

COGNITIVE DEVELOPMENT: ENRICHMENT OR IMPOVERISHMENT ?
HOW TO CONCILIATE PSYCHOLOGICAL AND NEUROBIOLOGICAL
MODELS OF DEVELOPMENT

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This chapter compares two conceptions of cognitive development. The psychological model called "enrichment" considers development as a shift from elementary to complex behaviors by means of mechanisms of coordination. The neurobiological model called "impoverishment" describes the opposite shift by means of selective mechanisms for adaptation. An interpretation based on a combination of these two models is suggested. From Edelman's neurobiological theory and Harnad's psychological one, the development of categorization skills is presented as the "groundwork of cognition." Finally, it is argued that the development of categories is accompanied by qualitative shifts usually ignored in contemporary research.

1. INTRODUCTION

The topic of this book is *cognitive development* but the chapters refer not so much to different "domains" but to different approaches or methods. However, this point of view will not be unanimously accepted by all the authors of this book nor by all the readers.

Perhaps it would be more judicious to speak of the development of 'cognitive functions' rather than to speak of 'cognitive development'. Cognitive functions are often described in terms of "components," "modules," "subsystems," "subprocessors," etc. These different terms imply the existence of one complex cognitive system, with a hierarchical functional organization (cf. O'Leary). Recent theories often suggest that the various components function separately, but this does not appear to be the case.

2. REFLEXIONS ON COGNITIVE DEVELOPMENT AND ITS STUDY

Concerning frames of reference

From this general starting point, I received the overall impression that most of the authors of the six chapters in this part of the book have been working in some conceptual and theoretical isolation. Except for a few references to Atkinson and Shiffrin (1968) and Anderson (1983), it is difficult to understand the lack of reference

to the work of Tulving (1972) on episodic and semantic memory, Baddeley (1976) on working memory, Craik and Lockhart (1972) and Snodgrass (1980) on levels of information processing, Fodor (1983) on modularity, and McClelland and Rumelhart (1986) on parallel/distributed processing. These different theories enable one to distinguish types of analysis and integration (e.g. physical and semantic aspects), simple vs complex levels of representation (for example of semantic attributes or chunks), and different coding systems (simple, double, triple), and processing levels (stock of prototypic images and propositional or semantic stock). These notions or others seem necessary for understanding the complex and often paradoxical problems of development.

The same applies to Piaget's theory which is often presented in an overly simplified manner. Often the distinction between figurative and operative systems is not made, nor are the roles attributed to them by Piaget discussed. Furthermore, no reference is made to the logical "functions" which define preoperative reasoning, according to Piaget. How can one speak of initial classifications without considering the difficulties 4- to 5-year-old children have dissociating infralogical and logico-mathematical aspects, or without considering current hypotheses on the elaboration of representations ?

Also, regarding classifications or categorizations, it is difficult to understand a lack of reference to the work of Kemler (1983) on problems small children have isolating pertinent dimensions of a situation, Rosch and Mervis (1975) on prototype structure, Smith, Shoben and Rips (1974) on semantic memory in categorization activities, and Smith and Medin (1981) on categories and concepts.

Concerning "domains" and cognitive processes

A brief review of the problem of "domains" may be helpful at this point. The existence of fields of knowledge cannot be doubted. Following the tradition of Kant, Piaget analysed children's behaviours according to "categories" of knowledge. The fact that a child's knowledge does not develop at the same rate in the different domains, in my opinion, does not present any major theoretical problem, although others may disagree (see e.g. Brainerd, 1978, and compare Levin, 1985). The fundamental problem is to know whether general mechanisms determine the process of development in the different domains, or whether specific mechanisms should be postulated for each domain and temporal sequence.

For example, in each domain, the objects that define it require an identification or categorization by the subject. Must we imagine processes of categorization specific to each domain --a hypothesis which has long been proposed for speech ("the speech-is-special hypothesis")-- or is it possible that general processes of categorization (perceptive, conceptual) apply to all domains ? My hypotheses clearly favor general processes.

A particular case illustrates this well. In her chapter on perceptuo-motor development in children, Laszlo said she tried to define specific experimental tasks that avoid, as much as possible, other "domains" like cognitive capacities. However, her tasks are

described as calling for motor planning activities and spatial and temporal motor programming. It would be difficult to consider these activities something other than cognitive, with planning usually regarded as a high level cognitive mechanism.

Let us examine in more detail one of these tasks involving kinaesthetic perception and memory. Blindfolded subjects are asked to trace curved nonsense patterns engraved in a support. Then they must either recognize the pattern among drawings, or reproduce it. They are described by Laszlo as having to "structure the sequentially received information into a spatially coherent pattern," to "extract sufficient information for accurate coding of the pattern," to "build a percept," to "form an image based on the sequentially received input," and to "store the kinaesthetic information." By all means, these processes seem to be cognitive. Why should this situation, which consists of identifying or categorizing a pattern, be different from other experimental situations of discrimination or categorization? While the task does involve specific receptors and effectors, I do not think that in psychology the difference in domains can be based on perceptual modalities. Psychology seems more concerned with the functional aspects of behavior than with particular sensori-motor modalities. Therefore, I suggest the chapters of this book differ more with respect to methods than domains.

Concerning identification and categorization

The fundamental problem of cognitive development is to understand how and under what circumstances children are able to identify, categorize, and conceptualize the objects or situations they confront. This supposes, of course, the capacity to detect invariance. However, most research examines cognitive development as if subjects have no problems identifying or categorizing objects and situations. It looks as if a subject's environment is composed of defined objects which can be characterized by a certain number of variables. However, the experimenter generally does part of the work himself by organizing the components of the situation for the subject when he selects the pertinent "objects," "dimensions," and "variables."

However, the subject's point of view is not always that of the experimentalist! If it is now clearly established that babies are born with identification and categorization capacities (the result of phylogenesis and embryogenesis), it must also be acknowledged that in the course of development, children build new capacities or new procedures to identify and categorize situations. In fact, the same applies to adults.

