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# Life and Organicism

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# CHAPTER 8

# Tracing the Biological Roots of Knowledge

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## MIND *AND* NATURE OR MIND *IN* NATURE?

Traditionally questions in epistemology took for granted the uniqueness of the human being, and therefore questions were raised about the relationship between the knowing being (the subject) and the nature (environment), the object. How does the subject understand/explain the natural phenomena around it? How does the subject establish true knowledge and how does it arrive at such knowledge? Although were not ill-posed, these questions bank on the wedge between human mind and nature, a dualism. Even though traditional materialist positions denied such dualism, they yet granted that mind as an emergent property is unique and that its emergence is to be understood on a materialist basis. Although the dominant discourses in philosophy continue to remain in the same mould, ecological and evolutionary approaches to mind began to mature, particularly during the last four decades (Bateson 1979). The ecological approach first considers human being as a component of nature, with other living beings as our cognitive fellow beings. With this standpoint, the kind of questions that one may ask in epistemology takes a new turn: How does one part of nature begin to know the other components of nature? How does one part of nature begin to know about itself? What is an object that a subject may know it, and what are the subjects, that they may know an object? These questions thus are based on the assumption that we as cognitive agents are natural; that is Mind in Nature.

This Chapter portrays the contrasting views in epistemology. It reviews the three possible approaches: empiricism, rationalism, and developmental view. Piaget's genetic epistemology, a developmental approach, is one of the first comprehensive account on the biological roots of knowledge. This developmental approach is currently opposed, without questioning the biological roots of knowledge, championed by Chomsky. Developmental approaches are generally coherent with cybernetic models, of which the Maturana and Varela theory of autopoiesis made a significant theoretical move in proposing an intimate connection between metabolism and knowledge. Modular architecture is currently considered more or less an undisputed model for both biology and cognitive science. By suggesting that modulation of modules is possible by motor coordination, a proposal is made to account for higher forms of conscious cognition within the four distinguishable layers of the human mind. In the end, the problem of life and cognition is discussed in the context of the evolution of cognitive systems. The access of the phylogeny during the ontogeny is unique in human beings. The problem of cognitive development cannot be understood independent of the evolution of coding systems in nature.

## EMPIRICIST, RATIONALIST AND DEVELOPMENTAL APPROACHES

The problem of knowledge can be approached broadly from either the empiricist or the rationalist standpoints. In the former, knowledge primarily originates through sensory experience and also finds justification in experience, on which reason as an instrument acts to enrich and generate inferential (indirectly reachable) knowledge. In the latter, knowledge is generated by assimilating the experience into pre-existing (innate) ideas. While both camps agree that knowledge is encoded in concepts, they disagree on how the concepts are generated. After Immanuel Kant's criticism and reconciliation of both the traditional approaches, and introduction of the distinction between analytic and synthetic kinds of knowledge, a new tradition, often called the semantic tradition (Coffa 1991), began in philosophy. In this tradition the semantic criteria determine what is empirical without explicitly referring to the sources of knowledge. Adhering to the analytic and the synthetic distinctions, Carnap and others of the Vienna school developed a new form of empiricism, called logical empiricism, which is a combination of logic with traditional empiricism. For a detailed historical account refer Passmore (1968).

Rationalists on the other hand argued that experience is required only to trigger the realization, whereas concepts and principles of reason are born with the agent. The rationalist's continued criticism of empiricism—that most concepts cannot be obtained from experience, and therefore must be innate—continues to gain support in the current intellectual ambience. After logical positivism in philosophy, and behaviourism in psychology were seriously questioned, currently it is the age of the rationalists and constructivists. The philosophy of the constructivists has been elaborared later.

In the modern context, rationalism is mostly projected as the biologically determined, evolutionarily selected abilities of a cognitive agent, rather than the traditional nativism where there exists a mind preoccupied with ideas and principles. In his famous work Fodor (1983) has characterized a theory of modules. Several practitioners in cognitive science today hold a version of nativism championed by the well-known linguist Noam Chomsky. Chomsky (1988) questioned both the empiricist and the developmental views of language and mind, and argued that highly specialized inborn mechanisms called modules exist for grammar, logic and other subcomponents of language processing, for the visual system, for the facial recognition and so on.

Currently, the debate is essentially between the two camps: the developmentalists and the modern rationalists. The former broadly follow Jean Piaget's genetic epistemology (Piaget 1972), and the latter follow Chomsky's nativism. Both are, in a sense, revolutionary, and became very influential research programmes in cognitive science. The best source to appreciate this debate is Piattelli-Palmarini (1980). Both the camps have some common grounds. The first of these is that both approach epistemological issues with a scientific bent of mind. For example, the researchers in these camps design interesting experiments to find out whether a concept is indeed innate, or at what stage the concept actually develops. The second common ground is that both the camps take the biological roots of knowledge seriously. The third common ground is that both of them are very critical of a passive cognitive agent and join hands in criticizing behaviourists and empiricists, and deny that experience alone can generate knowledge. However, it is in this context that the two camps mainly differ. Chomsky believes that the organism is born with *deep structures* which may include substantive knowledge in the form of genetically determined highly differentiated operations, providing the basis for the further development of knowledge. Such knowledge as may be generated is entirely determined genetically. Piaget argues that highly differentiated structures develop from a minimal, less differentiated structure similar to an *ovum.* Piaget frequently uses analogical reasoning from developmental biology to suggest how specialized knowledge develops. He attributes a major role to the agent's action in constructing the knowledge. Granted that the root actions are genetically determined, all subsequent development and differentiation take place by interaction with the environment. In this model it is possible for two organisms having the same genetic make-up to possess different content of knowledge due to differences in their interactions with the environment. Another major source of disagreement between the two camps is the issue of language, arguably one of the unique features of the human beings. Chomsky considers that the form and substance of the generative grammar, which make us all speak natural languages, are entirely innate, Piaget emphasizes the role of environment in the development and differentiation of the complex structures and functions, and considers that language is an entirely *learned* ability.

This indeed brings us to the familiar nature versus nurture debate. But this debate also impinges on a deeper debate in evolutionary biology, between the Lamarckian and the Darwinian views. Chomsky's rationalism is coherent with the modern wisdom of molecular biology and organic evolution, whereas that of Piaget is different, if not incoherent, from the current wisdom. If Piaget is right, both the foundations of biology and epistemology need a change, to accommodate the modern scientific findings. It is appropriate to discuss this issue and elaborate the relation between biology and knowledge.

