Concepts development and computation of the meaning Thought and language by Vygotsky

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"if a dog is a caw, if it's called cow, it has hourns. If one is called a cow one must have horns. That kind of dog has got to have little horns..."
Vygoski, "Pensée et Langage", p. 336

Abstract

Vygotsky's approach to the construction of concepts contrasts with the models which are commonly used in Artificial Intelligence. We shall present the main ideas of Vygotsky's work on the relations between thought and language, and the main steps of concept building in a child's mind. We shall compare this approach to those of other psychologists in the twentieth's century. We shall outline what makes this approach so modern and a potential basis for computing systems for the representation of meaning linked to learning and adaptation. We propose some architectural and structral choices for such a system. We hope this attempt will allow the testing of some hypotheses in the field of cognitive psychology.

Evolución conceptual y cómputo del significado. Pensamiento y lenguaje en Vigotsky

Resumen

El enfoque de Vigotsky sobre la elaboración de conceptos contrasta con los modelos más empleados en Inteligencia Artificial. Presentaremos las principales ideas de la obra de Vigotsky acerca de las relaciones entre pensamiento y lenguaje, y los principales estadios de la construcción de conceptos en la mente infantil. Compararemos este enfoque con los de otros psicólogos del siglo veinte. Subrayaremos lo que hace a este enfoque tan moderno y una base potencial para los sistemas artificales, de cara a una representación del significado vinculada al aprendizaje y la adaptación. Proponemos algunas alternativas estructurales y de arquitectura para un sistema con estas características. Confíamos en que este intento permita con estas características. Confíamos en que este intento permita la puesta a prueba de algunas hipótesis en el campo de la psicología cognitiva.

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1. WHY VYGOTSKY?

How can one justify the choice of Vygotsky in the framework of building the meaning? Why is one drawn to a psychologist's approach dealing with the relations between thought and language rather than choose more recent works on topical areas such as structured objects, prototypes or concentrated memory blocks? Our interest in understanding the human mental architecture finds in Vygotsky [Vygotski 34][1], and later in Luria [Luria 67], some principles which essentially lead to a dynamic view of «higher functions». The originality of this approach is that it takes into account the differentiation of mental processes during development and adulthood (e.g. writing does not imply the same operations in a young child and an adult after learning this skill): the mental operations vary according to the task. In other words this approach takes into account the changes related to learning and adaptation. Moreover this approach tends towards both theory and empiricism, with specific situations being used by the author. Finally, as we shall see below, Vygotsky's ideas can fit in with Hebb's, and with his desire to integrate human behaviour in a context. Current attempts proposed by neo-structuralists and developmental cognitivists encourage us to explore how the implementation of Vygotsky's approach could be relevant to assess some hypotheses in cognitive psychology.

There is a frequent discrepancy between the development of a theory and its taking over by another field. But Vygotsky's studies date from the beginning of the century and are nevertheless practically unknown in the field of Artificial Intelligence.

The limits of the standard models of representation and manipulation of meaning convinced us that the foundations of these models were not adapted. Neither learning nor adaptation were taken into account.

The construction of meaning must not be based on the avalanche of standard analyses of sentences (morphologic, syntactic, semantic, pragmatic). We consider that the meaning conveyed by textual knowledge is not found ready made in the texts, but that this meaning is elaborated by the interlocutors, while the dialogue develops or while reading goes on. This meaning is therefore dependent on the individual concerned. Moreover the text is not the only element playing a part in this construction. One must also consider all the preconceptions and expectations of the reader, and especially all his/her prior knowledge and state of mind while the process of understanding operates. In the construction of meaning the basic influence is attributed to the pre-existing relations in this particular individual between words and their meaning. One of the corollaries of this approach is that meaning must be considered as a process which evolves rather than an existing pattern once for all.

However the texts themselves remain very important sources of information and our goal is to take advantage from this mass of knowledge to enrich in quality and quantity the information that a machine can use and give to the user.

Within this approach, studies of child language learning seemed important to us. Vygotsky's constructive and dynamic view appears particularly appropriate.

Our task was to re-read this work through the Artificial Intelligence prism so as to reformulate it in operational terms.

2. CONCEPTS AS LIVING PROCESSES

2.1. Vygotsky's heoreical view

The experimental study of concept formation is for Vygotsky the only scientific way for psychology to explore the bounds between thought and language. This theoretical approach considers thought and language as different mental processes, differently rooted, in genetics as in phylogenetics. Language itself, according to Vygotsky, changes with stages of development and particularly from childhood to adulthood (egocentric speech and inner speech). His criticisms of former studies which focus on the «finished product» (method concentrating on the word) or on «an elementary process» (discovery of a common feature) in the method for studying abstraction, lead Vygotsky to put forward an instrumental method dealing with variations of process, and focusing the problem on the functional conditions of concept formation taking into account both the «material on the basis of which the concept is elaborated and the word which permits its appearance».

