetic, language, space and time, geometry etc.—Piaget applied more or less the same pattern of analysis, and in this sense his account is domain-general. Recent studies however seem to suggest that such an across-the-board model cannot account for the observed differences in performance on the cognitive tasks from each domain (Carey and Gelman, 1991, Hirschfeld and Gelman, 1994). Thus, Piaget's domain-generality and stage theory were as observed in the previous section, seriously questioned.

In an intellectual atmosphere where behaviorism and empiricism were belittled, Noam Chomsky's nativism took firm ground among several practitioners in cognitive science. Chomsky questioned the developmental views of language, and argued that highly specialized inborn mechanisms called modules exist for grammar, logic, and other subcomponents of language processing, visual system, facial recognition etc. (Chomsky, 1988). Jerry Fodor extended this line of thinking and provided a foundation by characterizing a theory of modules in his famous *Modularity of Mind* (Fodor, 1983).

Fodor proposed that the mind is constituted of peripheral (perceptual), domain-specific, informationally encapsulated, dissociable, functional subsystems that are mandatory, swift, and involuntary processing units, wholly determined by evolutionarily selected genetic endowment. However, the high-level central cognitive systems that are involved in belief, creativity, reasoning etc., are according to Fodor, amodular and non-encapsulated (Fodor, 1983; Fodor, 2000). In this model, the mind consists of several input subsystems producing swift *thoughtless* outputs. Interestingly Fodor included language also as an output of a module. While Fodor argued that the outputs are processed by non-modular central processing which works relatively slowly and *thoughtfully*, Tooby, Pinker, Sperber and Carruthers, argued that every faculty of mind is modular, aka massively modular (Cosmides and Tooby, 1994; Pinker, 1997; Sperber, 1994; Carruthers, 2005). However there is no clear consensus on what modularity means. For example, Carruther argues that some of the Fodorian specifications of modules, such as proprietary transducers, shallow outputs, domain specificity, fast processing and innateness, are not necessary, whereas modules have to be "isolable function-specific processing systems, whose operations are mandatory, which are associated with specific neural structures, and whose internal operations may be both encapsulated from the remainder of cognition and inaccessible to it." (Carruthers, 2005) The differences in characterizing modules is not so relevant for the issue at hand, except for encapsulation and domain specificity. We will return to a discussion of this in the next section.

Evidence for modularity comes from neurophysiological cases where several patients displayed loss of a *faculty* independent of others, due to partial damages in the brain. Modularity, being a computationally amenable property, attracted also those who took a computational view of cognition. Fodor[3] and Penrose[4] argued, though their arguments have different grounds, that higher faculties of mind cannot be assimilated in a computational framework.

Modularity, as a general feature, is commonly seen in biological organization at all levels of complexity. There is greater consensus that an

[3] Fodor argues that computational theory of mind cannot answer global inferences like *abduction*, which require embedding in a *non-local* aspects of a mental representation such as a theory, while normal inferences are embedded in *local* aspects of a mental representation such as a syntax (Fodor, 2000). I think his argument is *asymmetrical*, since in local inference he takes syntactical aspect of mental representation, while in global inference he takes *semantic* aspect of representation, and not the syntax of the theory.

[4] Penrose argued in *The Emperor's New Mind* that artificial intelligence cannot solve the problem of consciousness, since Gödel's theorem, which sets a limit to what a Turing's computer can do, proves the impossibility of AI (Penrose, 1989). In a ater work, *Shadows of the Mind*, he argued that classical physics cannot address the consciousness problem, while quantum physics can(Penrose, 1994). Based on Hameroff's findings of microtubules, which form a scaffolding for a cell constituting cytoskeleton, Penrose hypothesizes that they can form a basis for the complex mental operations where, at Planck-scale, quantum functions collapse to generate

organism is gradually and hierarchically constructed out of several subsystems (Simon, 1962). This therefore is taken as an argument in favor of massive modularity. The possibility of transplanting some subsystems by artificial ones, is also a stronger evidence in favor of modular architecture in biology. However, all of biological organs are not directly related to what we normally call cognitively functional organs, for example heart. Sense organs (as input subsystems) are not so different from other biological organs and organ systems, because each of them have a domain specific function to perform and they work independently of each other. Therefore, what seems to be missing in this characterization is something that makes some of them cognitive, while keeping others *merely* non-cognitive biological subsystems. Extending this, we may also ask: Are there some special subsystems that are responsible for the distinctively human cognition? The main contender for the special human module is language. However, it is not very clear how without any difference in genetic makeup, say between a chimp and a human being, a biological system begins to display language behavior. Therefore, what makes a subsystem cognitive and what makes human cognition so different are still open questions.