Concerning the perspective of information processing

If the categories by which we perceive the world are constantly modified, it may be impossible to study development from the perspective of information processing. But this was what most developmental psychologists did during the last twenty years.

What it means to place oneself in this perspective should be specified. Crépault and Nguyen-Xuan, in their chapter, write that from the perspective of information processing, the human subject is considered as "a system manipulating symbols." However, they do not

specify what the symbols are, and do not discuss symbols again in the rest of their text. Instead, they discuss "criteria," "modalities," logical and empirical "inference rules," "objects," "variables," "relations" and "inference schemes." Case and Griffin speak of "components" and "variables," "concepts" and "relations between concepts." Laszlo uses the terms "sensorial information," "perceptions," "images" and "coding." Koenig focused on the cerebral functions he calls "components," and speaks of "categorical or metric properties and relations," of "invariant properties," and of "cognitive strategies." Finally, Zanone deals with "information," "codings" of different nature and levels, and "rules" and their "abstractions."

Without trying to be exhaustive or systematic, this enumeration is interesting because it raises the following question. Is it possible to speak of information, objects, components, variables or properties as if they were realities having an equivalent status for all children at different ages, and without distinguishing levels of representation or abstraction? Also, is it possible to specify how children are able to identify these "realities"?

Let us examine the problem more closely with an example: The famous balance experiment (the "informational" version of the Piagetian situation) called the "balance beam task." This has been studied in particular by Case and also by other researchers. Case and Griffin analyze the situation in terms of variables (weight, length, number), these variables being described as either "polar" for 5-year-old children (relational stage), or "quantifiable" for 7-year-olds (dimensional stage). Whatever the age of the children (from 4 to 10 years), these authors always consider the same reality, the same dimensions, the same splitting or segmentation. However, in other studies together with Hayward, Case (1987) showed how a baby in the sensori-motor stage becomes progressively able to identify the different dimensions of the balance situation. But it looks as if this problem of object identification was specific to the sensori-motor stage, and that no similar problems arise later on. This is similar to Spelke's (1988) assertion that after the emergence of what she calls the "concept of object" in 2- to 3-month-old babies, there is no further development of object concepts at different levels of representation.

In fact, these "variables" or "objects" which they describe do not have the same status for a child of 5 or 7 years, and although they produce apparently equivalent judgements (concerning weight or length), these statements do not have the same status or the same significance, and do not correspond to the same "concept" of objects (cf. particularly Carey, 1978; Keil and Carroll, 1980; Mounoud, 1986b). The opposition between "polar" and "quantifiable" variables, introduced by Case and Griffin, also raises problems. It can be shown that before the age of 7, a child is able to analyze objects by means of quantifiable dimensions or variables.

A newborn, for example, manifests behaviors that show his/her capacity to process certain variables quantitatively, because of an organization I call "sensorial." Thus, the frequency of sucking in newborns is modulated in accordance with the different variables that characterize liquids (taste, viscosity, etc.) (Kobre and

Lipsitt, 1972). Furthermore, because of an organization described as "perceptual" (Mounoud, 1986b), 3 1/2 to 4 year-old children are able to fit objects into others taking into account size as a quantified variable (Greenfield, Nelson and Saltzman, 1972). This quantification might be described as intensive and not extensive, thus using a distinction introduced by Inhelder and Piaget (1959). Between 7 and 9 years, children will again succeed in quantifying certain variables because of an organization called "conceptual."

In this discussion, I hope to have shown the necessity of studying how, at different stages of development, children are able to isolate the "objects" which define a given situation and abstract the pertinent variables (characteristics, dimensions, properties). A child, like an adult, does not operate directly on the objects or variables, but on representations. These latter remarks lead to the introduction of another problem I call "levels of maturity."

Concerning the concept of "maturity"

It clearly results from the actual level of knowledge on development and, in particular, from the chapters of this book, that a satisfactory discussion of the problem of "maturity," of both neural structures and behaviors, is not yet possible. The preceding chapters contain many examples of this problem, either regarding the maturity of callosal or frontal neural structures, where variations of several years exist relative to the ages when these structures are supposed to become mature (cf. O'Leary; and Young), or regarding the maturity of a given behavior such as the apparition of the capacity to quantify variables which we have just mentioned.

One way to resolve this problem is to say that it stems from insufficiently defining the structures involved or the situations or tasks confronting the subjects. This is often true. Therefore, almost all the chapters give special attention to defining experimental situations. However, the problem remains. The main focus of developmental research has been determining the ages at which given behaviors appear or given structures begin functioning. This led to polar or global reasoning such as "a structure or a behavior is or is not mature," instead of considering levels of maturity as a relative concept. There are only relative states of maturity (Mounoud, 1971). A developing system attains only relative equilibrium and is always confronted with new changes or new problems. This results from either new capacities of the organism, or from changes in the external world. Thus, the organism (or the species) is faced with changes for which it cannot entirely compensate by means of its available structures and therefore must create new ones. There is no single solution or definitive comprehension of a given phenomena and consequently, every theory is relative to the issue raised or to the disturbance experienced. This meets Harnad's formulation (1987): "All categories and the features on which they are based will always remain provisional and approximate."

An example of the confusion caused by polar reasoning is the problem of "manual lateralization" in children from birth to 10 years. Gottfried and Bathurst (1983) concluded that a clear manual preference was present by 18 months, if not sooner. Bates, O'Connell, Vaid, Sledge and Oakes (1986) reported that a right preference was

clearly present by 13 months. However, McManus, Sik, Cole, Mellon, Wong and Kloss (1988) concluded that handedness was poorly defined before 2 years, and Archer, Campbell and Segalowitz (1988) reported that at 24 months, 41% of the boys in their study did not have a clear hand preference. However, it may be necessary to distinguish degrees of lateralization (cf. McManus et al., 1988), or different forms or types of manual lateralization. Furthermore, these may appear and disappear during the course of development due to both *relative* levels of maturity of certain neural structures, and the types of situations children confront. The problem of manual lateralization might best be considered in a wider frame which includes various forms of bimanual cooperation, and of which lateralization is just one particular case (cf. Corbetta, 1989; Corbetta and Mounoud, in press; Fagard, in press).