2.2. Goals of the method and general characteristics of its conception

Vygotsky insists on the functional role of the concept, the "concept [is] at work in the living process of problem solving ...". The concept doesn't live alone, it is not a dead thing, "an isolated ossified changeless formation but an active part of the intellectual processes, constantly engaged in serving communication, understanding, and problem solving» [Vygotski, 62, p. 55]. Referring to Ach's experiments [Ach 21]- which had the merit of introducing nonsense words (which mean nothing to the subject) and artificial concepts (a particular combination of object attributes) -, Vygotsky criticises the "old idea" that "a concept develops through the maximal strengthening of associative connections involving the attribute common to a group of objects, and the weakening of associations involving the attributes in which these objects differ". He insists that "concept formation is a creative not a mechanical passive process; a concept emerges and takes shape in the course of a complex operation aimed at the solution of some problem, the mere presence of external conditions favouring a mechanical linking of the word and object does not suffice to produce a concept". This formation, according to Ach, is a goal-directed process and not a link to the next (determinate tendency). Vygotsky argues this characterisation is still insufficient if one doesn't consider understanding and communication [Vygotski, 85, p. 151].

2.3. The instrumental method

Vygotsky uses the "method of double stimulation". The material consists of shapes varying according to different criteria and including "symbols'. Each set of stimuli plays a role: one as object (towards which the activity of the subject is oriented), the second as signs (for the organization of that activity). A number of issues have to be considered in order to characterize this situation:

a) the problem is given from the beginning, the means are introduced stepwise

b) concept formation is a "top down" process, from general to particular, as

much as a "bottom up" one. It doesn't work in an additive way, from concrete to abstract.

c) the concept formation process ("living process") is divided in three basic stages –each having a concept in action –: unorganized conglomerate or "heap", thinking in complexes, abstract thinking. Mental functions become the psychic ground of the formation of concept processes only in adolescence.

2.4. Concept formation

2.4.1. *The heap*

a) Beginning by the trial and error stage, the grouping of disparate objects together is the first step of concept formation for the young child, it implies a diffuse extension of the meaning of the word or its substitute sign; only the subjective bonds justify his choices. The word meaning is a syncretic linking of objects in the child's representation and perception in a single image, it is by chance that the meaning attributed to a word maps in the child and the adult because it is linked with concrete objects in the child environment.

b) this step is determined by the spatial position of experimental objects (the "related impression" is a subjective one linked to the child's immediate perception).

c) Finally the step ends with the unstable syncretic image (consciousness that each heap's element is a token of a single meaning).

In Vygotsky's terms, in this process the relationships allowing a child to understand a new word come from an elaboration at "two levels of syncretic relationships". "[We discover] behind the meaning of a childish word a perspective, a double set of relationships, a double cluster construction" [Vygotski, 85, p,162].

2.4.2. *Second stage: Thinking in complexes*

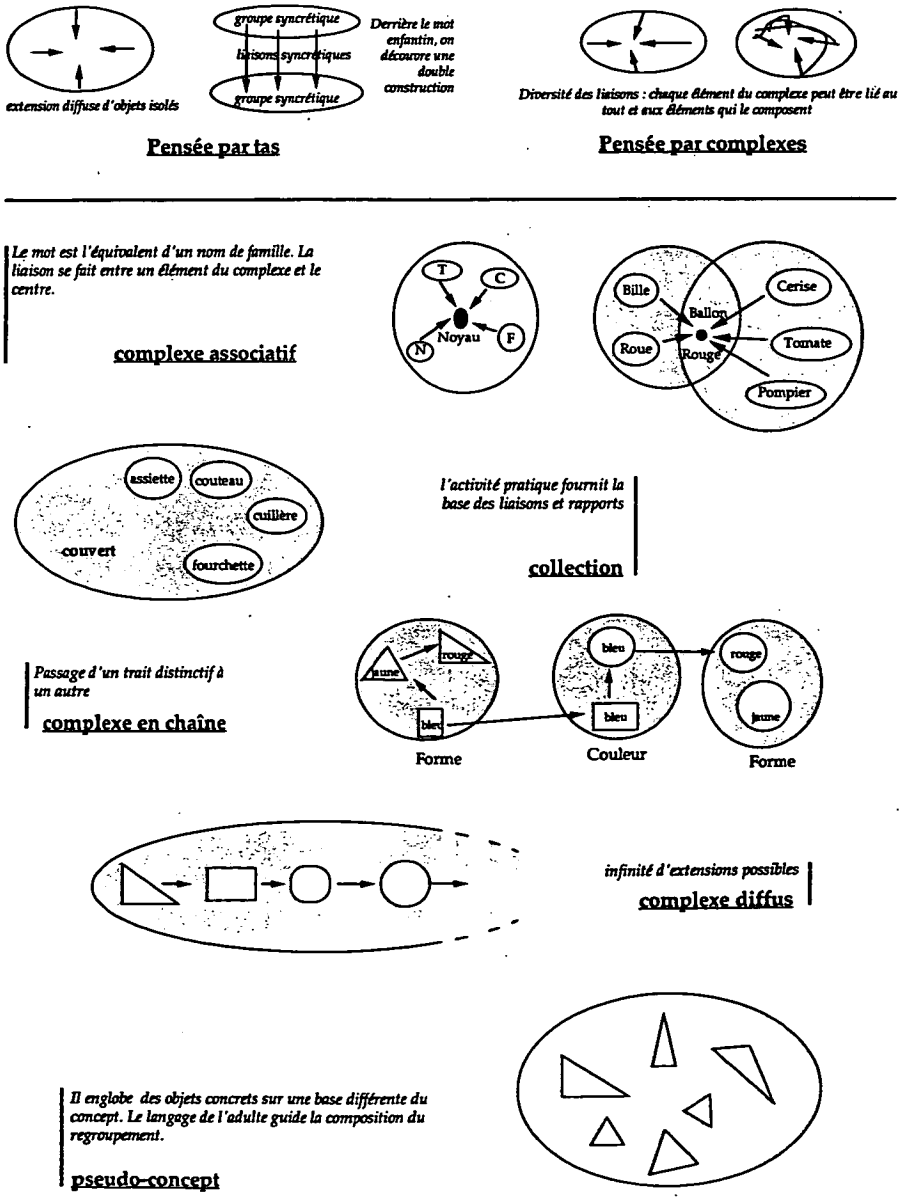
Complexes have the same functional meaning as adult concepts. They are the expression of coherent and objective thinking. Remains of complex-based thinking persist in the adult. Vygotsky refers to "family names", i.e. individual objects become organized into separate, mutually related "families", it is a real "membership (or relation)", "the bonds relating the elements of a complex to the whole and to one another may be as diverse as the contacts and relationships of the elements are in reality"[Vygotski, 62, p.62]. Five basic types of complexes are described by Vygotsky:

