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Cognitive circuits

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Abstract

The hypothesis formulated here is that the mind works through a circuital net that has an unlimited number of "logic circuits" (If → then… hypothesis → movement → verification … if →). The logic structure of these circuits is established by the activation times of the net's inner elements. After the first element, the anticipation of the second element occurs, which is followed by a motion (or shift) and the verification of the anticipation. The elements of the logic circuits are the relation, interrelation and association structures of the "what" pathway and the "where" pathway, both anticipated and verified. The memory of these structures is located in the anterior and posterior areas of the cortex. The perceptual memory of the "what" and "where" structures is located in the posterior areas; the functional memory, for the same structures, is located in the anterior areas.

Keywords: logic circuit, cognitive function, "where" pathway, "what pathway", functional memory, perceptual memory, cognitive synthesis, correlation, interrelation, association, anticipation, hypothesis, movement, verification.

1. The basic cognitive function

Cortico-cortical and cortico-subcortical circuits

Recent neuroscience studies (Faglioni, 1996) have shown that the cortical and subcortical areas are interconnected through rather complex circuits. They work through activation and inhibition mechanisms; the latter are present in the subcortical areas. The five major nuclei that form the basal ganglia together with thalamus, amygdala, and hippocampus are parts of these cortico-subcortical circuits. In addition to the cortico-subcortical circuits, cortico-corticals circuits which interconnect areas of the cortex were identified. Both types of circuits activate the frontal cortex and as such are also known as: frontal-cortical circuits and frontal-subcortical circuits. The known frontal-cortical circuits are:

a) The superior longitudinal arcuate fasciculus connects the Wernicke and Broca area via fibres that spread through the inferior parietal cortex (Catani et al., 2005);
b) The superior frontal-occipital fasciculus connects the frontal cortex and the insula with the temporal and occipital regions. According to Catani and coll. (Catani et al., 2002), the fibers seem to associate the dorsolateral prefrontal cortex with the parietal lobe almost exclusively.
c) The hooked fasciculus connects the orbital and polar frontal cortex with the anterior temporal areas.
d) The cingulum connects the orbital and medial areas of the frontal lobe with the hippocampus and the posterior parietal and occipito-temporal areas.

The known frontal-subcortical areas are:

e) The motor circuit. This includes the additional motor area, the premotor areas, and the primary motor and somatosensory areas;
f) The oculomotor circuit, which originates from the frontal ocular fields;
g) The dorsolateral-prefrontal circuit, which links the dorsolateral surface of the frontal lobe with other frontal areas and the parietal areas;
h) The lateral-orbitofrontal circuit, which belongs to the lateral orbital gyrus with connections to the insular-temporal cortex. It is connected to the dorsolateral circuit;
i) The orbitofrontal-medial circuit, which originates from the straight gyrus and the medial orbit gyrus, it is connected with the anterior cingulated cortex and receives afferences from the subcortical and mesencephalic structures involved in satisfaction and pleasure (Salzano, 2003);
l) The anterior cingulated circuit. This is divided into three subregions: rostral, with affective function; dorsal, with cognitive function; caudal with motor functions (Yucel et al., 2003);
m) The lateral/cerebellum cortex circuit, with executive functions.

These circuits are interconnected. Figure 1 shows the motor circuit of the basal nuclei (Coté e Crutcher, 1991). It is part of the more complex perceptual-motor circuit which includes the cerebellum, pontine nuclei, spinal cord, encephalic trunk and other cortex areas.