## THE THREE POSSIBLE LINES OF EPISTEMOLOGY

Piaget (1972) considers three possible lines of epistemology. According to the first line of thinking, development and differentiation of knowledge occur mainly due to the exogenous (environmental) factors that induce or constrain the formation of knowledge. This is considered similar to the Lamarckian views on organic evolution, according to which it is the environment that is mainly responsible for development. In epistemology it is analogous to empiricism. Just as the Lamarckian views are ridiculed in biology, empiricism too faced a similar fate in epistemology.

The second line of thinking considers the hereditary encoding of the development and differentiation of knowledge, wherein the environment plays only a triggering role. This is the dominant view in biology, both in evolution and in molecular biology, which – as suggested by the genetic dogma—precludes any possibility of 'learning' from the environment in the process of evolution or inheritance. There is no way that the offsprings could inherit an environmentally influenced **phenotype**. In epistemology this position is analogous to rationalism. Just as in biology, rationalism is dominant among epistemologists, particularly among the cognitive scientists. One may take this coherence itself as a justification, providing a stronger support for the belief that rationalism is not only philosophically cogent, but is scientifically grounded. But there is a third line, which is also sufficiently grounded in the emerging, if not accepted, dynamical systems view of science, often called complexity sciences.

According to the third line of thinking, hereditary origin is considered important, as in the second; but it considers that the environment constrains the unfolding mechanism, and the determinate character of gene expression is due to the self-regulatory (feedback) nature of the biological mechanism and not the information encoded in the genome alone. This thinking too is anti-empiricist, but is based on an ontological foundation that is different from that of the second line of thinking. The ontological foundation comprises mechanisms such as *assimilation*, *accommodation*, and *equilibrium* (Piaget 1971). A genetically determined structure provides the basis for initial assimilation of the environment. When the agent encounters a different environment, it introduces a challenge, and an autoregulatory accommodation responds to the challenge. This is a change in the internal structure arising as a result of the environmental factor.

Let us consider the immune system of higher vertebrates as a figurative example to understand Piaget's model. When an antigen encounters the agent, and if the agent had already produced an antibody, the antigen will be assimilated, otherwise the agent generates new antibodies. This is a case of accommodation, a change in the structures, in order to assimilate the changed environment. This leads to adaptation and equilibrium. A change in the conceptual scheme when it cannot assimilate a new fact is the analogical epistemological mechanism. The new conceptual scheme after accommodation is not imprinted in the genome, but it developed due to the inherent property of autoregulation. This capacity for autoregulation is genetic, but the specificity of accommodations that are carried out by the agent are not. They are *discovered* as and when the environment demands, and this way nature constrains the development and differentiation of knowledge. During this process, a *transfer of order*, so to state, takes place from the environment to the organism, through feedback. The character of the **genotype** is not entirely autonomous or completely predetermined. This is the central point of debate between Piaget and Chomsky.

A molecular biologist would argue, in a similar Chomskian style, that the regulating and the regulated are both biologically determined in the genome. The blueprint of the organism contains the total range of regulatory mechanisms and this *genetic envelope* is insulated from penetration except by mutations. And these mutations are independent of the factors that give rise to accommodation, and so there exists no environmental influence on what is inherited. Thus the ontological presuppositions of Piaget and

Chomsky are different. For Chomsky, the genotype provides the *competence* which is a large stock of logical potentialities defined for each species, while the phenotype is the context-dependent expression based on *performance* (Piattelli-Palmarini 1980). Stated alternatively the difference between the two propositions is what determines the set of all logical possibilities. While the Chomskian would argue that all possible phenotypes are predefined in the genotype, the Piagetian would argue that the set of all possible phenotypes is not contained in the genotype, but it is dynamically generated depending on the environmental constraints at the time of life; in fact life for Piaget is defined as its ability to invent through autoregulation compensatory mechanisms to environmental challenges.

This still remains an open debate. But, interestingly, this debate, unlike the traditional philosophical debates, may find a scientific solution, for both the propositions take their positions as hypotheses, and are therefore subject to falsification. What kind of evidence is required to falsify them?

Both the models predict that two individuals of an organism with identical genotypes in a similar environment would behave similarly. According to the second line, because the environment and the genotype are the same, no difference in behaviour is possible, for the same environment would trigger the same genes to express. While according to the third line of thinking, the expression of the genotype is a dynamically arbitrated solution, it is possible that the same environmental challenge may find alternative autoregulations (expressions). These alternatives could lead to different adaptations. Thus the third line of thinking is less deterministic than the second. But conducting a crucial experiment of this kind is not easy. Theoretically, both the approaches are strong research programs and are both live.

## METABOLIC ROOTS OF KNOWLEDGE

The third line of epistemology presupposes an ontology, wherein during the course of evolution, the biophysical space developed a defining feature called *self-organization*. The notion of self-organization is a generic concept that subsumes, under a single theoretical framework, the apparently different domains of metabolism, reproduction, evolution, ecology and cognition. Several phenomena such as autoregulation, self-reproduction, autocatalysis, self-production, and 'self-this' and 'auto-that' are all similar in the sense that they presuppose that physical matter could, under certain special conditions, organize into systems capable of producing living, evolutionary or cognitive behaviour. Although different scholars have proposed and held these approaches, their pattern of reasoning underlies similar style of scientific thinking, which for convenience can be called cybernetic. The notions are not defined similarly by the various proponents of this school of thought; therefore only the view that is easy to comprehend is presented. The general school of biology considers metabolism, structure, growth and development, as fundamentally distinct from reproduction of the organism. Eigen and Schuster (1979) proposed that organisms comprise functionally related self-replicative units formed into multiple feedback loops; i.e., autocatalytic hypercycles. This idea can be understood easily by taking into account that every metabolite in a living organism or cell participates in a set of metabolic interactions, and in the process they do become transformed. When a metabolite is transformed, it is replaced by its copy which is biosynthetically produced. Thus, every metabolite needs to be replaced by a biosynthetic process. Those metabolites that cannot be replaced within the cell must be obtained from outside the cell, usually by *ingestion.* Some of the participating metabolites help, as catalysts, certain interactions, in which the change that they undergo is often not destructive; so they retain their functionality even after the interaction. Such molecules are the catalytic enzymes. This description helps us to attribute enzymatic catalysis to any molecule that has such role. Indeed Eigen attributed enzymatic role to other molecules such as RNA. When we consider metabolism from this view, the reproduction of the cell as a whole can be seen as a culmination of a series of layered autocatalytic hypercycles. Thus, the biosynthesis of DNA which happens once in each cell cycle can be seen as a special case of the same replications that are happening all over the cell. The rate at which other metabolites replicate is always higher than that of replication of the genetic material, which replicates only once in a cell cycle.