a) associative complex: During the experiment, an object will be linked to the nucleus of the group to be built if the child can make any concrete associative relationship (by similarity or by contrast).The pattern is a type of centre. Elements are not interrelated between them "To the child at that stage the word ceases to be the proper name of an individual object; it becomes the *family name* of a group of objects related to one another in many kinds of ways" [Vygotski 62, p. 62]. For instance: a one year old child applies "bow-wow" to a dog barking, to a toy dog, to small oblong objects, to cuff links, to pearl buttons on a dress... The criterion for association to the dog is the oblong shape or a shiny surface resembling eyes shining.

b) collections: there is no hierarchical bond between the various characteristics. Objects are linked on the basis of some feature in which they differ and complement one another (heterogeneous, complementarity). They are rooted in concrete, intuiti-

ve and practical experience. For instance: glass, cup, spoon, and plate. A word can take a number of meanings sometimes opposite ("before" for both "before" and "after", or "tomorrow" and "yesterday"...).

FIGURA 1



c) chain complex: "This object may have nothing in common with some of the other elements either, and yet be parts of the same chain on the strength of sharing an attribute with still another of its elements"[Vygotski, 62, p. 64]. It has no nucleus, the original sample has no central signification, the bond changes from link to link.

d) diffuse complex: The relationship between objects is marked by the fluidity of the attribute that unites its single elements. "The complex... often acquires a vague and floating quality"[Vygotski, 62, p.65]. Complexes resulting from this thinking are in fact limitless. For instance: yellow triangle —> triangles —> trapezoïds—> squares —>hexagons —> circles ...

e) pseudo-concept: externally it looks like a concept, but inside it is a complex! for instance: if the child gathers all the triangles, it is because in fact they really look like one another. He makes an associative complex which fits in with the adult's concept. The pseudo-concept "is a bridge between concrete thought by intuitive images and abstract thought of a child" [Vygotski, 62, p. 190]. Word meanings as perceived by the child refer to the same objects the adult has in mind. That insures the understanding between a child's complex and an adult's concept. For instance: the word "dog" for the child fits in with the real concrete complex, for the adult with the abstract one. This stage is still found in adult thinking.

The variety of criteria associated allows an object to belong to many complexes and thus have several denominations.

2.4.3. *Final stage: the concept*

a) On the basis of the highest resemblance similar objects are grouped together. Then a differentiation is made within the various attributes which make an object most similar to the sample. A group of distinctive features is at the origin of the insertion of the object in a complex. Attributes are divided into two parts: positive (they become sharper) and negative (they are denied admission into complex).

b) potential concepts result from isolating abstraction, related to an expectation, and refer to detailed objects (Groos, quoted in [Vygotski 62, p78]). Their existence is already evident in higher animals. "Words enter into the structure of things and acquire a functional meaning, in much the same way as the stick, to the chimpanzee, becomes part of the structure of obtaining the fruit and acquires the functional meaning of tool". Linking an already known word to a new object is the equivalent situation for the child.

The abstract feature is unstable, as in complexes, but in a potential concept a feature once abstracted is not easily lost again among other elements. With the word, "the concrete totality of traits has been destroyed through its abstraction, and the possibility of unifying the traits on a different basis opens up" [Vygotski, 62, p. 78].

c) The concept "emerges only when the abstracted features are synthesized anew and the resulting abstract synthesis becomes the main instrument of thought" [Vygotski, 62, p. 78]. In this process the decisive role is played by the word deliberately used to direct all the part processes of advanced concept formation.

A concept is more than the sum of some associative bonds, it is a complex "act of thought". Does everyday and scientific concept formation have the same developmental process? The strength of the first is a rich saturation to reality, the seconds are first presented to the child under a verbal definition which situates them from

the start inside a conceptual structure. They are rich in conceptual relations but poor in relations to experience. One can say that the development of the ones and the others takes place in the opposite direction, from the bottom towards the top for spontaneous concepts, from top to bottom for the scientific ones.