The same can be said of hemispheric specialization where two divergent positions are found. Koenig, in this volume, suggests that cognitive functions are localized and lateralized from birth, with further development resulting from cognitive strategies which lead to the hierarchic and temporal organization of these functions. On the other hand, Molfese and Betz (V. Molfese and Betz, 1987; D. Molfese and Betz, in press), suggest that hemispheric specialization is progressive.

Concerning the concept of development

The problem of maturity is related to general theories of development, where two models coexist. One will be called *development-enrichment* and the other *development-impoverishment*.

The concept of *impoverishment* is predominant in developmental neurobiology. Several authors in this volume refer to it (O'Leary and Young, in particular), and, when discussing the development of the nervous system, refer to the elimination, reduction, or suppression of cells or connections. In other words, they are referring to decline and regression, if not decrease.

The concept of *enrichment*, which is predominant in psychology, describes development in terms of increase, adjunction, addition, and the appearance of new capacities and structures. In other words, they discuss progression and growth.

Psychologists resist defining development as an impoverishment. However, some do discuss developmental data which reveals regressions. For example, Zanone's chapter describes some examples of momentary declines in performance. Developmental regressions are also discussed by Bever (1982) and Strauss (1982).

It is interesting to note that the discovery of "regressive" phenomena in development was made independently by psychologists and biologists in the early 1970s. However, among psychologists, the coexistence of these two very divergent concepts of development is surprising. Biological models might enable psychologists to take the phenomena of impoverishment into more general consideration.

Therefore, an important part of this chapter will be the presentation of a biological model of development which deals particularly

with an explanation of categorization procedures.

Let us again briefly consider cognitive development in terms of categorization. The existence of perceptual or conceptual categories implies the *elimination* of irrelevant variability in the structure or configuration of representations. Similarly, the existence of a category of movement would mean eliminating or uncoupling irrelevant variability in a coordinated structure. What is invariant or relevant in relation to a given problem is retained, to sort, filter or decrease the structure of inputs or outputs. This way of thinking, where certain characteristics are discarded in favour of others, has also been called idealization or abstraction (Keil, 1987). This analysis of the categorization process should help us to conceptualize development as requiring selective mechanisms.

It now seems possible to reconcile the apparent antagonism between the terms "enrichment" and "impoverishment." Both should be thought of as relative. Therefore, the selective impoverishment, of which biologists speak, is only a relative impoverishment if it leads to a better adaptation to the environment. The same applies to "regressions" shown by psychologists which should be described as apparent regressions.

It is also possible to view development in a context I call "loss and gain" (Mounoud, 1988). The gains that are acquired with the ability to categorize, plan, and control time and space, but are relative to limited aspects of the environment, compensate for losses in other aspects such as elimination, discard, selection, and sorting certain dimensions of the environment or certain forms of behavior. An example is the loss at one year of the ability to discriminate between contrasting phonemes that do not exist in the baby's native language (Werker and Tees, 1983).

But there seems to be another way to reconcile these two antagonistic concepts. Could we not imagine development as alternating stages or periods which could even overlap? Some stages could be mainly characterized by the selection of behaviors most likely to achieve the best adaptation to situations and problems confronting the subject. This corresponds to what Paillard (1988) calls "the idea of a simple selection" and is related to "the debates which, at present, still agitate the psychology of development." But let me add that Paillard seems still concerned with theories creating order out of disorder. Other stages could be characterized by the appearance of variation or richness of behavior resulting either from internal transformations, confronting new problem-situations, or both, with a "proliferation" of new behaviors.

In this book, we were asked to take a position regarding to the Piagetian heritage. The concepts and interpretations of cognitive development proposed by Piaget focused on explaining novelty (new schemes, new structures). His concept of development is the enrichment type, although it was inspired by the theories of evolution.

Concerning some interpretations

One of the dominant themes in developmental psychology belongs to the "enrichment" orientation and is based on the mechanisms of *co-ordination* and the *establishment of relationships*, such as motor and sensori-motor coordinations, and the establishment of sensory or perceptual relations, or more generally, coordination or composition of elementary structures. Thus, the construction of new behaviors has often been explained exclusively by the coordination of elementary actions or intramodal or unimodal perceptions. Case and Griffin (this volume) often describe development in terms of co-ordination. This is supposed to help us understand how children establish or build intermodal (or crossmodal) correspondances from elementary actions or structures. For twenty years, I have strongly opposed this explanation, particularly in the context of Piagetian theory. Not only is it insufficient and incomplete, it neglects another fundamental mechanism: *Dissociation* or *decomposition*. Development does not proceed from simple to complex, from elementary to composed. If there were no initial motor, perceptual, and intersensori-motor coordinations (Mounoud and Vinter, 1981), the organism would never accomplish these general coordinations because of the extreme complexity of the system (Mounoud, 1971, 1976, 1979). I hypothesized that there must be initial coordinations or complex behavior, and that the first fundamental mechanism of successive (re)construction (development) was the dissociation or decomposition of these coordinated structures, not the coordination of isolated and disjointed structures (Mounoud, 1971).

This dissociation or decomposition into elements or components is a necessary condition before the re-elaboration at another level of representation by abstraction or transposition. This hypothesis was later supported by experimental results, including the phenomenon of precocious infant imitation (Maratos, 1973; Meltzoff, 1976; Fontaine, 1987; Vinter, 1983. For a review, cf. Vinter, 1989).