How can this view help us in understanding the phenomena of cognition? The two South American system theorists, Humberto Maturana and Francisco Varela made an ingenious proposal in extending this view of metabolism to cognition. Maturana and Varela (1987) proposed that the cellular metabolism is essentially a repairing of the self from the perturbations by self-production (**autopoiesis**[1]). According to this proposal the organisms' behaviour cannot be understood without relating it to the environment. An organism's constitution is nothing but a compensatory mechanism for environmental perturbations. An organism is adapted to an environment, if and only if it has a mechanism to compensate for the perturbation. For example, when light falls on our retina (the photoreceptor in the eye), the polarized state of the highly sensitive surface gets perturbed and it becomes depolarized. The part of the retina that is affected must be immediately repaired, so that it can be active again. This repair process is the compensatory mechanism, and this happens by reproducing the metabolites. This production process is called *autopoiesis,* meaning self-production. Apart from light, there are many other environmental factors that perturb a living cell, and a cell can sustain, only if it has a repair mechanism. Thus, all metabolic loops within the cell could be understood as special compensatory mechanisms. The example of the photoreceptor tells us, the occulocentric cognitive beings, how the process can be connected to cognition. A similar explanation can be given of other sensory organs.

We cannot perceive anything in the environment unless the object of perception is metabolically related to us. This seems counter-intuitive, because several of the inanimate objects in our surronding environment do not have any apparent metabolic relation with us. However, the objects of perception are not the objects out there, but a representation of them through the sensory organs. If the sensory organs do not metabolically react to what reaches from the external objects, through light, heat or mechanical sensation, such objects are not part of the perceptual field of the subject. For example, an organism that cannot repair the perturbation caused by ultraviolet rays cannot, as a consequence perceive the ultraviolet rays. An organism, therefore, can know only the dimensions of the environment to which it is adapted. Thus the relation between the subject and the object is defined as to what the subject can assimilate and accommodate. The theory of autopoiesis therefore should be considered as a extension of Piaget's proposal between biology and knowledge. Maturana and Varela (1987) transformed Piaget's notion of autoregulation in terms of assimilation and accomodation into autopoiesis, and proposed an intimate connection between knowledge and metabolism. In their model, to know is to live, and to live is to know. This cryptic remark raises several questions: Plants live, but do they have knowledge? If so, what is the nature of their knowledge? What knowledge do sponges, worms, and other 'inferior' animals have? These questions do indicate the limitations of the theory of autopoiesis, as pointed out later in this section.

Autopoietic systems are also organizationally closed (Varela and Goguen 1977), i.e., they have a circular network of interactions, as explained above. Organisms are in a continuous dialogue with Nature. The identity of a living organism 'emerges' in this dialogue *with* the environment. According to Varela, an organism asserts individuality through compensations of the perturbations caused by the interactions with the environment. When this process happens properly, there is adaptation and stability. But the stability is due to circular and interlinked organization. Although there are constant perturbations, and the compensatory responses, the organism maintains a relative order of the components. This is the dynamic network that identifies an organism's structure. Although the living systems are organizationally closed, they are open in terms of matter and energy. That is how autopoiesis produces stability by organizational closure. Stability or adaptation, thus, can be meaningfully considered only in relation to the surrounding environment.

This intimate relationship between the organism and the environment provides a framework to discuss the cognitive connection. Given this picture, should we understand cognition as merely due to the perturbations, or the resident repair mechanisms? According to Maturana, cognition must be understood from inside rather than the outside, i.e., the organism, rather than the structure of the external perturbations, constructs the phenomena. What appears does not depend on what is present outside the agent, but on what the agent can relate to. The external perturbations could neither control nor determine what happens inside. Therefore the structure of this relation is entirely internal. Thus this view is a constructivist position, because the agent constructed the phenomena. And the view is somewhat coherent with that of Piaget, because the agent must perform an action (compensation) in order to engage in a cognitive relation with an external object. What actions the agent can perform depends on what species it is, and what a species is depends on the genetic make-up of the agent. Thus, this is also a version of rationalist account of cognition.

What is an object that a subject may perceive? A perceptual object is that which can induce a perturbation in a cognizant system, if the system has an ability to repair the induced perturbation. Thus a close relationship between the living mechanism and the cognitive mechanism is established. Therefore, the fundamental questions related to life and cognition are not independent of one another, and the same logical space which enables life, also enables cognition. These are two manifestations of the same ontological phenomenon.

Even if we suppose that the foregoing account answered satisfactorily the biological roots of cognition, the picture is obviously incomplete. Although the metabolic compensations can be said to define what can be a part of the perceptual space, it may not enable us to understand how the organism becomes *aware* of the metabolic compensations. For example, every compensatory path in the agent is not known to the agent, in the sense of awareness. What is knowledge without awareness? Further, can cognitive agents opt for or opt out of certain perceptions? We also need to account for a situation in which an agent is aware that it is aware (consciousness). What about theoretical knowledge such as science and technical knowledge? We will now consider these questions and how the answers to them also depend substantially on the biological bases.

## MODULAR ARCHITECTURE IN BIOLOGY AND MIND

One of the characteristics of the complex biological organization, apart from organizational closure, is its modular architecture. A complex system is described as modular, if it is made of several components called modules or subsystems, and each module functions more or less independently of the other modules. Each module is highly differentiated in its structure and performs a specific function very efficiently, while it may share a generic base with the other modules. Understanding the physiology in terms of modular model is not new to biology. The organization of a complex multicellular organism is usually understood in terms of cells as the ultimate building blocks, which on differentiation produce tissues endowed with specific functions, and the tissues in turn become organized to form organs, then into organ systems, and finally to a single system in the form of an organism. Each organ operates as a module performing a specific function efficiently. It is also an important characteristic of the modules that the mechanism of each module is *domain specific.* Domain specificity implies that different modules behave differently, and they do not have any generic form into which their behaviour can be reduced. The functional efficiency is often attributed to the domain specificity.

The cognitive scientists take the modular architecture in biology very seriously, and extend the same pattern of thinking to the understanding of cognitive phenomena. Jerry Fodor is one of the first scholars to combine the modularity view with a computational view of the mind. In this model, the mind comprises several input subsystems producing swift *thoughtless* outputs. Cognitive modules, apart from being domain-specific, are said to be informationally encapsulated, i.e., the internal operations are not accessible to other subsystems. Their operations are involuntary. Fodor (1983, 2000) proposed that the modules are wholly determined by evolutionarily selected genetic endowment. According to Fodor, modularity is characteristic of only the input subsystems (the peripheral perceptual subsystems such as the visual, auditory, tactile and so on). The output of these subsystems is processed further by a *central processing system.* This is the high level central cognitive system that is involved in belief, creativity, reasoning and such other traits. The processing of the central system, unlike the input subsystems, is voluntary and relatively slow. Whereas Fodor argued that the outputs are processed by nonmodular central processing which works relatively slowly and *thoughtfully,* others namely Cosmides and Tooby (1994), Sperber (1994), Pinker (1997), and Carruthers

(2006) have argued that every faculty of mind is modular, also known as massively modular (Tooby 1994, Pinker 1997, Sperber 1994, Carruthers 2006). This debate among them is still on, although the majority is with the massive modularity view of the mind.