The development of spontaneous and non spontaneous concepts influence each other. Scientific concepts begin by a verbal definition and the child cannot see or experience them. The notion of scientific concept implies a certain position in relation to other concepts "a place within a system of concepts". School instruction makes the child conscious of his own mental processes.

2.5. Words, meaning, transfer, coexistence of various processes

Words and meanings are relatively independent. Word meaning increases through comprehension. Mutual comprehension allows the word which is at first a "complex of sounds" to acquire a meaning. The fusion of the semantic and phonetic levels which characterizes the beginning of language is progressively replaced by a greater and greater distance between these aspects. The child's words have the same concrete reference but not the same meaning as the adult's. The indicative function of the word comes earlier than its significative function. "The word is first a way of naming, then a way of meaning". Similarly in different languages one distinguishes between the meaning of a word and the naming which refers to a particular criterion characterizing the object which one names. For instance: in Russian the origin of the word which means "tailor" refers to sewing material; and in French to the act of cutting. The transfer of the meaning is found in the historic evolution of words. For instance "woo-woo" which means successively a whole set of very different objects, and the word "sutki" which in Russian first meant "sewing" came to mean "a twenty four hour day". The meaning is never from the start a concept (i.e. the choice of a distinctive criterion to name the object is not the logical criterion expressing the essence of the phenomenon). At the stage of complexes, the word appears as a family name which gathers together objects for the only reason that they have the same name. The child doesn't yet associate a meaning to it. He finds the complexes already formed in the words of the adult.

In meaning transfers, the word doesn't have an attributive naming function, but a denominative, indicative function. For instance: table leg, bottle neck, river arm. The transfer has as its basis concrete links, it "operates by association, contiguity, or similarity on the functioning of the image, i.e. thinking in complexes". The first step of the experience is represented in generalizing isolated elements by thinking in complexes. At this stage, the child places under the meaning of words the same objects as the adult. But the process of differentiation is very limited. Decomposing and re-uniting constitute in an equal measure the inner moments necessary to the construction of a concept.

The different genetic forms coexist. There is a gap between the formation of a concept and its verbal definition. The existence of a concept and its consciousness do not coincide. The transition from the abstract to the concrete is as arduous as the earlier transition from the concrete to the abstract. The rule is the transition from particular to general and inversely and not according to the traditional theory the sum of the traits (for instance "family portrait" in Galton's composite photographs). "Thinking doesn't move horizontally" [Vygotski, 85, p. 201].

3. VYGOTSKI, PIAGET AND OTHERS

3.1. A pioneer

Vygotsky critized the schools preceding him or which were in fashion at his time idealism, gestalt psychology, structuralism, and associationism. Though it is probable that certain critics were formal, and politically obligated, his most constant criticism, in his work, is that of associationism. We discussed this view above. In general he seriously opposed fixed conceptions which "reified" a type of mental process. He underlined the importance of the socio-historic nature of human development.

Although he was not an orthodox Pavlovian, Vygotsky as later Pavlov [Pavlov, 49], uses the idea of language seen as a "second" signal system, a unitary higher form of self-regulation–man creates a mediator between himself and the world of physical stimulations so that he can react in terms of his own symbolic conception of reality [Bruner 91]–. As Luria explained later, referring to Vygotsky, language intervenes in the activity of the first signal system. It is first linked to perceived reality, to cognitive functions. It allows by designation the isolation of an essential feature in a complex of elements. It intervenes in the activity of the child –creation of intentional memory–, it gives a framework to the perceptive organisation –some categories are incorporated in the structure of words–, it plays a role in the formation of established connections between stimulus and response. Speech, in stating the rule, avoids the repetition of the experience. Language permits the representation of action, it introduces mobility. Speech has a great significance in the formation of mental processes.

Piaget's book *le langage et la pensée chez l'enfant* (1923) is quoted by Luria, in his autobiography, as what feeds discussions with Vygotsky. Although they recognize the same purpose and approach, they disagree with him on the role of language in social communication. According to Piaget, speech is only a particular aspect of the symbolic function which allows the development of language. His continuous approach to psychic development goes from reflex activity to representation. Piaget's perspective implies a threefold grounding of cognitive attitudes, and the intellectual activities they organise: practical intelligence, preverbal communication, language structures.

However for Vygotsky, in contrast to Piaget, egocentric speech plays an important role in the child's activity: more than the accompaniment of the activity, it enables the child to search for and to prepare an answer, and it originates in social language. The egocentric speech does not disappear but becomes inner [Beaudichon & Rousseau, 70]. A noteworthy divergence between these authors concerns the stages. They are seen as successive for Piaget. For Vygotsky, the use of different processes used differently in various tasks is linked to the flexibility of the working of these stages, in particular during intermediate stages such as pseudo-concepts. On this point, Wallon is closer to Vygotsky than Piaget is. In contrast, there is an antagonism between automatic reflex and intentional action. This does not fit with the Soviet psychologists' perspective as accounted by Luria [Luria, 82]. The same can be said of the organisation of higher functions, which they do not see as hierarchical. The function of emotion which allowed the step to intentionality is emphasised by Wallon, but he seems on some aspects more related to Pavlov than Vygotsky and Luria: for them, the speech of the adult to the child has first a function of incitement before becoming a tool for thinking. In child development, this is explained in

terms of three stages: continuous interactions with adults, inter-psychic processes formation and intra-psychic processes.