A similar change in interpretation has taken place in theories of motor control. Influenced by information processing theories and classical neuro-physiological concepts, the development of movement was thought to consist of coordinated or sequentially ordered elementary units such as muscle groups or articulations controlled by a sensory system or subsystem. In fact, 15 years passed before Bernstein's ideas (1967) radically changed this interpretation by demonstrating that the basic units of movements are very complex. These units were called synergies or coordinative structures by Kugler, Kelso and Turvey (1982). However, the identification of coordinative structures does not explain their development or the learning of new behaviors. In this context also, the main mechanisms seem to be dissociation, decomposition, elimination, uncoupling and selection. While these dissociations can be momentary and partial, they help explain the development of more complex coordinative structures.

Those accepting the existence of complex initial coordinations have often been suspected of preformist thinking. However, even with a rich, complex initial organization, important transformations still characterize development. Initial intersensori-motor coordination does not imply the absence of subsequent reconstruction. In fact,

it suggests a basis for rich exchanges with the environment.

The notion that development is exclusively a coordination of elementary units is partly due to traditional conceptions of the nervous system as having a serial functioning where neurons act as feature detectors and transmitters of information. However, in the last ten years, an important discovery was made in neurobiology: The parallel functioning of the nervous system (Edelman and Mountcastle, 1978). Here, the fundamental unit changes to neuronal groups or populations. Thus, according to Feldman and Ballard (1982, p.208 quoted by Reeke, Sporns and Edelman, 1988), "Neurons do not transmit large amounts of symbolic information. Instead, they compute by being appropriately connected." For some, these discoveries led to a rejection of information processing theories (Edelman, 1987). Convinced that these theories are important for developmental psychology, I shall present Edelman's (1987) in detail. His main objective was to explain the development of perceptual categorization and generalization, an important issue in cognitive development. It is also interesting to discuss a psychological theory of categorical development and so I will present Harnad's (1987) recent model.

3. DEVELOPMENT OF CATEGORIES

Development of categories from the neurobiological point of view

Edelman and colleagues (Edelman, 1978, 1981, 1987; Reeke et al., 1988; Edelman and Finkel, 1984; Edelman and Reeke, 1982; Reeke and Edelman, 1984) attempt to explain the ontogenesis of categorization and generalization from a neurobiological point of view. They do not accept that objects of the physical world are divided into categories or classes prior to development and learning. Their rejection of information processing theories was suggested by the nature of the organization of the nervous system itself. No longer are neuronal models based on the functioning of conventional computers. In particular, neurons are not seen as binary threshold units, whose interconnections result in symbolic logical operations. "Conclusive evidence that computation on a symbolic or subsymbolic level actually occurs inside the brain is lacking" (Reeke et al., 1988, p.21).

This view clearly differs from present models of connectionism and parallel/distributed processing (PDP), where neurons are usually binary threshold devices without internal dynamic. The wiring of the connections is supposed to be exact, the connectivities are often complete and learning algorithms can only succeed if the exact desired output vector of the system is known in advance and purposeful microscopic synaptic changes are made. These features do not correlate well with known neurobiological facts (Reeke et al., 1988, p.17-22). However, it is important to note that authors of PDP models do not focus on neural modelling, but rather on neurally inspired modelling of cognitive processing.

For Reeke et al., the brain has highly *variable* units and connections where "not only are neuronal connections geometrically imprecise, but their strength can vary with experience" (op.cit. p.15). There is no precise point to point wiring, but immense dendritic and axonal overlap. Although precise neural map boundaries can be defined,

there is immense variability in cortical mapping. Neural areas dedicated to single sensory modalities are multiple, parallel, and widely dispersed (Edelman, 1987, p.39). The units are defined as collections of strongly interconnected neurons, called *neuronal groups* (or populations). These neuronal groups are themselves assembled in *primary anatomical repertoires* (higher order population) and *secondary functional repertoires*. The stimuli an organism receives from its environment or echoniche are described as *polymorphous sets* and are sampled by independent parallel channels. Finally, the world of potential stimuli and the collections of neuronal groups are two initially *independent domains* of variation.

The theory of neuronal group selection (Edelman, 1987) defines principally two periods of selection. (1) A first period of *developmental* selection leads to the construction of primary repertoires and (2) a second period of *experimental* selection leads to the construction of the secondary repertoires. Let us examine these two periods in more detail.

(1) The *primary repertoires* are anatomically variable neuronal groups of a given brain region serving a specific function. Anatomical connections composing the primary repertoires are the result of a variety of selective mechano-chemical events regulated by cell and substrate adhesion molecules (CAMs and SAMs). This selective process is called the *regulator hypothesis*. This regulator process produces a significant number of non-identical groups of cells within a primary repertoire. Each of these cell groups can respond more or less well to a particular input. The presence in each repertoire (brain area) of different neural structures (groups) that are functionally equivalent but non-isomorphic, is the consequence of a process called *degeneracy*. Thus, the existence of various degenerate networks of neuronal groups is the obligatory result of epigenetic events that occur in developmental selection (mainly embryogenetic). Although structures in a particular area of the brain are similar among members of the same species, there is a large degree of *individual* variation in shape, extent, and connectivity at the level of axonal and dendritic ramification. This perhaps is one of the origins of interindividual differences.

(2) *Secondary repertoires* are functioning groups of cells which develop during the period of experimental selection. This selection invokes independent pre- and post-synaptic rules (dual rules) altering synaptic efficacy (variation in the strength of synaptic connections) at short-term or long-term and produces a continuous source of new variation in the system. Thus, the sampling of stimuli by independent sensori-motor channels progressively selects certain degenerate sets of cell groups that will form the secondary repertoires. These temporally relate stimuli (according to frequency and situation) with receptor sheet space so that specific responses of certain groups of neurons are favored. In this way, *local maps* are formed. These subserve different modalities, each with the possibility of independent disjointed sampling in one stimulus domain. When different stimuli simultaneously affect different reciprocally connected local maps after motor activity, because of the temporal correlation, *global maps* are created.