Another argument in favor of modularity stems from evolutionary assumptions. Slow, non-modular, domain general processing would not be selected since they are not evolutionarily advantageous, and would not have evolved. General processing systems may not even behave consistently and would not give reliable results. Only swifter automatic subsystems would have been naturally selected during the course of phylogeny (Cosmides and Tooby, 1994). This argument goes against Anderson who argues that there would not have been enough time to evolve so many special modules, for human evolution has relatively a very short history

(Anderson, 1983). Most of the higher cognitive abilities seen in human beings have several things in common. Thus, a single change responsible for a general architecture may have resulted in the modern human mind.[5] The fact that there is almost a complete match, between the genetic code of Apes and human beings, supports general architecture.

When we look at the apparent differences between other beings and humans, encephalization[6] and lateralization of hemispheres with analytic left and synthetic right side, dexterous erect posture standing on two feet, are the striking biological differences, while language and social culture are the striking behavioral differences. The problem is to understand what differences determine what, and whether biological differences determine the socio-cultural, or vice versa. It is also important to note that unitary or modular theories are possible among biological as well as socio-cultural accounts.

In the following sections, I will propose a way of bridging these apparent divisions: modular and non-modular, domain specific and domain general, biological and cultural. It is also important to note that unitary or modular theories are possible among biological as well as socio-cultural accounts. I suggest that there exists a mechanism of *modulating* the modules, which eventually generates the higher and peculiarly human cognitive abilities.

[5] See (Donald, 1991) for a comprehensive comparison of modular versus unitary models of cognition.

[6] Encephalization is the increase in the relative size of the neocortex. Size of the brain of human beings is the largest (about three times that of the nearest primates) in relation to the rest of the body with about double the number of neurons. The large size is attributed to the increased size of the neocortex (cerebral cortex) which contains three fourths of the neurons in the human brain, which are organized into the two hemispheres.

This mechanism transforms the implicit into explicit, and this is the fundamental cognitive transition. This mechanism is recursive and is capable of generating new complex modules, which in turn get dissolved by modulation and cross-representation, generating complex layers of cognition.

Modulation of modules: Dissolving encapsulation

Informational encapsulation (insulation), inaccessibility of internal data and processing details, is proposed as a defining feature of a cognitive module. Without this feature nothing significant can be said about modularity (Fodor, 2000). Why is this hypothesis significant for understanding cognitive phenomena? Why do the believers of this hypothesis think that it explains cognition, and which aspect of cognition? What happens if an input subsystem is not encapsulated?

So much of data, we assume, must be generated by several of our input subsystems, particularly the sense organs (transducers). If our consciousness attends to each bit and processes such information *deliberately*, the processing of even a snapshot of all the *chunks* generated in a moment will take a long time. It is very unlikely that such a processing is happening. Our consciousness selects and attends to one chunk here and another chunk there, but cannot possibly process all the chunks and process. The assumption that the modules must be processing automatically and swiftly without ‘thinking’ and without the intervention of any other subsystem or central system seems therefore legitimate.

This is followed by another assumption that though the internal details of how the information is processed is not available, the output produced by them is available to the central system. Though this approach does eliminate a lot of processing details, the generated output of the modules at each moment is not small either. Also our consciousness does not seem to be attending to every chunk of the output. But by assuming that there exists an access to the output since it is not encoded in a proprietary format, we create a situation whereby when we wish we can attend to it. But, since we do not seem to be taking into account all of the accessible chunks, there seems to be another layer of 'encapsulation' or some other unknown mechanism, but at this step unlike in the first step of encapsulation, the data is not encoded in a proprietary format. However, we still need an explanation about how we can attend to one among the bundle of chunks at any given moment. The problem therefore does not disappear by supposing informationally encapsulated modules. By assuming that the information processing takes place by an inborn evolutionarily developed mechanism, we are completely insulating ourselves to see the most fundamental problem of cognitive science (by enclosing the problem in a capsule, and then worry about why the problem is not getting solved). This I think is the problem.