In Vygotsky's theory, there are two major facts. Superior psychic functions are based on a series of external aids such as language, formed in the process of social history, they are mediated by them and during ontogeny "it is not only the structure of mental processes which changes, but also their relation with each other, or in other words their interfunctional organization" [Luria, 73, p. 32]. Secondly, the organization of higher mental processes is never static but moves "about essentially during development of the child and at subsequent stages of training" (id). According to Piaget's (1923-1967) and later on to Wallon's perspective (1934-1956), formation of the preconcepts, which allow mental operations, is linked to sensori-motor intelligence behaviour. This behaviour works with, and also against, imitation, imagination, speech. At last, the conceptual stage is reached. For all these authors, language is a mediator between functions and not only between forms of knowledge. The designation of things maps a practical experience. However Vygotsky's principle called "extracortical organization of complex mental functions" (quoted in [Luria, 73, p. 31]) and his systemic concept of mental processes give him a strong position up to today.

3.2. Vygotsky up to date

Vygotsky, in introducing the notion of development -and not acquisition- of a concept, formulated a number of propositions which are still current. Different fields of problems exist, for which the system is pluri-competent. Each functional system has a type of procedure. The contextual supports are optimal or suboptimal. Vygotsky expresses this idea by insisting on the fact that the subject can have at his disposal a conceptual level but only use a "functional" level. However Vygotsky does not infer the hierarchical functioning of these levels. The idea of plurality of possible strategies to solve a similar situation is put forward. The role of cultural transmission and emotion. Between the specialized functional systems, there exists a subjective contrast linked to the history of the subject. But Vygotsky quotes explicitly the role of motivation and pleasure. By contrast, Vygotsky does not have a dualistic position opposing percept and concept, he does not base his work on a logical procedure of deductive inference but he refers to the meaning of behaviour in a communicative situation. The subject is in situation. He does not propose a specific analysis of modalities, yet he does not only refer to a linguistic one. He describes global non figural classes and "natural" collective classes characterized by spatial contiguity. Compared with the others, Vygotsky's theory looks nearer to us, because his conception of higher functions is a more dynamic and non hierarchic one. As Luria said later on, they both presumed that when the higher forms of action are organising, the overall structure if psychic processes is moving.

4. IMPLEMENTING VYGOTSKY?

Vygotsky's work takes place in the domain of verbal thought. In this, it is of great interest for us. Our aim is to formulate the links which he describes between thought and language, as well as the nature of thought itself in computing terms. Vygotsky's approach to the development of spontaneous concepts as well as the lear-

ning of scientific concepts seems quite easily expressible in computing terms, even if some steps are not very clear at first and need some more interpretation to arive at a programmable form.

The constraints bound to our approach

As seen before, meaning cannot be represented without a context, especially without the individual concerned by the understanding. The whole experience of that individual is involved in that understanding of a given utterance. Therefore, memorized or computed, this experience must be present in the machine, and that means a lot of data to be stocked and manipulated, and access times which can be prohibiting, with regard to the cognitive processes we intend to simulate. We are now going to justify our choices for massively parallel structures and machine, as long as parallelism appears to be necessary according to our approach which is centred on emerging processes.

4.1. Computational choices

4.1.1. *Architecture*

In 1985, Hillis said about his "Connection Machine" (CM): "It is not difficult today to build a machine with hundreds of thousands or even millions of tiny processing cells which have a raw computational power that is many orders of magnitude greater than the fastest conventional machines. The problem lies in how to couple the raw power with the applications of interest, how to program the hardware to the job. How do we decompose our application into hundreds of thousands of parts that can be executed concurrently? How do we co-ordinate the activities of a million processing elements to accomplish a single task? The Connection Machine architecture was designed as an answer to these questions."[Hillis, 1985, p. 5].

Binding the acquisition of language to the perceptions and to the emotions which have accompanied this acquisition, so that some meaning representation could emerge from that construction, appears to be one of these interesting applications for which the CM architecture is particularly appropriate. We need to compile and then to use a huge amount of knowledge of various natures: emotional, perceptual and verbal. The organization of the data has to keep evolving if we want to simulate the "concept evolution" described by Vygotsky. The changes must be very quick if we want the program to be really useful. Beside the fact that the computing processes involved appear to be numerous but simple, it is the reason why we opted for a massively parallel architecture.

A fact may be interesting to note: in the book already quoted, Hillis explained that the Connection Machine has been conceived at first for cognitive applications, namely for an implementation of the semantic network NETL [Fahlman 1979]. Although our cognitive application is different, the data we manipulate are quite huge and complex, and involve the same kind of structures and processes.

4.1.2. *Data structures and techniques*

If we can imagine to use massively parallel computing, it is because the "natural" structure of the data are suitable to it. When we consider understanding like a

process of activation in a network which bind words and experience we only speak about oriented and valued graphs through which links activations are propagated.

Their large size and the importance of the valuations require the use of highperformance numeric techniques, static ones like data analysis tools, and dynamic ones like connectionist techniques.