These temporal correlations are possible because of the presence of phasic reentrant signals which are moved by the reciprocal (re-entrant) connections between different local maps. These reciprocal connections are realized, for example, by thalamo-cortical and cortico-thalamic pathways, callosal connections, and various connections between primary and secondary sensory and motor areas. This dynamic linkage among different systems of neuronal groups belonging to separate repertoires but forming global maps, is a mechanism for perceptual categorization and generalization.

Edelman specifies that reentrant connections within sensory systems are not sufficient to insure the spatial and temporal continuity required for perceptive categorization. It is also necessary to include output to the motor system for two tasks. The first task is to select appropriate inputs by altering the relationship between sensory systems and the environment by spontaneous or learned movements. The second task is to verify by action the instantaneous and dynamic responses and the enhanced connectivities that result from the action of neuronal groups in both primary and secondary repertoires.

To illustrate this complex process, Edelman (1987) describes the "classification couple." A classification couple is composed of the following.

- 1) One set of sensory *feature detectors*, such as neurons in the visual system that act as feature detectors. These features are represented as local maps in a higher level brain structure which contains repertoires (cf. under 3).
- 2) Another set of *feature correlators* which work simultaneously with the detectors, either in a different modality or in a sensorimotor system that correlates connected features of stimulus category or object by means of motion. Thus, other neurons, for example those related to the tactile exploration of an object, act as feature correlators. These features are represented in local maps in another area of the brain (cf. under 3).
- 3) *Independent repertoires* of degenerate groups to which these two sets of detectors and correlators are separately connected (neuronal network and structures of the CNS connected with receptor structures) and which realize representations in the form of local maps.
- 4) *Reciprocal connections* which exist at the anatomic level and connect the repertoires with a means of controlling or correlating the direction and reentrant flow of signal traffic. These reentrant connections insure that the patterns of neuronal groups responding to unique features in one map can be associated with another map to yield new invariant patterns.

If certain groups in a mapped network show simultaneous activity with certain groups in another mapped network, then the possibility of linking these independently activated groups arises by strengthening their mutual connectivity via synaptic alterations in reentrant fibers. If these synaptic alterations are maintained, a *global map*, is formed and will function to correlate or categorize simultaneously occurring features of an object. Generalization can occur by

combining local features or feature correlations that result from disjunctive sampling of signals from novel objects.

Edelman's model of neuronal group selection resembles Changeux's model of "selective stability" (Changeux, 1983; Changeux and Dauchin, 1976; Changeux, Heidmann and Patte, 1984). This latter model has been discussed elsewhere (Mounoud, 1986b). However, as Edelman points out, both Changeux and Young's model on memory (J.Z. Young, 1973, 1978) do not provide "a detailed consideration of relationships necessary and sufficient to yield categorization." (Edelman, 1987, p.321).

These neurobiological models have an important feature for developmental psychology. They discard what Edelman calls the paradigm of *instruction* and (re)introduce the paradigm of *selection*. These theories place the organism in an *adaptation* perspective. Developmental psychologists have tended to ignore this essential aspect of Piaget's theory, the notion that thought is the most specialized "organ" for *adaptation* to the environment. To appreciate the originality of Piaget's genetic psychology, "one has to refer to the great problems of evolution and the theories of transformism reevaluated at the beginning of the century in the light of new discoveries in heredity. Since then, interest in these problems has readily increased as a result of new concepts in population genetics and in cellular biology. The problem of evolution is to determine the basis of variation, whether at the level of the individual (ontogenetic) or at the level of the species (phylogenetic). It is necessary to define the roles of the organism and of the environment, that is, the roles of the subject and the object, when we consider phenomena such as *selection* and *adaptation*" (Mounoud, 1971).

As a result of neurobiological discoveries, this new concept of development is in opposition to prevailing ideas in developmental psychology. Edelman's and Changeux's work reveals an extraordinary richness and variety in the NS. They try to explain development mainly by selective mechanisms. Here again we find the concept of "impoverishment" towards a better adaptation.

Criticism of Edelman's theory

However, Edelman's ontogenetic theory does not take into account initial capacities for categorization and generalization. This is similar to Piaget not acknowledging the existence of initial general coordinations which determine the behavior of the newborn. Piaget described ontogenesis as beginning with heterogeneous, disjunctive spaces corresponding to isolated elementary schemes. He also failed to acknowledge primitive forms of representations in newborns, as if the existence of these initial competencies would have simplified too much the explanation of behavioral ontogenesis. Why should a complex organism like the human being not be provided with categorization and generalization capacities at birth, resulting from evolutionary adaptation? Such reasoning is in opposition to Edelman's theory. He writes in particular that, "It would be a mistake to indulge glib analogies between the theory of neural group selection and evolution" (Edelman, 1987, p.321). Nevertheless, as a result of research by Eimas (1982), Jusczyk (1981), and Kellman and

Spelke (1983), Edelman seems to acknowledge categorical perception in newborns. He concludes that the world may not be amorphous, but it does not come in fixed or predesignated categories. Referring to Marler (1982), he states that certain "natural categories" can be fixed during the evolution of a species in a relatively stable eco-niche. "It does not preclude the possibility that morphogenetic variants arising in ontogeny can be selected during evolution to yield certain built-in patterns and species-specific categoriza-tions" (Edelman, 1987, p.320).

This careful formulation seems rather ambiguous. Why should feature detectors and correlators be the only inherited structures in evolu-tion? Why are global maps not inherited? Either the model of neuronal group selection explains the development of categories from an initial state of no capacity for categorization, or else the organism is provided with this initial capacity. In the second case, the problem is different. It becomes necessary to explain new categorizations or re-categorizations while taking into account existing ones. Edelman chose extreme conditions which do not cor-respond well with the ontogenesis of human behavior. His theory is an interesting hypothesis from a phylogenetic point of view. How-ever, from the ontogenetic point of view, acknowledging initial categories may simplify, although not eliminate, the role of ges-tures and movement in his model.