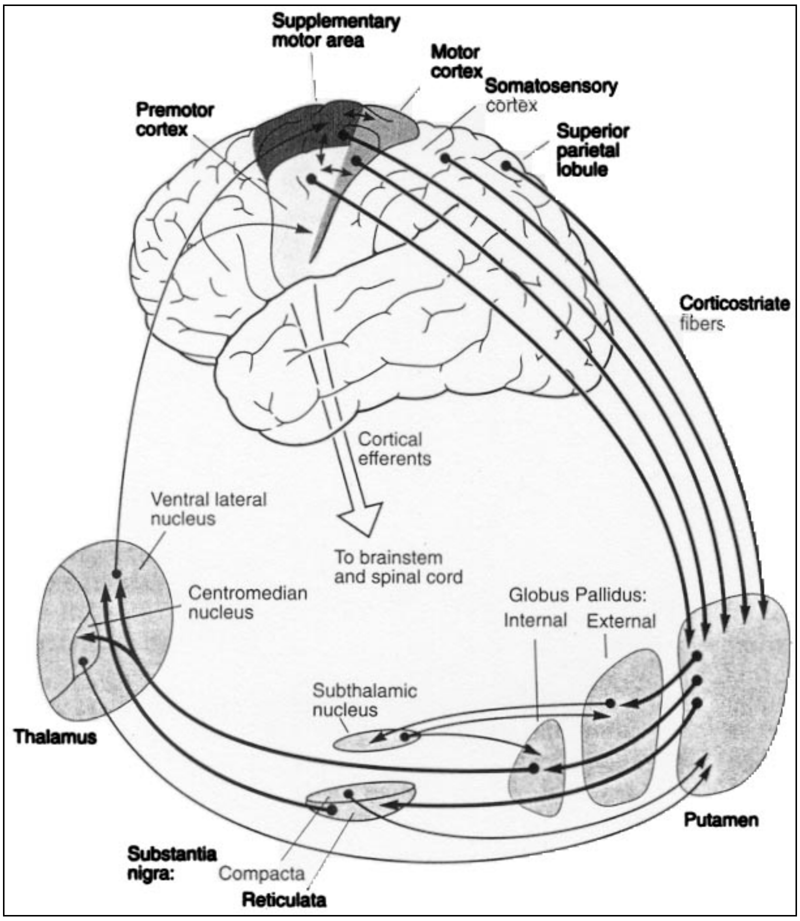

Figure 1. The motor circuit of the basal nuclei (The motor circuit of the basal nuclei is a feedback subcortical circuit which, from the motor and somatosensory areas of the cortex, passing through parts limited by the basal nuclei and the thalamus, returns to the premotor cortex, to the supplementary motor area and to the motor cortex)

1.2 The basic cognitive function

The presence of these circuits leads us to make an observation. Does each of these have a simple associative function, limiting itself to transmitting, through various connections, information from an area to another, or does the presence of these circuits imply, in the general architecture of the nervous system, that they have some cognitive function? And if so, which cognitive function?

Take the the perceptual-motor circuit for example. One of the simplest acts caused by perception is a reflex. If we touch an incandescent object with our hand, we immediately remove it from the object. This gesture is automatic and spontaneous. The cognitive function that controls this mechanism can be expressed by the terms “if…then”. If a sudden pain is felt in an external part of the body, then, this is automatically moved away from the source of pain. Could this be the cognitive function of this circuit?

The answer is only partially positive. The perceptual-motor circuit also has a learning function. Experience teaches us that animals learn by moving and exploring the environment. They acquire new motor competences and new knowledge. If a hypothesis on a possible cognitive function for this circuit is to be formulated, it must include the learning function. At this point a digression is appropriate.

Studies on classic and operating conditioning have shown that, if a stimulus or an action is followed by a reward or a punishment more than once, the animal learns to associate the stimulus or action with the reward or punishment. An example of classic conditioning is that of a hungry dog that receives food after switching on a light. The dog will quickly learn that switching on a light means the arrival of food (Pavlov, 1982). Learning takes place through a mechanism of anticipation. Once it sees the light, it expects to see the food.

A similar process occurs in the operating conditioning. A mouse that acquires knowledge of the fact that, by pushing a lever, it receives food, pushes the lever mentally anticipating the appearance of food (Skynner, 1938). In addition to an activation mechanism there is also an inhibition mechanism. If, after switching on the light, the dog doesn't receive food more than once, expectation gets lower until it disappears.