Massively parallel changes on the data structures allow us to use the program as an experimental tool for may be validation of some psycholinguistic or neuropsychologic hypothesis, such as some phenomenon which have been observed about impaired access and degraded store disorders.

4.2. Mental processes revisited from a computational point of view

4.2.1. *Modelling complexes*

From a computational point of view, a complex can easily be modelised by a graphic structure which ties the word to the perceptions which have been received by the individual while hearing or using that word. We can use, for instance, some kind of multi-layer perceptron. The perceptions can be represented as an input vector of numbers representing the intensity of the different perceptions. The word to be associated to that perceived situation is coded on the output layer. Learning changes the weight of the connections through the different layers. Learning goes on as long as the system needs to be confirmed in its use of the word Later on, if the environment (let us say "the adult") does not agree with the system's way of using a word, it seems reasonable to question the environment's advice instead of the completed learning. But that process of questioning appears to be too difficult, considering the state of the model. The number of hidden layers, the nature of the perceptions, the choice of their coding on the input layer, require simplifying hypotheses, and we are well aware of that. However, this stage of complexes, which Vygotsky has explicited, is very important to express the first links which appear between word and perceptions, and how some meaning can emerge one day from that mass of experiences.

4.2.2. *The status of word*

Vygotsky clearly explains how the word stands for a tool. But its status changes while stages are passed through in the concept's spreading. Because the word behaves either like an object to be perceived (sounds or letters), the linguistic sign of an abstraction or the name of an object from the real world, its status must take these changes into account, along with the fact that its place must be central in the meaning representation process.

4.2.3. *Potential concepts*

We shall express the computational processes by saying that the child proceeds by pattern recognition as long as he works with complexes, and that he proceeds by symbolic reasoning when he becomes conscious of the features of a conceptual class and is able to name them.

The qualitative switch corresponding to the change from complex to concept is not easy to model. Some work has been done, in the neural networks domain on the

problem of emergence of structures and extraction of features [Crucianu & Memmi, 91] [Elman, 89] [Bouchereau & Bourgine, 89]. Although some results have been obtained, especially in the comparison of connectionist and data analysis methods [Gallinari, 91], it is not easy to express how the main features of a class can be modelled through a set of neurones and how to determine them automatically through some numerical treatment of perceptual data. Vygotsky's study on the way a child learns scientific concepts, and how this acquisition have an influence on his/her own development may be of some help. Therefore we shall go further in that aspect of his work.

4.2.4. *Scientific concepts*

It is as difficult to model the qualitative switch in the transformation of spontaneous concepts as the moment when the scientific concept is assimilated. It is the moment of the "ahah" experience (in Vygotsky's terms) after which the child can say that he/she has understood. This understanding can be expressed for instance by a verbal reformulation of the concept. And that reformulation will no longer be a succession of meaningless or isolated words but the result of a re-appropriation of the concept as part of his/her own experience. In Vygotsky's point of view, this assimilation is not the end of the spreading of the scientific concept. One could say that its development only starts then, a thesis which is central in Vygotsky's work. This dynamic aspect of the concepts can easily be modelled in terms of activations and propagations in a graph. The intensity and the range of that activation may change depending on some stronger pre-activation of certain nodes in the graph, expressing the importance of associated words and concepts in the child's mind.

4.3. Development and learning: how to modelize their mutual influence

Let us consider the previous image of a scientific concept connected to the words which have been used to define it. It is obvious that the "ahah" experience is reachable only if those words are bound, somehow, to the child's previous experiences, and if those words are semantically rich, that is to say strongly bound to other concepts already assimilated.

The mutual influence of the development of thought and the learning of scientific concepts depends on two notions which are very important in Vygotsky's work namely the maturation of the pseudoconcepts and the proximal development area, which we shall reformulate in computational terms.

4.3.1. *How to recognize the state of maturation of a pseudo-concept*

The notion of maturation allows Vygotsky to determine when a pseudo-concept is ready to become a concept, that is to say when it is ready for the "qualitative switch". For us, that maturation will depend on the richness of the associated experience, i.e. the size of the complex and its "dispersion" in the set of the elementary percepts. In terms of valued graphs, maturation of a complex depends on its richness in internal links, its internal cohesion and its relative poorness of external links. We shall say that the pseudoconcept is mature enough if a slight modification in the graph, for instance caused by the adjunction of a link, makes the internal cohesion

pass beyond the threshold above which crystallisation becomes possible. That process of crystallisation should be partially simulated by a graph contraction [Berge, 87]. But this contraction is clearly not sufficient. One must remember that, to become a real concept, the pseudoconcept must also be a potential concept. Therefore, its maturation also depends on the capacity of producing the rapid emergence of main features of the class of objects which that pseudoconcept ties together. We already said how difficult it is to explain this step. We shall have to imagine a representation which, through numerical processes, is able to take into account the strong connections which exist between the developing concept and the concepts already assimilated standing for the features of that new concept.