Do we theoretically need encapsulation? What purpose does this serve? One may argue, as Fodor does, that the concept was invoked to explain the mandatory and independent nature of certain perceptual results. The Müller-Lyer illusion, for example, is experienced despite our knowing that the two horizontal lines are of the same length (See Figure 1). The explanation given is that another subsystem or central system which 'knows' that the lines are of the same length cannot influence the input subsystem to perceive differently, because the input subsystem is encapsulated. Perception of illusion is therefore mandatory. There are alternative explanations to illusions that do not use the notion of encapsulation.

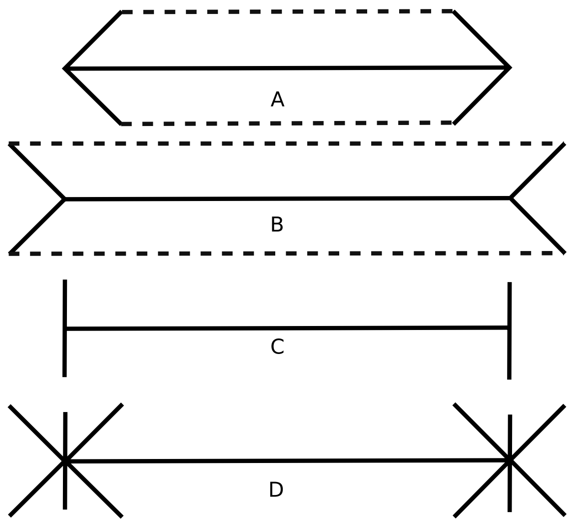

Figure 1: Resolving the Muller-Lyer Illusion by modulation: translating the lines A, B, and C producing D not only demonstrates the equality of length, but also that appearances can be modulated.

Piaget employs the idea of relative centration (Piaget, 1969), and a very recent analysis offers a theory that explains various classes of optical illusions by proposing that noise causes bias leading to alteration in appearances (Fermüller and Malm, 2004). The illusion can also be resolved by assuming that there exists a genetic bias for shapes than for lines, or that it is *easier* to see shapes rather than lines. The assumption of informational encapsulation or proprietary databases seems unnecessary for explaining illusions.

Appearances can be deceptive as is well known. But how do we resolve them as deceptions is an issue that we should look at. When we do that, we will realize that the resolution of deceptions (and other perceptual illusions) happens by *modulating* our perceptual field. By modulation I mean modifying the effects of perception by altering certain conditions keeping certain other conditions constant. If our perceptual field can be modulated, then how can we say that there is encapsulation?

We can bring the lines A and B together, as shown in Figure 1 and see that they are equal in length, or we can bring another line C and compare the lines by measuring. But the very act of measurement involves modulating our appearances, by moving and matching the lines or bringing an yardstick like C. Though *we may not be able to alter the way our input subsystems work, we can change the conditions under which the object appears*. It is by *doing* so, which I call modulation, we resolve appearances, not merely the deceptive kind, but all.

I am not arguing that appearances are not mandatory, they indeed are. The point I am making is that the appearances being mandatory cannot generate knowledge without modulation. Collecting all appearances (chunks) would not constitute knowledge. Only the modulable part of the incoming information is perceivable. Modulation makes perception possible by introducing the necessary bias. This possibly also explains how *attention* is realizable. Knowledge is generated by an alteration of input and therefore the output. But *given the same conditions of input plus modulation, the subsystem must generate the same output*. This is the only assumption required of modules. The internal mechanism is also of no consequence, it can be an artificial mechanical system, or a natural biological system, or one can be transplanted by the other, so long as the above condition is met.[7] This is another way of saying that modules are sensitive to specific

[7] Researchers at the University of Wisconsin-Madison developed a tongue stimulating device that can be used for making the blind *see* (Sampaio et al., 2001). This possibility vindicates the flexibility of representation mechanism of our mind, and there is no one unique way of making an input subsystem.

input, which is domain specificity. We don't need any other notion such as informational encapsulation or proprietary databases to explain cognition. Subsystems are required to be modulatable and domain specific (by virtue of sensitivity of input systems to an aspect of environment), apply Occam's Razor to every other notion.