Tolman's experiments (Tolman, 1948) on the mouse's learning of spatial maps confirm the anticipation process. There is a water maze with four platforms (Figure 2):

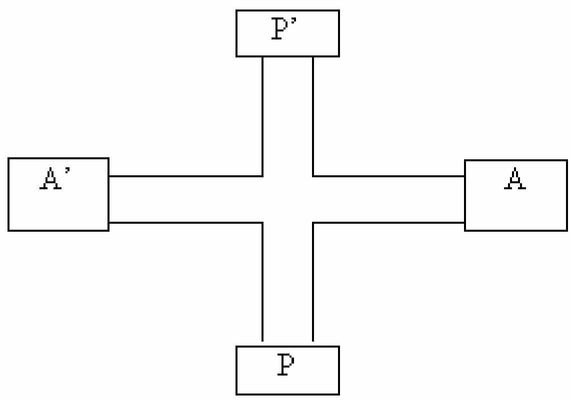

Figure 2. Water maze with platforms

The mouse is put on platform A; for the first times, the food is placed alternatively in P and in P'. Then the food is placed only on platform P. After repeated experiences, as soon as the mouse is put on platform A, it goes towards P, since it has learned that there is food in that platform only. However, when the mouse is put not in A but in A', it keeps going immediately toward P, showing that it has memorized the place map. The interesting fact about these experiments is that the mouse is surprised if it doesn't find the food where it was supposed to be.

In light of these experiments, the cognitive process developed with the intervention of the perceptual-motor circuits could be described as in Figure 3:

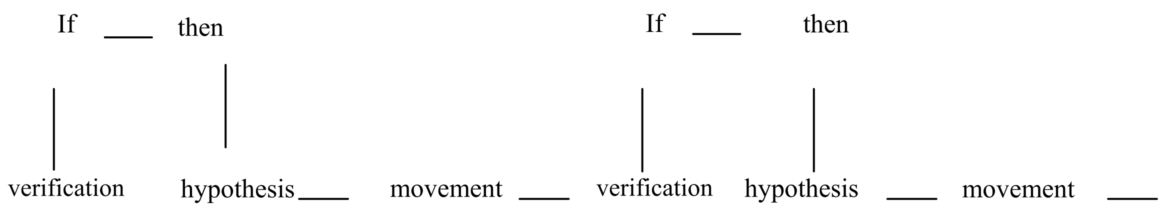

Figure 3. Cognitive process

The mouse's action corresponds to the movement; the hypothesis to what it expects to find; the verification to what it finds versus what it expected. Yet before making a hypothesis about something, the mouse recognizes the environment in which it is placed, that is, the water maze, walls, and platforms. This awareness is what we have indicated with "if". These are the objective data from which the cognitive process starts. The consequences of this acquired knowledge have been indicated with the term "then". In our case the mouse deduces that in platform "A" there is food. This deduction is also a hypothesis which has to be verified through movements and actions.

1.3 The sensory systems

Before starting a discussion on the functioning of circuits, we should talk about sensory systems. The sensory receptors, together with the primary areas, collect information in a bottom-up way, differentiating and arranging it according to times, modalities and spaces. When we touch an object and perceive the sensation of "hard", the duration of this sensation is determined by the length of the contact time. For few seconds Meissner corpuscles and Merkel receptors send a series of action potentials, which, once elaborated by various relay nuclei, reach the primary somatosensory cortex (Kandel e Jessel, 1991).

Something similar occurs when we look at an object. The retinal receptors send an input to the primary visual cortex for the length of time they receive signals from the object itself.

As regards the modal component, since ancient times five modalities, or sensory systems, have been distinguished: sight, hearing, taste, touch, smell.

In these sensory systems, (together with the motor and the motivational ones) we can distinguish various subsystems both from an anatomic and a functional point of view, each of which performs specific tasks. For example, each sensory modality (hearing, sight, touch, etc…) is mediated by a particular system. Within each specific system even more specialized pathways can be identified. The visual system, for example, possesses different pathways for the perception of static objects and for the perception of moving objects. These pathways act in concert to support the perception of the movement of the objects. In the same way, anatomically-identified somatosensory pathways, such as touch and pain, relay the information arriving from different cutaneous receptors to the cerebral cortex (Martin, 1991).

As regards space, it should be pointed out that the peripheral receptors as well as the primary areas have a topographic organization. The most impressive feature of the sensory systems is the fact that existing spatial relations within the peripheral receptive surface, whether it is the retina, cochlea or cutis, are stored in the different levels of the central nervous system. For example, groups of contiguous retinal cells project onto groups of contiguous thalamic cells, which in turn project onto contiguous regions of the visual cortex. Therefore, a visuotopic map of a nervous nature exists at each synaptic station of the visual pathways.