Evidence for modularity comes from the neurophysiological cases in which several patients displayed the loss of a *faculty* independent of others, due to partial damages in the brain. Another argument in favour of modularity stems from evolutionary assumptions. Slow, nonmodular, nonspecific domain processing would not be selected, because it is not evolutionarily advantageous, and would not have evolved by natural selection. General processing systems may not even behave consistently and would not give reliable results. Only the swifter automatic subsystems would have been naturally selected during the course of phylogeny (Cosmides and Tooby 1994). Anderson (1983) on the other hand believed that there would not have been enough time to evolve so many special modules, for human evolution has relatively a very short history. Most of the higher cognitive abilities 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. That there is almost a complete match between the genetic code of apes and that of human beings supports the existence of general architecture. Donald (1991) has offered a comprehensive comparison of modular versus unitary models of cognition.

Affinity toward modularity arises also due to possible computational implementations. Computationally it is possible to implement automata which are assemblies of several independently functioning modules. Therefore modular aspects of mind can be implemented computationally. However, the higher cognitive functions, such as thought and reasoning, do not seem to be modular. Following this line, Fodor argues that computational theory of mind cannot answer global inferences such as **abduction**. Abduction is a special kind of inference that yields a statement which explains a given situation, only if we suppose the statement. Peirce (1931, refer Hartshorne and Weiss 1931) was the first to propose this form of logic; recently this logic has attracted a lot of attention in philosophy of science and computer science. Fodor (2000) argued that no modular processing can arrive at such a statement in a reasonable period of time, and that global inferences such as abduction cannot be accounted. However, according to Penrose (1989), artificial intelligence (AI) cannot solve the problem of consciousness, because Gödel's theorem, which sets a limit to what a Turing's computer can do, proves the impossibility of AI. Penrose (1994) further argues that classical physics cannot address the consciousness problem, while quantum physics can. Based on Hameroff's findings that **microtubules**, which form a scaffolding for the cytoskeleton of a cell, Penrose hypothesizes that the microtubules can form a basis for the complex mental operations where, at Planck-scale quantum functions collapse to generate consciousness. Both Fodor's and Penrose's arguments suggest that higher faculties of mind cannot be assimilated in a computational framework, although their arguments are different.

Modularity, as a general feature, is commonly seen in biological organizations at all levels of complexity. There is a greater consensus that an organism is gradually and hierarchically constructed of subsystems (Simon 1962). This therefore is taken as an argument in favour of massive modularity. The possibility of transplanting some subsystems by artificial ones, is also a strong evidence in favour of modular architecture in biology. However, not all the biological organs are directly related to what we normally call cognitively functional organs, for example, the heart. The sensory organs (as input subsystems) are not so different from other biological organs and organ systems, because each of them has a domain-specific function to perform and works independently of others. 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. In addition to 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 the language. However, it is not very clear how without any significant difference in the genetic make-up, say between a chimp and a human being, a biological system begins to display language behaviour. Therefore, what makes a subsystem cognitive and what makes human cognition so different are still open questions.

When we look at the apparent differences between humans and other beings, encephalization, i.e., an increase in the relative size of the neocortex in the brain, stands out prominently. Human brain is the largest (about three times that of the nearest primates) in relation to the rest of the body, and has about double the number of neurons present in the nearest primate. The large size of the human brain is attributed to the increased size of the neocortex (cerebral cortex) which contains three fourths of the total number of neurons in the brain; the neurons are organized into two hemispheres. The other anatomical differences are the lateralization of the two hemispheres (the analytic left, and the synthetic right), and the dexterous erect posture enabling the human being to stand on two feet. Language and social culture are the striking behavioural differences that make us markedly distinct from other beings. Although these differences are well known, what still remains a problem is to understand which differences determine what. Also whether the biological differences determine the socio-cultural behaviour, or vice versa. It is also important to note that both the unitary and the modular theories are plausible with respect to biological as well as sociocultural accounts.

We will explore a way of bridging the apparent divisions presented in the previous paragraphs, namely the modular and the nonmodular, the domain-specific and the domain-general, the biological and the cultural. There seems to exist a mechanism of *modulating* the modules; this eventually generates the higher and peculiarly human cognitive abilities, making the human beings distinctive even while sharing the same biological base. It is suggested that the mechanism of modulating the modules transforms the implicit instinctive procedural behaviour into explicit declarative knowledge with awareness.

Jean Piaget's theory of cognitive development is today considered to be a domain general unitary theory. 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—for example, perception, concept formation, arithmetic, language, space and time, geometry and so on—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 differences in the cognitive tasks of each domain (Carey and Gelman 1991, Hirschfeld and Gelman 1994). The recent developmental psychologists question both the domain-generality and the stage theory of Piaget.

In an intellectual atmosphere where behaviourism and empiricism are belittled, Naom Chomsky's nativism has taken firm roots among several practitioners in cognitive science. Chomsky questioned the developmental views of language, such as Piaget's, and argued that highly specialized inborn mechanisms called modules exist for grammar, logic and other subcomponents of language processing, visual system, facial recognition and such other features (Chomsky 1988). Fodor (1983) as stated earlier, furthered this line of thinking and provided a foundation by characterizing a theory of modules. We shall see how modularity can be dissolved for developing higher cognitive abilities without affecting the modular biological basis.

## MODULATION OF MODULES AND AUTOREGULATION

We have elaborated two suggestions: the first, that all functions, including the higher level cognitive functions, are modular; and the second, that most functions are modular except the higher level cognitive functions (intelligence, reason, and consciousness) which are nonmodular. If we can demonstrate that everything is modular, it would be easy to establish a biological basis for cognition, because each module is considered genetically endowed and naturally selected during evolution. If certain faculties are not modular, this may suggest that these components are not automated, and their behaviour may leave room for some nonbiological basis. It is important therefore to note that the thesis, the modularity of mind is a version of nativism. For those who argue for massive modularity, cognitive development is more or less a genetically determined process. Developmental psychologists such as Piaget argued against such a view, for they thought that there exists a general unitary mechanism which is genetic, but the various behavioural manifestations are all learned after birth.