I will now connect modulation to concept formation, and argue that unmodulated appearances don't generate knowledge, that is concepts. I will argue that even rudimentary conceptual knowledge cannot be properly accounted if modules are encapsulated. However, it is mandatory that modules must be domain specific. We should not confuse implicit with inaccessible. Different subsystems interact with each other, and control each other. It is unnecessary to bring in a central control system, when control can be explained without it. That the mind is some kind of central processing unit, with privileged access to the output of all the modules, is a myth. We should replace that picture with *cellularity* of mind. In this alternative picture, all the subsystems, including the 'central' nervous system, interact with each other to produce a conscious cognitive loop.[8]

Modulation and concept generation

Let each input subsystem produce output in whatever format. Let us suppose that each subsystem is domain specific, meaning it is specific only to a kind of input and ignores others. Let us call each output thus produced a dimension. Each input subsystem thus produces a domain specific output as 'sound dimension', 'light dimension', etc. Now let us suppose a cognitive

[8] Please see my argument that a conscious cognitive loop cannot be made without bringing in the motor subsystem (Nagarjuna G., 2005b).

agent that has only one input subsystem, therefore generates only one dimension. However sophisticated be the subsystem, as long as it is domain specific, such an agent with only one input system can not generate any bit of information. Why? Because, such a perceptual space is *blind*.[9] It is like an undifferentiated ether. Information is a result of *differentiated difference*, which comes only by *interference* of another dimension. When two or more dimensions *cross* with each other, either concurrently or serially, a logical mark is possible in the undifferentiated space, for recognition needs an identifiable mark. This is very similar to the way a point is obtained by crossing two lines. It seems therefore impossible to think of individuating any *differentiated difference* without *cross-representations*.

Let us look at the computational theory of vision proposed by Marr. He proposes quite a few *modular* devices, each of which detect motion, edge, surface texture, etc. The resulting *vision* is a coordination of these modules. To generate a chunk of vision, so to speak, we need quite a few dimensions (Marr, 1983). There seems to be sufficient cross representation in this so as to generate useful information.[10] Each chunk of vision is already informationally very complex, since it comes with notions like space, position, shape, size, color, edge, motion, etc.

Assuming that each dimension comes to us from an independent module, and that information is impinging on our mental 'screen', we may think that the story of perception ends. But it doesn't. We may be able to see

[9] My allusion that perceptual space is blind may remind readers of the Kantian aphorism, that perceptions without conceptions are blind, and conceptions without perceptions are empty. Though insightful, my purpose here is to break this circle, and not depend on it.

[10] Fodor thinks that this provides confirmational basis for modularity (Fodor, 1983).

changes in the screen, but how do we know what causes (constrains) each of these changes? Mere cross-representation is not enough, since we will never know if there is a cross, if it is invariant. We need to introduce a mechanism to control (modulate) the crossing too. Karmiloff-Smith's theory that representational redescription happens by re-encoding cannot be the answer, though the line of argument is correct, because it begs the question. We still need to search for the mechanism of re-encoding.

I am proposing that this happens by *modulation of modules* which introduces the required differentiation of *cross-representations*.[11] Modulation of dimensions is a process where a cognitive agent introduces differences in some dimensions by keeping certain other things constant in the perceptual space. What I am suggesting is that the cognitive agent to begin with *consciously* performs certain operations that alter the perceptual space in a controlled way. For example, we move our eye muscles to focus once on the window pane, and once on the distant trunk of the tree in order to perceive the depth. Once used to it, we do this unconsciously, but the fact that this can be done consciously explains why there is no encapsulation. The motor input system can affect the visual field. Since this operation is deliberate, we could be certain that the differences in the appearance are constrained by controlled motion. This way, the difference gets differentiated. I propose that *differentiation of difference* is the foundation of all conscious cognition, which happens by modulation. Differentiation

[11] Though modulation of cross-representation is stated to be the basis, I believe there exists another fundamental kind of modulation of states, a set of cross-representations, and the mapping between them leading to *across*-representations. While the former becomes the basis for analytic reason, the latter for analogical reason. Analogical reason is as fundamental as analytic, and should not be neglected. John Sowa's contribution on "Knowledge Soup" in this volume does to some extent fill this gap, though he argues analogies to be more primitive than analytic.

of difference produces the required cross-representation. One can see much of what I am proposing implicitly in Marr's theory, but what is missing is the requirement of *modulatory action by the agent* which introduces the constraint required for differentiation.