The surface of the body is also represented by a somatotopic map at the level of the somatosensory cortex. In motor pathways, the neurons that control specific body regions are grouped together and on the whole form a motor map, which is particularly evident at the level of the primary motor cortex (Martin, 1991).

This topographic organization becomes a spatial order that is related not only to our body's perception and to its movements, but also to the perception of external objects. These are also perceived, because of this organizational structure of our brain, as having an order in space.

If we analyze our somatosensory system, we notice that it has a somatotopic organization. Therefore it too is structured on a spatial basis; moreover it elaborates four major modalities:

1) discriminative touch, which has the function of recognizing the size and shape of objects, and the characteristics of their surface (smooth/rough, hard/soft) and movement on the skin;
2) proprioception, which determines the sense of static position and the sense of the movement of limbs and body;
3) nociception, whose function is that of perceiving tissue damage felt as pain;
4) sensitivity to heat, which makes us feel heat and cold

The information related to these modalities is transmitted to the brain by two important systems. The proprioceptive information and most of the tactile information is transmitted by the dorsal column-medial lemniscus system; the information on pain and heat is transmitted by the anterolateral system (AAVV, 1991a).

1.4 The primary visual cortex

All the sensory systems are based on common general principles, but, since the visual one is the most studied, we will deal briefly with visual perception. It is believed that vision implies the intervention of three parallel pathways, which separately elaborate information relating to motion, shapes, sense of depth and color. These systems are known as:

- *Magnocellular* (motion)
- *Parvocellular interblob* (shapes and sense of depth)
- *Parvocellular blob* (colors)

The *magnocellular system* is specialized in analyzing the motion and spatial relationships of objects, it also contributes to the stereoscopic vision. It has been observed that the magnocellular system plays a role in perceiving the sense of depth, while it is absolutely ineffective in analyzing static objects.

The *parvo* system (which has terminal station in V4) analyzes color and shape through the direction-sensitive cells present in V2, V3, V4.

Further projections of these systems probably follow two major pathways, *ventral* and *dorsal*, which, according to Mishkin and coll. (1983), transmit information elaborated by visual areas to superior centers. The ventral pathway consists of a series of multisynaptic connections that follow the course of the inferior longitudinal fasciculus, and interconnect the occipital areas with the inferior temporal areas where the visual identification of the stimulus takes place. V4 projects onto these areas. The dorsal pathway consists of multisynaptic connections that follow the course of the superior longitudinal fasciculus and interconnect the striate and prestriate areas with the inferior parietal lobe, where the localization of the stimulus takes place. From the occipital cortex, sensory information projects onto area MT, which in turn projects onto the parietal cortex (Livingston and Hubel, 1988).

1.5 Space and time as pure forms of perception

In *Transcendental Aesthetic*, Kant maintains that there are two pure forms of sensible intuition: space and time. They are the principles of a priori knowledge of objects. Space is the *form* of intuition that comes from the five external senses; time is the *form* of intuition that comes from the inner sense (or empirical apperception), that is, the sense by means of which a person perceives himself and therefore also his representations as modifications of his soul. Kant uses the term form to describe how this functions, that is, the necessary condition for the sensible representation of internal and external objects. Kant denies that space and time are absolute realities that are independent of the form of our sensible intuition. Human beings perceive things as spatially and timely determined only because they possess a sensibility that is structured in this way. Space and time are forms of the "subject" and not of the "object"; they have empirical reality and ideality.

. According to Kant, the objects which are out of our perception are appearances:

In stating this we mean that all our intuition is nothing but the representation of appearances (Erscheinung); that the things which we intuit are not in themselves the same as our representations of them in intuition, nor are their relations as they appear to us; and that if we remove the subject, or even only the subjective constitution of our senses in general, then not only the nature and relations of objects in space and time but even space and time themselves disappear; and that these, as appearances, cannot exist in themselves, but only in us. What may be the nature of objects considered as things in themselves and without reference to the receptivity of our sensibility is quite unknown to us. We know nothing more than our own mode of perceiving them (Critique of the Pure Reason, B 65).