Karmiloff-Smith (1992) addressed this problem by a reconciliation of Fodor and Piaget. She accepted that modularity is an important character of cognitive functions, but suggested that modules have a developmental history, proposed a theory of *representational redescription.* According to this theory, knowledge to begin with is implicitly represented, and like modular knowledge, not accessible to conscious awareness. Such implicit knowledge gets re-encoded during the course of cognitive development, and each re-encoding makes it less and less implicit. This process is called representational redescription. Thus, when such a process happens recursively, knowledge becomes more and more explicit. However, this process is not linear. Along the way modularization takes place. Each module makes the knowledge procedural and becomes implicit. For example, when we learn how to drive a bicycle, we follow certain procedure consciously, to begin with, and when we master the procedure, the declaratively accessible explicit knowledge soon becomes an implicit procedure. There is a stage, before modularization, when the behaviour is imperfect, and after achieving behavioural mastery we do no more mistakes and the behaviour becomes modular. During this process, we may begin with conscious awareness, but after modularization we do it without any explicit awareness. Thus, modular phase is an automated phase.

There exists therefore a sort of the dialectical process between the implicit and the explicit, the unconscious and the conscious, the procedural and the declarative, and the nonmodular and the modular. During cognitive development this process happens recursively generating more and more explicit knowledge. Modularization in this way can be a part of learning itself. This mechanism helps us to understand why everything need not be innate in order to account for modularity.

Having explained how modularity need not be innately specified, let us now examine whether informational encapsulation (insulation), inaccessibility of internal data and processing details, should be a defining feature of a cognitive module. According to Fodor, without such a feature nothing significant can be said about cognitive 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 if so, which aspect of cognition? What happens if an input subsystem (a module) is not encapsulated?

So much of data, we assume, must be generated by our several input subsystems, particularly sensory 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 so long a 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. 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 in Fodor's model: although the internal details of how the information is processed is not available, the output produced by them is available to the central system. Although this approach did eliminate a lot of processing details from out of the gaze, the generated output of the modules for each moment is not small either. Our consciousness does not seem to be attending to every chunk of the output from each input system. But by assuming that there exists an access to the output, and by supposing that it is not encoded in a 'proprietary' format, we created a situation so that when we wish we can attend to the output. Because we do not seem to account for all of the accessible chunks, there appears to be another layer of 'encapsulation', or some other unknown mechanism; but at this encapsulation, unlike in the first encapsulation, the data are not encoded in a proprietary format. However, we still need an explanation as to how we can attend to one among a bundle of output chunks at any given moment. That there exists a mechanism of controlling or modulating the processing of modules. Let us call this mechanism, the *modulation of modules*, which introduces the required informational access. What is being suggested is that the cognitive agent to begin with *consciously* performs certain operations that alter the perceptual space in a controlled way. For example, when we move our eye muscles to focus once on the window pane, and once on the trunk of a distant tree, we are controlling what enters our eyes, and therefore the output of visual module. Once we learn how to do it, we do it unconsiously, but the fact that it can be done consciously explains why there is no encapsulation. The motor input system can affect the visual field. Because this operation is deliberate, we are possibly certain that the differences in the perceptual field are due to motor action.

To recognize the causal connection between differences in the appearances, we need no higher form of inference like abduction, as Fodor thought. The preconditions for inference are already available to the subject, because the motor modulation, which can be voluntary, is initiated by the subject. This makes the inference fast and direct. If we assume a loop between the sensory subsystem and a modulation system, we do not need another central processing unit to solve the problem. Voluntary muscles controlled by the central nervous system could form a loop with the sensory subsystems to generate the required self-modulation. This way we eliminate the need for another unknown and mysterious central processing system. Looking for such a centre in the brain or any other portion of the body will be a futile exercise.

What is central in this proposal is that there exists a cognitively vital subsystem that does action, such as motor action, which serves as an input system **(proprioceptor).** This subsystem alone can generate explicit declarative knowledge of the conscious kind, and not the sensory organs or the neural circuitry as most cognitive scientists believe. This is not to undermine the role played by the neural or sensory subsystems. Indeed, to have controlled actions we do need a complex circuit, which the nervous system provides, and the sensory organs provide the input. Further details of this proposal are given in (Nagarjuna 2005).

Making activities the basis of cognition is coherent with Piaget's theory. According to Piaget, a cognitive agent actively constructs knowledge by acting on the objects. These activities are generally considered to be some kind of inaccessible *mental actions,* and not substantial and accessible actions like the motor actions.

Another argument can be advanced to demonstrate that some sort of interaction is essential among modules to generate meaningful knowledge. Let us suppose a cognitive agent that has only one input subsystem, and 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 cannot generate any bit of information. Why? Because, such a perceptual space is *blind.* That will be like an undifferentiated ether. Information is a result of *differentiated difference,* which comes only by the *interference* of another dimension generated by another subsystem. When two or more dimensions *cross* 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 Marr's (1983) computational theory of vision. Marr proposed quite a few *modular* devices, each of which detects motion, edge, surface texture and such other traits. 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. Fodor (1983) thinks that this provides a confirmational basis for modularity. Each chunk of vision is already informationally very complex, because it comes with such notions as space, position, shape, size, color, edge, and motion. Thus the processing that happens within the vision module is already a result of cross-representations.

Assuming that each dimension comes to us from an independent module and from the information impinging on our mental 'screen', we may think that the story of perception ends here. But it does not. We may be able to see changes in the screen, but how do we know what causes (constrains) each of these changes? Mere cross-representation is not enough, because we will never know if there is a cross, and if it is an invariant. We need to introduce a mechanism to control (modulate) the crossing too, in order to detect the difference.

If the proposal is valid, one thing is clear: knowledge is generated due to modulation of representations which produce cross-representations. Each cross-representation is supposedly a good candidate for a percept or concept. This mechanism then may be either innate or learned. The potential to modulate is supposedly innate, while the context for modulation is behavioural and cultural. What seems the likely basis for concept formation is a loose physiological coupling, characterized by interactive and functional relations between different domain-specific subsystems, rather than the encapsulated modular structures.

Consequently, we, at least the human beings, are not relegated to accepting what the input subsystems have to offer. We have the ability to differentiate the differences caused by the input systems. We can simulate? the differences without the input systems by codified modulatory actions. This provides a possibility to 'operate' without sensory organs. Is not this possibility enough to account for thought as simulation. Most animals may be permanently attached to appearances, but due to our freedom to modulate perceptual field and simulate without perceptions we gain consciousness and thought.

## LAYERS IN THE FABRIC OF MIND

The previous section suggested that the domain-specific modules can be modulated, and that this process has the potential to explain the genesis of conscious declarative knowledge. In the process the implicit procedural 'knowledge' transforms itself into explicit declarative knowledge. By demonstrating that modules can be modulated by the agent's actions, the modules become Piaget's *schemes.* This reconciliation of nativism and Piaget is different from that of Karmiloff-Smith. In the latter's account, the modules are the product of postnatal development. My suggestion is that the input subsystems are hardwired and biologically given, and are a result of embryogenesis. This embryological process is purely biological. And the biological ontogeny in the form of maturation continues even after birth, and this process may enhance the sensory-motor potential, but it remains biological nevertheless. This developmental process is the bedrock for other layers in the story.