To see the causal connection between differences in appearances, we need no higher form of inference like abduction, as Fodor thought. The constraints for inference are already available to the subject, since modulation is initiated by the subject, making the inference fast and direct, and therefore avoiding the frame problem. The assumption of proprietary database also serves the purpose of avoiding the frame problem.[12] Since in the current proposal no proprietary database is assumed, one may think that the frame problem might arise. However, as mentioned above, modulation itself provides the required constraint for faster and direct inference. If we assume a loop between a sensory subsystem and a modulation system, we do not need expensive computation to solve the problem.[13]

If this line of argument is valid, one thing is clear: knowledge is generated due to modulation of cross-representations, a sort of multi-dimensional/ inter-modular interference or interaction. This mechanism then may be either innate or learned. I believe the potential to modulate is innate, while the context for modulation is culture. What seems the likely basis for concept formation is: loose physiological coupling, characterized by interactive and functional relations between different domain specific subsystems, rather than encapsulated modular structures.

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[12] See the discussion by Weiskopf on modularity and frame problem (Weiskopf, 2002).

[13] The nature of this loop is discussed in (Nagarjuna G., 2005b), where voluntary muscles controlled by the central nervous system form a loop with sensory subsystems to generate the required self-modulation.

Consequently, we, human beings, are not compelled to take what the input subsystems have to offer. We have the ability to differentiate the differences caused by the input systems. It is this *freedom* that makes us *reflect*, and thus begets our thought. Other animals may also be getting deceived by appearances, but due to our freedom to modulate our perceptual field we resolve several of those deceptions. I started this section with a discussion of an illusion, let us end it with another illustration.

In Figure 2 the horizontal line in A appears smaller than the vertical line though they are of the same length. That our perceptual modules have no bias to vertical lines becomes clearer if we see the case of E, where the vertical looks smaller than the horizontal. Interestingly the lines in situations B, C, and D are seen as equal. The situation in D is more interesting, since both the lines look smaller than the line F, though all the figures are constructed by using a line of the same length as F. D is produced by rotating B but looks smaller than B. Our judgments about the length are based on modulation by translation or rotation of the lines. We break the mandatory appearances by altering not only the relationship between the modulatable components of the figure, but also our relationship with them. Though the appearance depends on the context, the context itself is modulable. In fact we can make the illusion appear and disappear by doing so, and also understand the conditions under which the illusion happens. Appearance is mandatory only because the context is similar and not due to any encapsulation.[14] There are neither proprietary databases nor private encodings. Sensory subsystems are domain specific, i.e., sensitive only to a specific input.

[14] The encapsulation hypothesis is not even required for nativism, for nativism is logically possible without assuming it. I haven't come across any argument from a nativist that nativism and encapsulation must go hand in hand.

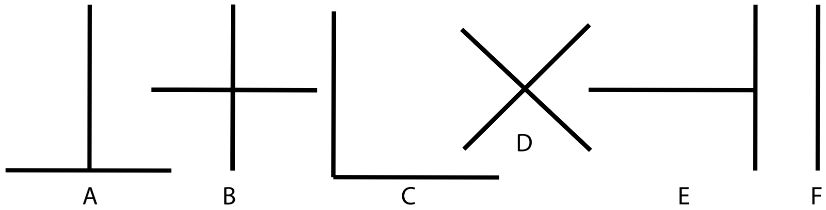

Figure 2: Modulation resolves the deceptive appearances

Layers in the fabric of mind

I argued above that domain specific modules can be modulated, and this process has the potential to explain concept formation. In the process the implicit procedural 'knowledge' transforms into explicit declarative knowledge. By demonstrating that modules can be modulated by the agent's actions, modules become Piaget's *schemes*. This reconciliation of nativism and Piaget is different from that of Karmiloff-Smith's. In her account, modules are the product of post-natal development. I am suggesting that input subsystems are hardwired and biologically given. However, to remain consistent with a developmental account, they are also products of a developmental process. But this process is embryological, and therefore purely biological. Biological ontogeny in the form of maturation continues even after birth, and this process may enhance the sensory-motor potential, but remains biological nevertheless. This developmental process remains the bedrock for other layers in the story, forming **Layer 1**: biological ontogeny.