As soon as the organism possesses the capacity for categorization, it is possible to say that sets of stimuli represent "information," as recognized by Edelman (op.cit. p.317). If we study the function-ing of an organism already adapted to a given environment without considering the development of that adaptation, information proces-sing models seem adequate. A great deal of research on children and adults has been conducted with this perspective. Thus, there are many studies with babies between 2- and 3- months-old that do not deal with development and try exclusively to define a state of adap-tation. However, information processing models are inadequate to account for the processes of development and learning, for reasons mentioned in the first part of this chapter.

Thus, development is not a question of the presence or absence of categorization capacities. Instead, it can be defined as passing from one level of categorization to another. Consequently, we suggest considering the construction of categories as a reoccurring process. Edelman's theory, in fact, explains the continuous appear-ance of variation within the system.

Because Edelman does not recognize initial categorization capaci-ties, he treats stimuli from the environment as polymorphous sets. However, in my opinion, stimuli from the environment are only poly-morphous sets in relation to developing categorization capacities. With regard to existing categorization capacities, certain stimuli form organized information patterns. The initial categories are not necessarily fixed and they are only predesignated for somatic but not evolutionary time.

For Edelman, there are initially two independent domains of varia-tion: The world of potential stimuli and the collections of neuro-nal groups. Again, I partially disagree with this affirmation.

There is a relative independence concerning the categorization procedures in construction, but there is, of course, no independence as to the initial categorization procedures, which --let us repeat-- change considerably the explanation of development.

To conclude, I will use Edelman's terminology to describe the features that I think characterize any developmental and learning process.

(1) Both stable repertoires of neuronal groups causally linked with events, and variable repertoires of neuronal groups not linked causally with events. Later, these variable repertoires will be the basis of the selection process.

(2) Opportunities for contact with the environment. Properties of the environment will change because of both internal and external variation and this allows the selection of favorable alternatives. In development and learning, exchanges between the organism and its surroundings should be considered as both strictly determined with regard to certain subsystems (repertoires) and events, and as partially determined with regard to others. These are the phases of lability in the system (Mounoud, 1984, 1987b). Edelman adds a third essential category (1987, p.9 and 17), "A means of differential reproduction or amplification with heredity of the selected variants in a population." This seems to correspond to one of Piaget's (1967) main biological theses, the neolamarckian notion of heredity of acquired features, something for which he was strongly criticized.

As you could realize before, I do not share Edelman's strict view when he rejects any form of reasoning by analogy. From my point of view, reasoning by analogy is one type of scientific reasoning, weak but necessary and at the origin of all our theories at stages where a certain maturity has not yet been achieved.

As a developmental psychologist, despite of a partial disagreement with Edelman's theory, what interests me about it are the following features.

1. The noninstructionist explanation of the development of perceptual categories.
2. Through selection processes, the progressive construction of local maps (linked with sensorial modalities), and then global maps (plurimodal or supramodal and motoric) to account for the appearance of perceptual categorization and generalization capacities.
3. The fact that the constructed categories or categorization procedures are always relative and not absolute.
4. The capacity of the model to explain not only the features characterizing the species but also individual features.
5. The fact that it is a motor theory of the development of categories. Global maps cannot be established without activity.

The development of categories from a psychological point of view

Edelman's neurobiological theory can be compared to Harnad's (1987) psychological theory of the development of perceptual categorization capacities. Both attempt to show that models for simple featu-

- re detection or those based on the existence of prototypes fail to produce a general explanation of the development of categorization. Also, both adopt an inductive "bottom up" approach.
- Harnad describes two types of internal representation to explain the learning of perceptual categorization by sensory experience or "acquaintance," rather than by verbal description.

(1) *Iconic representations* (IR). An iconic representation is an analog of the sensory input (more specifically, the proximal projection of the distal stimulus on the device's transducer surface). The physical transformation is called analog because the process is invertible (reversible). Iconic representations make stimulus discrimination possible (same-different judgements, stimulus matching, copying). These discriminations are modality-dependent. The iconic representations (like Edelman's local maps) preserve the spatio-temporal structure (i.e., the physical "structure") of the input. They blend into one another and share some overall similarity because the configurations they represent share physical similarities (in the same way that Edelman's cortical maps have important overlaps). They are strengthened by repeated exposure to a class of input. Their principal characteristic is that they are "unbound" in the sense that nothing links them to a shared category.

(2) *Categorical representations* (CR) are the result of an analog/digital filter of the unbound feature configurations (IR). The transformation is called digital because it is not physically invertible (reversible), but a formal one which depends on conventional rules. The filter sorts invariant features, *eliminating* most of the raw configurational structure of IRs and retaining only what is invariant. The conjunction of the CR with the IR preserves the spatio-temporal structure of the input (as reentrant connections maintain spatio-temporal continuity in Edelman's model). In this case, it is also a selective process, in a manner similar to the way global maps are constructed from local maps in Edelman's model. However, Edelman's more complex and detailed model better specifies this detection of invariance, principally by the temporal correlations between local maps and reentrant circuits. Categorical representations, like Edelman's global maps, are plurimodal or supra-modal. They allow identification and categorization of objects. CRs are considered to be "bound" representations. They have the limits or boundaries of categories.

To these two types of internal representation Harnad adds a third type called *symbolic representation*. He considers that categorical representations are associated with the names of the categories used as atomic symbols of the symbolic representations. The symbolic representations sustain speech and make learning by description possible. Moreover, Edelman considers that his theory provides the initial basis to take into consideration the superior brain functions related to the formation of concepts and language and to the beginning of learning by social transmission (Edelman, 1987).

For both Harnad and Edelman, categories are provisional and approximate in the sense that they are relative to experience. There are no absolute features but only certain invariant features in a particular context of alternatives.

Harnad's theory does not give the role of action as much importance as Edelman's. Harnad thinks the motor theory of categorical perception produces more questions than answers. Nevertheless, he states that "temporal processes seem by their nature to require active "realtime" filtering and integration" (Harnad, 1987, p.553). This is precisely one of the reasons Edelman considers action so important.