4.3.2. *Conditions for a pseudo-concept to "crystallize": the proximal area of development*

That notion is bound to the maturation of concepts. We shall say that a concept is in the proximal area of development of the child, at a given age, when the notions upon which that concept is built have reached a certain level of maturation. This level of maturation must be sufficient for the concept to reach the "ahah" experience only by mean of the stimulations that the verbal definition of the concept start through the whole structure. On the contrary, the concept will not be in that proximal area if no verbal definition is able to allow the experience to follow that path. But a concept may also be no longer in that area if the notions on which it is built have been abstract for a long time. It seems to work as if the top-down connection was impossible without a certain motivation of the child to resolve the problem of understanding, as if that connection was possible only while a crystallisation is taking place, the energy of the one being used by the other. All of these phenomena can be expressed as energy flows and phase changes. We shall have to model them in terms of weight of links and propagation of activations through a graph, combined with partial contraction.

4.4. How to formulate those links which change between thought and language

Scientific concepts first appear in a "system", in Vygotsky's terms. We shall interpret it as a "structure", more specifically a graphic structure.

4.4.1. *Two levels of representation*

— representation of the experience which is memorized while spontaneous concepts are built.

— the conceptual structure in which the scientific concepts are first encountered.

Vygotsky says that the adjectives "systematic", "conscious", "voluntary", applied to conceptsj are synonymous, and "spontaneous", "unconscious", "involuntary" are equivalent (p. 244). That is to say that the awareness of a concept means its integration in the structure, linking it to the other concepts. In the meanwhile, its nature changes. So, we must distinguish between the materialisation of the complex, being interpreted as a regrouping of affectivo-perceptive experiences and its abstraction which is materialized partly by a node in a conceptual structure.

a) The experience level

For Vygotsky, the set of all the experiences and of the links which arise between these experiences and the words while the complexes are built is of a different nature than the conceptual structure. There are relations of proximity, influence, propagation of activation which suggest that this level includes the characteristics of a valued oriented graph and those of a topological space. Some neural networks accommodate with these characteristics, such as Kohonen maps, but they are also regular, and that feature is not appropriate for our model. We have not yet encountered in the literature any network useful for us.

b) The conceptual level

For Vygotsky, concepts are not settled entities but they are moving and spreading processes. They exist inside a system which is rooted in experience by means of words. This means that the conceptual level is not only a level in which concepts are materialized by nodes, but a level from which start all the connections which bind every abstraction to words and experiences (real or virtual ones). This means that a concept will be materialized by a part of a graphic structure temporarily activated by internal and external stimulations, hybrid structure binding abstractions, words and elements of experience.

4.4.2. *Processes*

a) Emergence of spontaneous concepts in the conceptual structure

Thought is rooted in the perceptive and affective experience of the child, and gets realized in the word, by means of the interactions between the child and the adults, because (Vygotsky says) the emergence of meaning only exists if words are involved. It is the word which is central for the construction of the pseudoconcepts, it is the word which allows the qualitative switch to adult concepts.

b) Assimilation of scientific concepts

After the child has integrated the scientific concept within his own knowledge, the concept and its semantic environment acquire a "physical" reality. That phenomenon can be translated by the building of hybrid structure made of conceptual elements along with perceptual elements which allow the child to rebuild an imaginary experience about that concept, an experience which he/she is able to describe. And because he/she is able to describe it, that means that the experience is no longer passive, but voluntary. He/she has changed his/her level of processing. He/she has managed to make the concept concrete and to reabstract it by formulating it with personal words.

c) Transfer of structure

For Vygotsky, the assimilation of a scientific concept participates to the development of the child inasmuch as it makes possible the abstraction of some spontaneous concepts.

The hybrid structure which has been built during the assimilation process assumes a given shape. This shape can be compared to some similar but incomplete shapes, especially because of a lack of conceptual elements. If we assume that such an incomplete shape is the shape representing a pseudoconcept near the top of its maturation, the complete shape, presently active may be a sufficient incitement for the qualitative switch to take place, i.e. for the contraction to be processed. Crystallization means completion of the structure with conceptual elements resulting from the contraction. The compledon should be a process of building a full structure, by analogy with the structure of the scientific concept which was at the beginning of that upheaval.

5. CONCLUSION

Vygotsky's instrumental method points out aspects which remain very relevant especially for a computational reformulation.

The notion of concept development seems fundamental in a perspective of the modelling of meaning. It favours a dynamic approach to representation by allowing one to understand the adaptability of the mechanisms of evolution and of adaptation. It makes it clear that the execution of a task goes back to different mental processes during the genetic development; some of these mechanisms remain functional and accessible once the conceptual level is reached.

According to Vygotsky, communication is the meaning ground for a subject "in context". This view contrasts radically with those usually adopted to represent meaning in Artificial Intelligence. The standard approaches are based on the existence of a semantic network and its predefined conceptual links (concepts are connected statically to lists of words). They don't show the fundamental bonds existing between experience (e.g. spontaneous learning of language), concepts, and conceptual links which then take place for him. They don't explain why the meaning of an utterance is so fluctuating.

How can one into account consciousness of the concepts, auto-reflexivity of language, the plasticity of processes "in perpetual transformation", mutual influences of learning an development, affective aspects, how can one formalise the construction of concept without falling into "reproductive" associationism? How can one take into account the multimodal aspect of experience?

Can one imagine a "weaving" of stable representations which would be read in various modalities according to the situation of "activation" or of "rest"?