Cognitive development essentially begins after birth. A new-born child is like a cognitive 'ovum', it gets 'fertilized' by experience of both the cultural world and the ‘natural’ world. This onsets the development of the **Layer 2**: *subjective cognitive ontogeny*. This process also continues to develop, though reaches maturation (meaning modularization) very fast. The character of representations that are produced at this stage are *cross-representations*. These representations are a result of the subjective cognitive ontogeny, and remain *procedural*. This corresponds to the nature of knowledge generated during the sensory-motor stage of Piaget, and the percepts of Mandler. Let me clarify here that this account is not a stage theory, it is the character of knowledge generated that corresponds to the Piaget’s sensory-motor stage and not the stage to the Layer 2. One important difference is that these layers continue to exist and develop, and they don’t stop or transform into another at any time. Subjective experience doesn’t cease when we tend to become inter-subjective or objective. This layer produces the mandatory appearances that sometimes result in the illusions we discussed in the previous section. Most of animal cognition remains at this stage, since the process that generates the other cognitive layers, modulation of cross-representations, doesn’t seem to be available to them. Karmiloff-Smith’s representational redescription, for the same reason is also not available to them. This corresponds to the ‘implicit’ level in Karmiloff-Smith’s theory.

The first two layers now become the foundation for the **Layer 3**: *inter-subjective cognitive ontogeny*. In some of the higher cognitive agents, particularly human beings, the implicit procedural knowledge transits to explicit declarative knowledge by modulation of cross-representations, leading to representational redescription, generating explicit representations. This is what we called the fundamental cognitive transition. The cognitive agent for the first time in cognitive ontogeny begins to develop a *detachment* between *sign* and *signifier*, where the former is publicly (inter-subjectively) accessible. This is when percepts become concepts. This layer is sufficiently complex and amenable for further layers within. Karmiloff-Smith distinguishes three 'levels' of this Layer 3: Explicit 1 (E1), Explicit 2 (E2), and Explicit 3 (E3). E1 is explicit but not accessible to consciousness, E2 is explicit and accessible to consciousness, and E3 is accessible, conscious, and verbally reportable (Karmiloff-Smith, 1995).

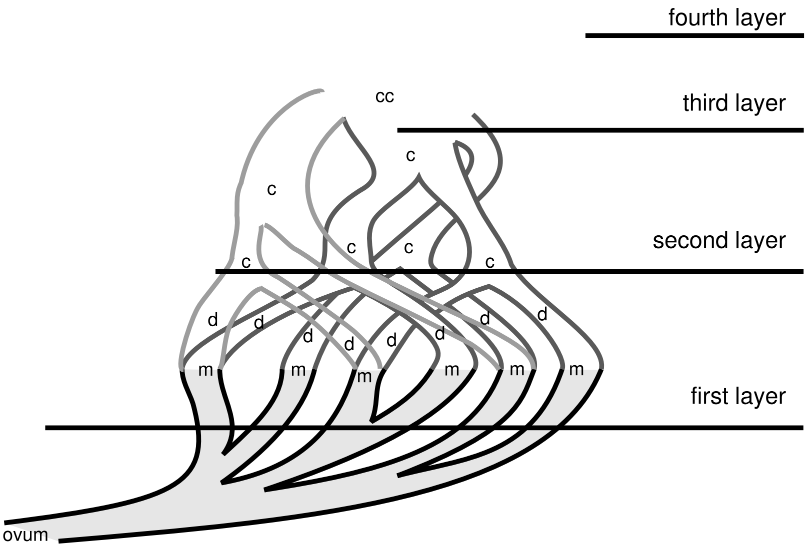

Figure 3: Layers in the Fabric of Mind: A diagrammatic representation of the layered view. Undifferentiated ovum develops by embryogenesis into a modular differentiated organism. Each module (m) generates a domain specific dimension (d) the dimensions cross with each other by modulation to produce cross-representations (c) which upon differentiation of difference produce a unitary conscious cognition (cc). The arrows indicate roughly that the lower layer continues to develop and exist while the other layers develop on top.