It is not surprising that both Edelman and Harnad do not accept Gibson's theory. Although Harnad recognizes the important contribution of this theory to the concept of invariance in perception, he thinks that "direct perception has not so far proven useful in modeling invariance extraction in category formation, particularly in the *important cases in which learning is involved*." However, he admits that external invariance must certainly underlie all successful categorization (Harnad, 1987). Edelman also states that while laws of physics provide major constraints, they are insufficient for explaining the ontogeny of categorization (Edelman, 1987). According to Edelman, "the ecological viewpoint of Gibson has served an important function in directing attention to those adequate combinations of stimuli that simultaneously excite different receptor sheets. But it surpasses the problem of categorization and ignores the nature of the neural systems and the continual motor sampling ..." (Edelman, op.cit., p.234-235).

This criticism seems justified in the context of development and learning. However, if one studies the *adapted* functioning of an organism in his ecological niche, as Gibson did (1966), it is possible to discuss direct perception because, in this case, there is an optimal coupling between the organism and its environment. We thus uncover the Gestaltist point of view that inspired Gibson. It should be remembered that the Gestaltists went so far as to postulate the existence of an isomorphism between the structure of the environment and the nervous system.

On the other hand, in the Gibsonian view, it is not possible to analyze the process of development. The concept of "affordance" does not resolve the difficulties raised by the concept of direct perception. An "affordance" is the result of an adaptation process, which is still to be explained. The problem of its transformation during development remains.

Criticism of Harnad's theory

I shall make the same general remarks regarding Harnad's theory as I did for Edelman. Why insist on explaining the development of perceptual categories without taking into account the initial capacities of the newborn? In his/her interactions with the environment, the newborn does not confront a confusing, completely variable universe. Only certain aspects and events in the environment are initially confusing and unintelligible. The environment is "intelligible" for the baby in that it calls for adapted behaviors which are determined by already acquired capacities and by certain particularities of the niche. It is also probable that this initial organization serves important adaptative functions such as guaranteeing the unity of the subject and that of his environment and constituting a sort of anchorage for future constructions.

Consequently, in spite of my admiration for Harnad's attempt, I do not favor the purely inductive explanation ("bottom up"). The development of categories should be explained as both inductive and deductive. We should acknowledge that a newborn begins his/her life with some initial deductive capacities.

4. QUALITATIVE SHIFTS IN THE GENESIS OF CATEGORIZATION PROCESS

The major reproach addressed to several authors in the first part of this chapter relates to the fact that they consider the environment as consisting of definite objects, characterized by a number of variants. This perspective is the result of adopting theories of information processing. I hope to have shown the problems associated with regarding the physical world as a composition of categories or classes of well defined, non-ambiguous objects. For this reason, the last part of this chapter will focus on qualitative shifts in the way a child categorizes the world throughout development. I shall concentrate on one essential class of shifts, with the risk of drawing too simple a picture of development.

The existence of general qualitative shifts in cognitive development has been recognized for a long time, particularly regarding the development of categorization and classification capacities (Inhelder and Piaget, 1959; Piaget and Inhelder, 1941; Piaget and Szeminska, 1941; Vygotsky, 1962; Wallon, 1945; Werner et Kaplan, 1968). During the last years, renewed attention has been given to these qualitative shifts (e.g. Carey, 1978; Karmiloff-Smith, 1979, 1986; Keil, 1987; Mounoud, 1976, 1986b). The strategic changes discussed in the chapters of Koenig and Zanone seem related to these qualitative shifts, especially the passage from metric to categorical judgements discussed by Koenig. On the other hand, the chapters by Case and Griffin, Crépault and Nguyen-Xuan, and Laszlo do not sufficiently account for the changes in the way children perceive and segment reality at the various stages of development.

Reporting on the construction of tools by children (Mounoud, 1970), I emphasized a substantial qualitative shift around the age of 6 in the construction of tools and their categorization and classification. At a symposium in Tel Aviv in 1983 on "Stage and Structure," I described a general shift in the manner children define and understand objects. A child goes from conceptions based on *elementary juxtaposed* (or amalgamated) *properties* to conceptions based on *whole defining property(ies) by means of relationships between parts of object* (or on relationships between objects related to one or various properties or features) (Mounoud, 1986b). This shift was compared to the shift from the pragmatic or semantic to the morphological or formal segmentation of sentences (Bronckart, 1977), to the shift from syllabic ("concrete") to phonemic ("abstract") segmentation of words (Lieberman, Shankweiler, Fisher and Carter, 1974) and to the shift from surface markers to deep structure markers in the acquisition of language (Karmiloff-Smith, 1979). More generally, this shift was defined as a shift from a principally *pragmatic or semantic* to a *morphological or abstract* organization.

Table I: Qualitative shifts in conceptual representations.

| MOUNOUD (1986b) | KEIL AND KELLY (1987) |
|--|---|
| - <u>Object Conceptions</u> | - <u>Perceptual and conceptual development</u> |
| <i>elementary juxtaposed (or amalgamated) properties</i> | <i>all salient dimensions</i> |
| ↓ | ↓ |
| <i>whole defining property(ies) by means of relationship between parts</i> | <i>a few meaningfully related dimensions</i> |
| - <u>Motor development</u> (Mounoud et al., 1985) | - <u>Perceptual categorization</u> (Garner, 1974) |
| <i>local control and planification</i> | <i>integral dimensions</i> |
| ↓ | ↓ |
| <i>global control and planification</i> | <i>separable dimensions ("integral-to-separable shift")</i> |
| - <u>Language acquisition</u> (Karmiloff-Smith, 1979) | - <u>Word meaning</u> (Smith et al., 1974) |
| <i>surface makers</i> | <i>characteristic features</i> |
| ↓ | ↓ |
| <i>deep structures</i> | <i>defining features ("characteristic-to-defining shift")</i> |
| - <u>Words segmentation</u> (Lieberman et al., 1974) | - <u>Syllables similarity</u> (Trieman et Baron, 1981) |
| <i>syllabic segmentation</i> | <i>overall similarity</i> |
| ↓ | ↓ |
| <i>phonemic segmentation</i> | <i>phonemic constituents</i> |
| - <u>Sentences segmentation</u> (Bronckart, 1977) | - <u>Lexical categories</u> (Maratsos, 1983) |
| <i>pragmatic or semantic indices</i> | <i>semantic heterogeneity (prototype)</i> |
| ↓ | ↓ |
| <i>formal or morphosyntactic indices</i> | <i>structural homogeneity (structural rules)</i> |
| - <u>Representations</u> | - <u>Representations</u> |
| <i>analogic</i> | <i>prototype-based</i> |
| ↓ | ↓ |
| <i>abstract</i> | <i>theory-based</i> |