Despite the complexity of Vygotsky's approach and the difficulty of access to his research in terms of Artificial Intelligence, his exploration of concept development seems to us a way of avoiding the pitfall of an exclusive reference in the framework of semantic memory or structural models of mental processes. His non dualistic approach fits in well with a formulation associating symbolic and connectionist methods and allows one to define more clearly their respective roles for the treatment of meaning[2].

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Bibliography

ACH, N., *Veber die Begriffsbildung: eine experimentelle Untersuchung,* Bamberg, 1921.

BEAUDICHON, J. & ROUSSEAU, J., *Rôle du langage dans une situation de résolution de probléme,* Bull. de Psychologie, 1970-71, 24-10-38.

BERGE, C., Hypergraphes, Gauthiers-Villars, Paris, 1987.

BOCHEREAU, L. & BOURGINE, P., *Implémentation et extraction de traits sémantiques sur un réseau neuro-mimétique: exemple de la première annonce au bridge,* Neuro-Nîmes 89, les réseaux neuro-mimétiques et leurs applications, pp. 126-141, Novembre 1989.

BRUNER, J., *...car la culture donne forme à esprit*, Eshel, Paris, 1991 (traduit par Y. Bonin, de Acts of Meanings 1990, Harvard University Press).
CREED, R.P., *What is language?,* ESSCS, 6th workshop, Varenna, Juin 1988.
CRUCIANU, M. & MEMMI, D., *Extraction de la structure implicite dans un réseau connexionniste,* Notes & rapports internes du LIMSI, Octobre 1991.
ELMAN, J.L., *Representation and structure in connectionist models,* Rapport n.° 8903, center for research in language, University of California, San Diego, 1989.
FAHLMAN, S.E., NETL: *A System for Representing and Using Real World Knowledge,* MIT Press, 1979.
GALLINARI, P. & al., *On the relations between discriminant analysis and multilayer perceptrons*, Neural networks, vol.4, pp. 349-360, 1991.
HILLS, W.D., *the Connection Machine,* MIT Press, 1985.
LURIA,.R. *Les fonctions corticales supérieures de l'homme,* PUP, Paris, 1978 (Traduction française N. Heissler et G. Semenov-Ségur de Vissshie Korkovie Funcii Tcheloveka, Moscou, 1967).
LURIA, A.R., *The working brain, an introduction to neuropsychology,* London, Penguin Press, 1973.
LURIA, A.R., *Itinéraires d'un psychologue,* sous la direction de E. Khomskaïa, Editions du Progrès, Moscou, 1982.
PAVLOV, I. Oeuvres Complètes, Vol III, Ed Moscou, 1949.
PIAGET, J., *Etudes sur la logique de l'enfant I, Le langage et la pensée chez l'enfant,* Delachaux & Niestlé, Paris Nouchâtel, 1923 5° ed 1962.
PIAGET, J. *Etudes sur la logique de l'enfant II, Le jugement et le raisonnement chez l'enfant,* Delachaux & Niestlé, Paris Neuchâtel, 1924 5° ed 1963.
PIAGET, J., *La naissance de l'intelligence chez l'enfant,* Delachaux & Niestlé, Neuchâtel, 1936.
PIAGET, J. *La formation du symbole chez l'enfant,* Delachaux & Niestlé, Neuchâtel, 1945 2.° ed 1959.
PIAGET, J. *La psychologie de l'inlélligence* Delachaux & Niestlé, Neuchâtel, 1947.
PIAGET, J. INHELDER, B., *Genèse des structures logiques élémentaires,* Delachaux & Niestlé, Neuchâtel, 1967.
RUMELHART,D.E. & MCCLELLAND, J. (eds), *Parallel Distributed Processing,* MIT Press, Cambridge, 1986.
VYGOTSKI, L.S., *Pensée et langage,* Editions sociales, Paris, 1985 (Traduction de Myschlenie y rechécrit en 1933 et publié dans Izbrannye psikhologicheshie issledovanya en 1956 à Moscou).
VYGOTSKI, L.S., *Thought and language*, M.I.T. Press, Cambridge, 1962 (Traduction abrégée).
WALLON, H. *Les origines du caractére chez l'enfant,* PUF, Paris, 1934, 3.° ed 1954.
WALLON, H. *L 'evolution psychologique de l'enfant,* Paris Colin 1941 5.° ed 1957.
WALLON, H., *les étapes de la personnalité chez l'enfant,* PUF, Paris, 1956, réedité dans Enfance, Pans, 1963.

Notes

[1] L.S. Vygotsky, Russian psycholinguist, born in 1896, died in 1934. References in square brackets pint to the bibliography, dates in round brackets are given to allow different studies to be situated in time. Note that the Russian texts were published late in relation to the start of their dissemination.

[2] Our project is still a working site. The purpose of this paper was to expose its theorical foundations. The problems encountered while programming are beyond its scope, therefore we shall only note that most of the tools we need are not immediately available. For instance, some work has been donde on graph contraction but, as long as we know, none has been done on a massively parallel computation. The connectionist literature provide no model for distributed representation of the experience, expecially for complex events involving time. We had explore other domains such as visual perception and signal processing. Several people, including three graduate students, are taking part in this project wich is developed at LIMSI, whose group "langage et cognition" is supporting our approach for several years, although it is quite atypical in the "good old fashion" AI field!