### Layer 1—The Biological Ontogeny

Cognitive development essentially begins after birth, although we now know that some learning actually begins even while in the womb. The newly born child is like a cognitive 'ovum', gets 'fertilized' by experience of both the cultural world and the 'natural' world. This onsets the development of the layer 2.

## Layer 2—Subjective Cognitive Ontogeny

The process of subjective cognitive ontogeny also continues to develop, although it reaches maturation (meaning modularization) rather fast. The representations that are produced as a result of the subjective cognitive ontogeny are *cross-representations*, and they remain *procedural*. This corresponds to the Piaget's sensory-motor stage, and the percepts of Mandler (2004). One important difference is that these layers continue to exist and develop, and they do not stop or transform into another layer at any time. Subjective experience does not cease when we tend to become intersubjective or objective. Layer 2 produces the mandatory appearances that sometimes result in illusions. Most of the animal cognition remains at this stage, because the process that generates the other cognitive layers, and the modulation of cross-representations do not seem to be available to the animals. Karmiloff-Smith's representational redescription, for the same reason is also not available to them. This more or less corresponds to the 'implicit' level in Karmiloff-Smith's theory.

## Layer 3—Intersubjective Cognitive Ontogeny

The first two layers form the foundation for layer 3 called inter-subjective cognitive ontogeny. In some of the higher cognitive agents, particularly the human beings, the implicit procedural knowledge transits to explicit declarative knowledge by modulation of cross-representations, which lead to redescription of the representations and generation of the explicit representations. The cognitive agent for the first time in the cognitive ontogeny begins to develop a *detachment* between the *sign* and the *signifier*, in which the former is publicly (intersubjectively) accessible. This is when the precepts become the concepts. Layer 3 is sufficiently complex and amenable for further layers within.

Karmiloff-Smith (1992) distinguishes three 'levels' in Layer 3, namely, Explicit 1(E1), Explicit 2(E2), and Explicit 3(E3). E1 is explicit but not accessible for consciousness, E2 is explicit and accessible for consciousness, and E3 is accessible, conscious, and verbally reportable. Although there is no strict matching with our account, Merlin Donald's three stages in the phylogeny of the modern human also fall in Layer 3. Donald (1991) identifies in the phylogeny a stage of episodic representations to begin with leading to semantic externalized representations, mediated by mimetic and mythic layers. It is during this process that the most unique human character, namely the language module, develops. This view is unlike those of Chomsky and Fodor, who both argued for the innate language module(s). However, the language is mostly 'hereditary' in the broader sense that includes both biological and cultural inheritance. This model precludes the possibility of the development of language without a social world. Behaviourally, lot of play, practice and enculturation (training) are responsible for this layer 3 to develop. Socialization and language go hand in hand, for they are not possible without one another. It seems therefore plausible to hypothesize that representational redescription is an *essential* mechanism in producing *external* memory space to help enhance the much needed memory capacity for storing the cultural heritage, and also for the *detached* processing of information (Gärdenfors 2003). Thought and imagination too are due to the *detached* processing of representations, but it happens in the subjective space—internal modulations. Layer 3 is too elaborate to explain in a paragraph or two. To sum up, what happens in layer 3 is that implicit procedural representations transform into explicit declarative knowledge by 'rewriting'. This proccess is the hub of all eventual higher cognitive functions. Layer 3 has all the necessary paraphernalia for developing the peculiar socio-cultural human life. It culminates to produce folklore.

## Layer 4—Formal Cognitive Ontogeny

The three layers thus formed become the foundation for the exclusively human layer 4 called the formal cognitive ontogeny. This layer develops by transformation from the folklore of layer 3. In this new layer, layer 4, the declarative knowledge of the folklore becomes redescribed in formal operations. In this layer, no assumptions remain implicit. The knowledge of the layer 3 depends a lot on the implicit and subjectively available experience. All the knowledge is stated as a declarative representation. During formal cognitive ontogeny, the concepts are artificially and operationally *represented* without a direct bearing on the experience. They may be idealizations of the layer 3 concepts. The concepts that form the basis of formal knowledge may or may not have an observational grounding, but only an operational basis. Here, operational means rule-based construction which itself is founded on definitions. Because definitions state the conditions explicitly, confining to a constructed conceptual space, it makes the 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; this means that the logical space of a possible world extends beyond the actual space of a real world. This constructed form of knowledge ends up as formal, mathematical and scientific knowledge; formal does not mean only mathematical or algebraic. A knowledge becomes formal, when any representation—the symbols, the rules of combining them, relations between them, and such related aspects—are fully made explicit. This requires that knowledge be re-represented in an entirely artificial language. What has been said above comes closer to certain branches of science such as physics, but for other sciences such as biology, economics and social science this view may be rejected. The possibility of reconstructing an artificial language by using the mostly available vocabulary from the folklore masks 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 bearing the same terms, the notions of heart and of species in the folklore do not extend into biological space. If this view, that science is not a part of layer 3, is true, then it will have serious implications for the philosophy of science. Most science education practices assume that science is an extension of common sense. The view that is being argued for demands an epistemic break from common sense. For a complete statement of this position, see "Layers in the Fabric of Mind" (Nagarjuna 2006), where a demarcation criterion in the form of conditions that make the transition from folklore to science is presented.

A few lines on the nature of the layers would be relevant. What relationships hold 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 nonliving layer, the formal layer depends on the folk layer, and the folk layer depends on the biological layers. Once developed, the top layers do not replace the bottom layers; they merely cover them. This view is different from that of Kuhn (1970) who argued that a given revolution replaces a former body of knowledge. Kuhn's view is the most outlandish, and, yet unfortunately the most influential view from an otherwise careful historian of science. Elsewhere it has been argued (Nagarjuna 1994) that Kuhn confuses psychological (ontogenic) replacement that *may* happen in a believer with an epistemological replacement. The 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. The stage view suggests that the cognitive being transits from one kind to another. The 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 *escaping* form the subsequents shown in Fig. 8.1; 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.