Though there is no strict matching with our account, Donald's three stages during phylogeny of modern humans also fall in Layer 3. He identifies during phylogeny a stage of episodic representations to begin with, leading to semantic externalized representations, mediated by mimetic and mythic layers (Donald, 1991). It is during this process that the language module, the most unique human character, develops. This view is unlike that of Chomsky and Fodor, who argued for innate language modules. While I disagree with them on this, language is mostly 'hereditary' in the sense that is almost entirely due to cultural inheritance. Behaviorally, a lot of play, practice and enculturation (training) are responsible for this layer to develop. Socialization and language go hand in hand, for they are not possible without each other. It seems therefore plausible to hypothesize that representational redescription is an *essential* mechanism in producing *external* memory space helping to enhance much needed memory capacity for storing cultural heritage, and also for *detached* processing of information. Thought and imagination too are due to *detached* processing of representations, but happening in the subjective space—internal modulations. Layer 3 is too rich to capture in a paragraph. To sum up, what happens in this layer is that implicit procedural representations transform into explicit declarative knowledge by 'rewriting'. This process is the hub of all eventual higher cognitive functions. Layer 3 has all the necessary paraphernalia for developing the peculiar socio-cultural human life and culminates in the production of folklore.

The three layers thus formed become the foundation for the exclusively human **Layer 4**: *formal cognitive ontogeny*. This layer develops by transformation from folklore of Layer 3. Declarative knowledge of folklore in this new layer gets redescribed in formal operations. In this layer, no assumptions remain implicit while knowledge of Layer 3 depends a great deal on implicit and subjectively available experience. Here all the knowledge is stated as a declarative representation. During formal cognitive ontogeny, concepts are artificially and operationally *represented* without a direct bearing on experience. They may be idealizations of Layer 3 concepts. The concepts that form the basis of formal knowledge may or may not have observational basis, but they do have an operational basis. By operational I mean rule based construction based on definitions. Since definitions state the conditions explicitly, confining to a constructed conceptual space, this makes these new constructions completely *detached* from perceptual experience. Scientific knowledge, for example, is an *explicitly constructed* form of knowledge in the sense that the rules of construction are overtly specified. This form of possible world construction creates an idealized description of the actual world that describes indirectly (mediated by models) the phenomenal world. They 'touch' the real world here and there. By this I mean the logical space of possible worlds extends beyond the actual space of the real world. This constructed form of knowledge results into formal, mathematical and scientific knowledge. By formal I do not mean only mathematical or algebraic. A piece of knowledge becomes formal, when any representation-the symbols, the rules of combining them, relations between them, etc., are fully made explicit. This requires the knowledge to be re-represented in an entirely artificial language. One may see what I am saying comes closer to some branches of science like physics, but the view may be rejected for other sciences such as biology, economics and social science. The possibility of reconstructing an artificial language by using mostly available vocabulary from folklore, makes us see the essentially formal nature of the latter sciences. Just as the folklore notions of force, energy and work do not just extend into the scientific notions by the same names, the folklore notions of "heart" and "species" do not extend into biological space. If this view, that science is not part of the Layer 3, is true, then it will have serious implications for science education. Most science education practices assume that science is an extension of common sense. The view I am arguing for demands an epistemic break from common sense. I do not have space to provide a complete argument here. Please see "From Folklore to Science" for a complete statement of this position (Nagarjuna, 2005a), where a demarcation criterion in the form of conditions that make the transition from folklore to science is presented.

Before I close this section, a few lines on the nature of the layers would be relevant. What is the relationship between the layers? The top layers depend on the bottom layers. This dependence is substantial. Just as the living layer of the world depends on the physical non-living layer, the formal layer depends on the folk layer, and this folk layer depends on the biological. Layers on top, once developed, do not replace the bottom layers, they only cover them. This view is different from that of Thomas Kuhn who argued that revolutions replace the former body of knowledge (Kuhn, 1970). Kuhn's view is the most outlandish, and unfortunately the most influential, view from an otherwise careful historian of science. I argued (Nagarjuna, 1994) that Kuhn confuses psychological (ontogenic) replacement that *may* happen in a believer with historical (phylogenetic) replacement. Top layers emerge due to changes in the functional relationship of the underlying ontological layer. Substantially there exists only one ontological world, the distinctions of the layers are methodological helping us to theorize. Thus this position can be characterized as ontological monism and epistemological pluralism.