The shift was explained as a construction of representations ranging from *analogical* to *abstract* representation (today I would say from disjunctive analogical and abstract to conjunctive analogical and abstract representations). The peculiarity of the model was its recurrent character. This general developmental sequence reoccurs several times in the course of development. These general qualitative shifts take place around the age of 6 years (between 5 and 7 years) for "conceptual" organization, and around 9 months (between 6 and 12 months) for "perceptual" organization. In my opinion, these general shifts concern the functioning of cognitive structures, which might result from shifts in inter- and intrahemispheric collaboration determined by maturation processes (Mounoud, 1988). The qualitative shifts of representation can take place only when the neural structures involved achieve certain levels of maturation. But the maturation of these structures does not imply that shifts will appear simultaneously in different domains. They depend, of course, on the subject's experience. The capacity to segment words phonetically is a good example. In fact, it appears only with learning to read and write in our alphabetic system. It consequently *does not exist with illiterates*. The temporal decalages between domains do not allow one to reject the hypothesis of a general shift in the functioning of cognitive structures.

I was happy to discover that Keil also specifies a general qualitative shift (Keil and Kelly, 1987) comparable to one I proposed. A comparison of the two approaches appears in Table I. For Keil and Kelly, this shift applies to conceptual as well as perceptual development. Because of this shift, a child passes from a level where he/she uses *all salient dimensions* in a given domain to define and categorize objects according to their maximum resemblance, to a level where he/she uses only *a few meaningfully related dimensions*. This shift is comparable to the shift from using "characteristic features" to using "defining features" in the development of comprehension of word significance ("characteristic-to-defining" shift; Smith, Shoben and Rips, 1974) and to the shift from the use of "integral dimensions" to "separable dimensions" in the development of perceptual categories ("integral-to-separable" shift; Garner, 1974). Keil and Kelly also bring together other experimental data related to the development of the perception of similarity among syllables (Trieman and Baron, 1981) and to the development of lexical categories (Maratsos, 1983).

More generally speaking, the qualitative shifts are defined by the shift from *prototype based representations to theory based representations*. Keil and Kelly (1987) suggest various mechanisms to explain these qualitative shifts. First, of course, they describe the importance of *experience* and the *degree of expertise*. Then, they discuss "an *internal tendency* toward principled organization of conceptual domains" (p.505). Thus, since the conceptual domains organized around prototypes are atheoretical by nature, the internal tendency to construct theory-based representations produces the principal motivation for the shift. They also mention an adaptive explanatory mechanism borrowed from social psychology: That qualitative shifts are linked to requirements related to *communication efficiency*. Finally, they discuss a mechanism linked with the word itself, which according to Vygotsky (1979), is a tool

rather than a sign. As young children often sort objects in terms of thematic rather than taxonomic relations, the *power of the word* seems to direct their attention to taxonomic relations (Markman and Hutchinson, 1984). I confess, however, that I am not entirely convinced of the utility of these mechanisms related to "internal tendency," "communication efficiency" and "the power of the word."

However, in conclusion, Keil and Kelly also affirm that these qualitative shifts "are determined by a priori domain-specific and domain-general constraints and predispositions" (p.508). Furthermore, they suggest that "*broad structural constraints* on conceptual structure may be at work throughout the period during which knowledge differentiates and shifts away...."

My views on the construction of new capacities in children for conceptualizing or categorizing the world appear elsewhere (cf. in particular Mounoud, 1986*a* and *b*, 1987*a*, 1988; also Vinter, 1989). Many examples show the shift from prototype based representations of "iconic" or "analogic" or "presymbolic" objects or events where objects are represented as sets or amalgams of unbound features (cf. local maps by Edelman) to theory-based, "categorical" or "abstract" or "symbolic" representations, in the form of delimited, bound, invariant sets of features (cf. global maps by Edelman). In this case, the levels of representations are distinct and correspond to two of the five stages, which I defined in the recurrent process of construction of representations.

As described by Keil and Kelly, these qualitative shifts reduce a complex domain of knowledge to a few criterial dimensions and to a few values along these dimensions.

To conclude, categorization can be defined as a process of sorting, filtering, elimination, reduction, and discard, which corresponds to the concept of development-impoverishment. Thus, we realize again the importance of the selection and impoverishment phenomena, which plays a fundamental role in the process of cognitive development. I hope to have expressed clearly that selection phenomena can only exist as a result of preliminary enrichment phenomena. Cognitive development, therefore, results both from enrichment and impoverishment. The internal and external surroundings of an organism are thus the source of enrichment and selection.

The opposition between two stages of the complex process of representation that I have tried to emphasize in the last part of this chapter corresponds partly to the opposition introduced by Piaget (1968*b*) between the so-called qualitative *identities* and quantitative *conservations*. In his opinion, the first results from dissociations and syntheses of properties of objects and explains the pre-operative reasoning of a child. The second results from quantitative compositions possibly due to logico-mathematical operations, which themselves spring from the general coordinations of action and which demonstrate the presence of operative reasoning. Without agreeing to Piaget's interpretation, this final reference is to pay homage to the notion of categorization, introduced so brilliantly by Piaget in the domain of cognitive development in children.

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