How does this layered view of mind based on actions modulating the modules address the problem of this essay: whether knowledge is a product of development and learning, or it is entirely innate and biologically determined. The account presented here suggests that the ability to act is entirely genetic. But, which specific action to perform at a given time is not; this is environmentally specifiable. Knowledge, particularly conscious knowledge, arises from this loose physiological coupling between action and environment. If this coupling is strong and mandatory, our cognition will not be different from that of primitive animals. Higher animals, more specifically human beings, developed an ability to modulate due to more sophisticated motor system. This modulation introduces freedom, which increases from layer 1 to layer 4. Thus the picture seems to corroborating the third line of epistemology mentioned in the earlier section where the expression of the genotype is a dynamically arbitrated solution with the environment. In human beings, such an environment also includes other subjects. Any disregard of the social environment in understanding human nature is, in my opinion, futile.

## NATURE AND NURTURE IN THE CONTEXT OF PHYLOGENY INTERACTING WITH ONTOGENY

The nature versus nurture debate can be approached from a broad evolutionary history of the cosmos. Most accounts of the history of time tend to give us a linear image of it,

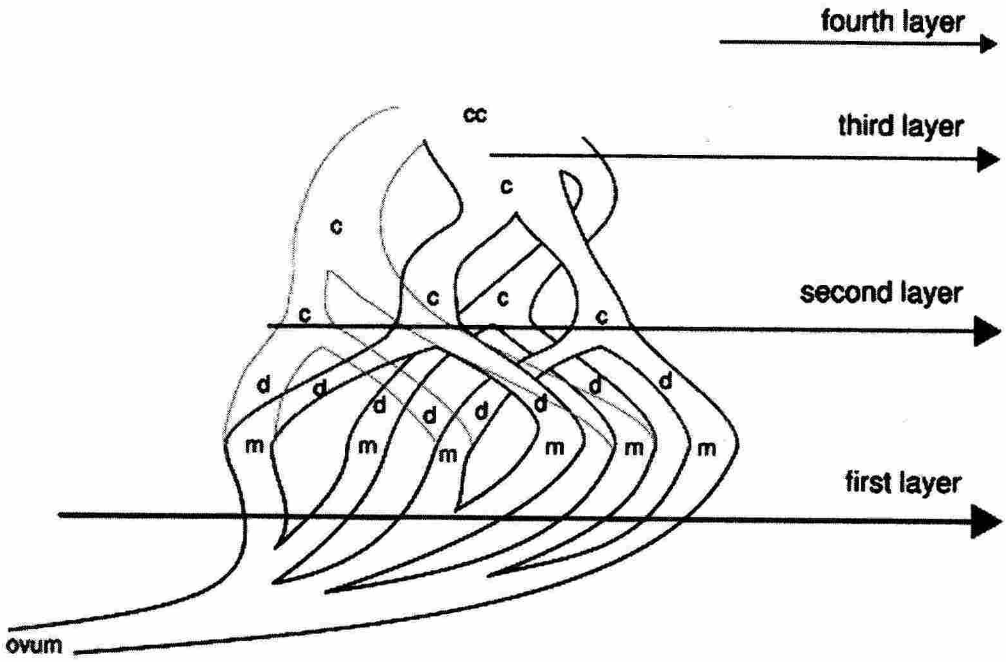


**Fig. 8.1.** Diagrammatic representation of the layered view; the four layers in the Fabric of Mind. The undifferentiated ovum develops through embryogenesis into a modular differentiated organism. Each module (**m**) generates a domain-specific dimension (**d**), which crosses each other by modulation to produce cross-representations (**c**). Upon differentiation of the different cross-representations originate a unitary conscious cognition (**cc**). The arrows indicate roughly that the lower layer(s) continue(s) to develop and exist while the upper layers develop.
(See colour figure on Colour Plate 3)

from the big bang to the current state. In contrast to this, the history of time has been portrayed here in the form of several orthogonal layers (Fig. 8.2). Each layer in the figure represents the history of *a time* that is orthogonal to the one before it. One layer depends on the other transitively and asymmetrically. The following examples will make this clear and will also provide a deeper context to the debate.

We are familiar with the concept of origin and evolution of the universe as a whole; we talk of understanding the entire span starting from the ultimate constituents such as quarks, if we are allowed to begin there, to galactic clusters, if this is where we stop at the other end of the span. This story is about the smallest to the largest, a story of *aggregation* of masses. The nature that we know is unfortunately not as simple as that, for the simple to the complex is not merely a story of the aggregation of small masses to become massive.

Orthogonal to this layer of history is another spectrum of combinations of simple structures to form complex structures. This is more akin to the story of chemistry, where complexity is not determined by a mere aggregation of masses, but of the formation of different *identities* or *elements*. Here we deal with the difference between simpler elements such as hydrogen on the one side and more complex and heavy radioactive elements on the other.

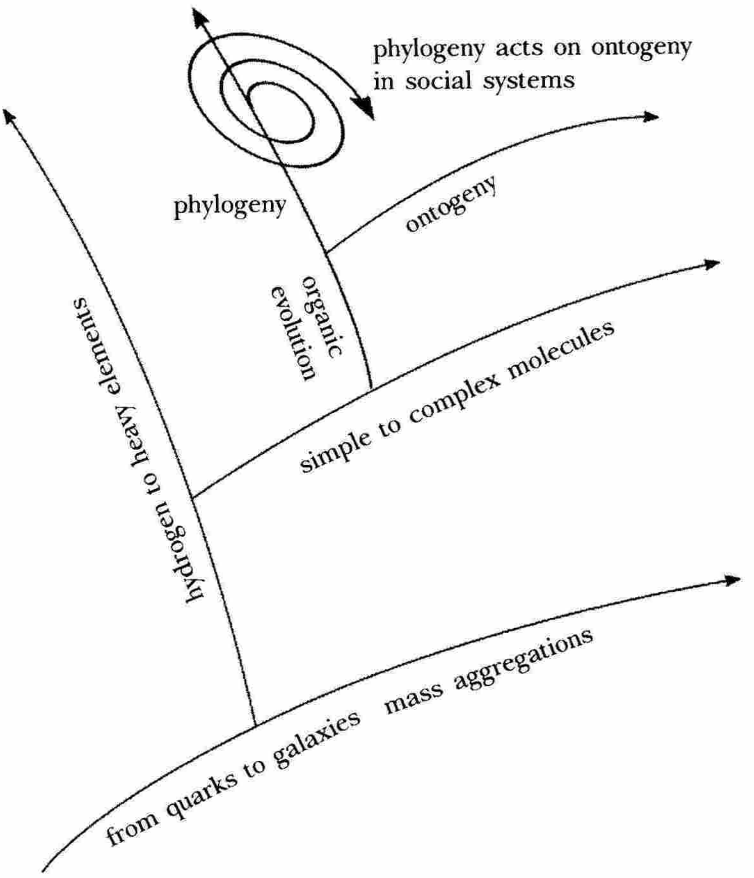


**Fig. 8.2.** Orthogonal time arrows in the evolution of complexity.During organic evolution, phylogeny and ontogeny remain more or less independent paths of development for most animals. In human beings, ontogeny develops an access to the immediate phylogeny of the species, after the development of sociocultural inheritance. The spiral arrow represents the unfolding ontogeny under the inflluence of human being's access to the past in the form of culturally encoded knowledge.