A question also arises naturally regarding the relation of the layered view with that of Piaget's stage theory. Stage view suggests that the cognitive being transits from one kind to another. Layered view suggests that the being develops an additional layer without losing the earlier base. Metaphorically it is more like a few threads of the fabric of the bottom layers *escape* to form the latter layers. As shown in the Figure 3, the layers in the fabric of mind, for each *thread* of development, it is possible to provide a stage theory, but not for the cognitive being as a whole.

Implications

The layered view of cognitive phenomena presented above, if plausible, indicates a few fundamental changes in the way we view ourselves. The view suggests that the direction of human cognitive development involves the transformation of implicit procedural knowledge into different forms of explicit conceptual knowledge. The mechanisms that play a role in such transformations are not genetic in the classical sense, but arise from our cultural or social inheritance. The bundle of peculiarly human characteristics are strongly tied with the social fabric of human life rather than arising from the genetic, neuro-physiological domain. Evidence is gradually accumulating to suggest that the larger size of human brain (encephalization) is mostly to do with this new-found socio-cultural context. The fact that the genetic and anatomical differences between apes and humans is so marginal indicates that this problem cannot be answered by gene and brain-centric viewpoints. In (Nagarjuna, 2005b) I proposed a hypothesis to explain the genesis of conscious cognition. The fundamental cognitive transition, explained above, is argued to be due to the emancipation of biologically driven modular operations, resulting in conscious cognitive operations, including those related to the social and symbolic life of humans. During this process the inaccessible knowledge begins to expose itself through modulations, and this process itself generates the symbolic life of higher animals.

While arguing against the behaviorist model we tended to be excessively 'inward' looking in our search to describe human nature. If my arguments have any weight, we should be looking mostly at what is publicly accessible to understand what is peculiarly human, and how they transform the private into public. This will have implications for Wittgenstein's private language argument, where he argued against the possibility of private representations. Neuro-physiology can inform us about the manner of encoding episodic memory, but possibly not of semantic memory, an essential form of human cognition. It is highly likely that semantic memory is stored exclusively in the externalized public socio-cultural mind-space. However, procedural and episodic memory form the basis for socio-cultural semantic memory. Scientific knowledge is necessarily and undoubtedly located in the inter-subjective space. Scientists tend to have 'gut' reactions against socio-cultural foundations of science. But, I think, this does not by any means make it less objective, since externalizing by re-encoding is the only means of making private subjective knowledge public and potentially objective. By interpreting Wittgenstein's argument as applying only to semantic memory and not episodic or procedural, I suggest a transformation mechanism in terms of modulation and representational redescription, which explains one of the mechanisms involved in learning and discovery.

Lastly, a remark on implications of this view for science education. Most leading cognitive psychologists (e.g., Alison Gopnik) believe in a strong working hypothesis called "theory-theory". According to this view no knowledge worth the name can be non-theoretical, and the basic mechanism (or methodology) of knowledge formation and evaluation happens by theory-change, and this mechanism is universal. By demonstrating that even infants in the crib are little theoreticians, they argue that the mechanism that makes us know the world is the same as that which makes science. If our account of Layer 4 is correct, the theory-theory view comes into question. While I agree that there are general cognitive mechanisms (or methodologies), it is necessary to make certain finer distinctions which weaken the strong form of theory-theory. First of all, we need to make a clear distinction between conceptual and analogical: the former is a result of cross-representation while the latter is a result of *'across' representation* drawing in similarities across domains based mostly on relational knowledge. Further, all theories are not of the same nature, particularly the model driven, counter-intuitive scientific theories. The latter theories are artificially constructed, explicitly rule governed and hence not in continuation of folk-lore. The character of theories in folklore and formal science must carefully be distinguished. If we think that science is not an extension of common-sense, our approach to formal science education needs to change.

References

Anderson, J. R. (1983). *The Architecture of Cognition*. Cambridge, MA: Harvard University Press.

Carey, S., & Gelman, R. (Eds.). (1991). *The Epigenesis of Mind: Essays on Biology and Cognition*. Hillsdale, New Jersey: Erlbaum.

Carruthers, P. (2005). The case for massively modular models of mind. In R. Stainton, (Ed.), *Contemporary Debates in Cognitive Science*. Oxford: Blackwell.

Chomsky, N. (1988). *Language and Problems of Knowledge*. Cambridge, Massachusetts: MIT Press.