Orthogonal to this evolution of chemical elements, there is another line of history, and that is of molecules. Interactions among elements generate new possibilities of combinations leading to a wide variety of simple to complex molecules. Toward the more complex end of this spectrum we see the complex organic molecules.

Another layer of orthogonal evolution is the familiar organic evolution, which takes off from the self-organization of organic molecules to produce the identities called cells. Of all the stories of natural evolution stated above, a new kind of history begins after the emergence of cells. This time the structures formed (cells) develop a unique property of maintaining their identity (organizational closure) and develop and differentiate without lossing that identity. This development and differentiation happen in two, again, orthogonal lines of history: phylogeny and ontogeny. Phylogeny reflects the maintenance, development and differentiation of life into different species, while ontogeny reflects the maintenance, development and differentiation of an ovum into a multicellular organization. The time scale of the latter is a small moment compared to the geological time scale of phylogeny.

One further layer of orthogonal evolution takes place on top of the previous one, which also differentiates into the phylogenetic and ontogenetic time scales. This is actually the topic of the essay, about knowledge. An organism during the course of its life does develop knowledge about its surrounding environment, and this knowledge is essential for its survival. The organism acquires a memory of its past successes and failures, which guides it through its life. This memory is what we normally call knowledge, usually encoded and recollected as concepts. In human beings, and possibly in a few other organisms, the ontological time is not the only source of knowledge. The phylogenetic time, in the form of history of knowledge, does play a substantially influential role in determining the life of the human organism. The human being's survival depends not so much on what it can learn during its ontogeny, as, almost exclusively, from what it learns from phylogeny. This transfer of order, so to state, takes place through enculturation or education in human life. This is some times dubbed as social inheritance—inheritance through ***memes***.

The amazing richness of what came out of this multilayered history of the cosmos can be understood by contrasting, say a 70 kg of helium, or a diamond, with 70 kg of Einstein. Organic life is not a mere aggregation of physical substance, but a wonderfully orchestrated group of interacting *agents*, acting both within and with the environment. It is the nature of interactions among the various agents that determines the emerging character of the organism.

When we compare the various layers so far discussed, one of the most striking differences is that in human history, most likely for the first time in the history of the cosmos, phylogeny interacts directly with ontogeny. The past is working, as it were, in the present. This is one of the main reasons our current life cannot be studied independently of the social history. We have access to our phylogeny, unlike other beings, however indirect it may be. The access though is not so indirect. The longer life time of each individual enables us to interact with quite a few generations—both younger and older of other individuals. Added to this access is the symbolic records of phylogeny encoded in our cultural heritage, including particularly the languages, making the process even more efficacious. Therefore what is essential is to understand what makes this access to the past and future possible. Knowledge is just another name for our access to the past and future. Human knowledge is so rich, even without modern science, that an understanding of this process is no easy task. This subject is so special that it cannot be understood without tracing its roots in biology, and without the influence of socio-cultural life. What physical, biological and social factors make knowledge possible? Currently this is the engaging problem in cognitive science. One of the most fascinating and not well understood relationship, therefore, is between phylogeny and ontogeny.

## EVOLUTION OF COMPLEXITY, KNOWLEDGE AND FREEDOM

To end this essay we need to comment on ontological issues pertaining to knowledge. Modern science, with the influence of physics, mostly deals with the conserved part of nature, such as matter, energy and time. Knowledge is not a conserved part of nature, because all knowledge must be encoded, and the code is copyable unlike matter and energy. Matter and energy can only be recycled, but are not copyable. Should we therefore partition the world into conserved and nonconserved parts, or copyable and noncopyable parts? If we do this, we would be constructing a dualist picture: mind and nature. Or should we generate copyable part from the noncopyable part of the world? Alternatively, should we generate the nonconserved part from the conserved part of the world? If we do this, we would be constructing a monist picture: mind in nature. What is portrayed in this essay tends to be the latter kind.

If we consider that the world is made of systems of varying complexity, where complexity is construed, if not defined, as the portion of code, the system is capable of generation and interpretion. Generation of the code would mean the act of encoding, and interpretation of the code would mean the act of decoding. No science of knowledge can be considered worthwhile unless these basic ontological processes of encoding and decoding are identified and understood. The systems that are capable of performing these actions or operations are complex, and we find them in nature, in the living organisms, as well as in the artificial world in the form of computers. Epistemology done in a context devoid of this reality is futile. Piaget's project of genetic epistemology, therefore, becomes more relevant today, and Piaget's line of engagement is more or less the proper way to deal with knowledge. Piaget's was the first research project that not only identified knowledge as taking its birth in actions of the cognitive agent, but tried to trace its roots within the biological space. For Piaget epistemology is a subject matter of biology. Chomsky could not get out of the clutches of the Cartesian dualism and Darwinian decontextualism, but Piaget is emancipated. Unfortunately, most of the cognitive scientists continue to remain entrapped.

The other context in which Piaget is relevant is in the understanding of the relation between phylogeny and ontogeny. As portrayed in the previous section, human nature cannot be understood without understanding its history, which consists of the history of the species. The human being is peculiar not only in his ability to modulate the biologically determined modules, but also in accessing the memory of the species as a whole. So much of externally encoded memory was left in the form of human history, which we as humans have access to during our socially institutionalized education process. Most of the enculturation process is nothing but providing the ability of decoding what was encoded by the human species in the past generations. This peculiarity keeps us remarkably distant from even the closest of the hominoid species, and this is what Chomsky ignores, while Piaget takes cognizance.

In a volume that is discussing the development of biological thought, it is important to take note of the emerging sciences of complexity which are mostly inspired by biological metaphors. Although the development of molecular biology gives a feeling that the reductionist view inspired by physics and chemistry are reaching biology successfully, it is important to realize that it was the discovery of the *code*, the copyable aspect of nature, that brought the real scientific revolution in biology. But genetic code is not the only code of life (Barbieri 2003). In almost all the physiological interactions in life several kinds of 'languages' other than genetic code are being uncovered. The future of biology lies in understanding the nature of these 'languages', and their role in biology. It is neither surprising nor incidental that knowledge can be constructed only by biological beings, which are essentially complex systems capable of coding and decoding. Coding and decoding are the bedrock of life as well as cognition. Modulation of these processes yields a conscious mind *within* the nature: mind in nature.

## NOTES AND REFERENCES

1. See also Chapter 1 "Origin and Diversity of Life".

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