1.6 The "where pathway" and "what pathway"

The two pathways ("where" and "what"), which have been identified in the visual perception, have been also noted in the hearing perception. In my opinion, this division also applies to touch, smell, taste, internal perceptions (hunger, thirst, etc.) and emotions. For each sense therefore, knowledge is organized through two systems which we will define dorsal system ("where" pathway) and ventral system ("what" pathway).

We have referred to the "conception" of space and time in Kant for a specific reason. The Koenigsberg philosopher understood that sensations are organized through space and time, which are a priori "forms" of knowledge. He stated that the space/time relations of objects are a priori forms of intuition, which don't exist without the perceiving subject. Kant's statement is valid for the dorsal system. This system deals with everything that is part of the spatial/temporal context.

The "objects" processed in the ventral system are isolated from any context. They are, therefore, "outside space and time". This isolation occurs exactly in the inferior parietal lobe. Here the figure is separated by the context (the background). The figure/background separation is the process through which mind separates the perceived object from the context. “Perception” consists exactly in this separation.

1.7 Presence keeping

Any movement we make is a dorsal system function. Movement, in fact, can’t occur outside spatial relations. The oculomotor circuit, which is the visual attentional system, carries out three kinds of movements:

1) presence keeping
2) vergence
3) saccadic

When an object moves or changes, we activate “presence keeping”, which allows us to follow its changes or movements. The “vergence movement” starts when we fix our eyes on an object as it moves closer and farther away. Here, each eye moves in a different way (not conjugated) to maintain the image of the object exactly aligned with the fovea. If the object gets closer, the eyes must converge; if the object gets farther away, the eyes diverge (AAVV, 1991b). Saccadic movements move the attention from one conscience quantum to another.

The function of both the presence keeping and vergence movements is to keep the focus of attention on the quantum of consciousness selected by the attention. There are essentially three presence-keeping modalities:

1) The first modality is perceptual. If we observe an animal that moves in its environment or that changes its color, we will keep the focus of visual attention on the animal for a couple of seconds, through the presence keeping and the vergence movements. This function is of premotor origin.
2) The second modality is anticipation. A typical experiment is to train a monkey to perform a particular gesture when a light appears in a specific position of the visual field. The monkey’s expectancy to see the light in that particular point is anticipated by a discharge of action potentials of groups of prefrontal neurons. They keep present what is expected (Goldberg, 2001).
3) The third modality is postponement. When we make comparisons or relate a referred figure to a reference figure, the reference figure is kept present while the other figure is selected. Here too,

the presence-keeping function is performed by the prefrontal cortex, where families of neurons discharge in unison for all the time that we bear in mind something which, at that moment, we don't perceive.

2. The organization of movement

2.1 The motor circuit

The motor circuit can be divided into two levels for explanatory purposes. The first is related to the organization of movement which is intended as being the modification of the space/time relations of body districts (at this level of cognitive elaboration, involving movements and visual correlations, position and relation has not been achieved yet. The terms "relation" and "position" have been used for the sake of simplicity only). The second concerns the modification of the space/time relations of external objects, one with respect to the other and each with respect to the subject performing the movement.

The perceptions related to different modalities are gathered by different sensory systems. The basic cognitive circuits must be different too. We know, in fact, that we use specific motor systems. Sight, for example, uses the oculomotor system, hearing uses head through body movements, touch uses the movements of the upper limbs, smell uses air inhaling and body movements, taste uses tongue and buccal system movements. Moreover it is the phonoarticulatory system which produces the sounds of language.

Even if all the various motor circuits differ, they are reciprocally interconnected. If, for example, we want to perceive an object in detail, we get closer to it, observe, touch and smell it, and hear its sound. This series of movements occurs coherently because the mind constantly controls the position of each body district (including the eyes within the orbital cavities), and when it moves some of them, it also takes the position of the others into account.

In order to understand how motor systems are organized, we should consider how words are articulated. The syllable is the ordering unit of articulatory gestures, since their execution depends upon the position of the phonemes within the syllable (Denes et al., 1996). Syllables consist of a nucleus. In Italian this is always a vowel, an onset (or incipit), that is, all the consonantal material preceding a vowel, and a coda, that is, a consonant that closes the syllable. In turn, the nucleus and coda make up the rhyme, as in Figure 4, which refers to the Italian word "carta" ("paper"). The empty set indicates the linguistically unexpressed coda.

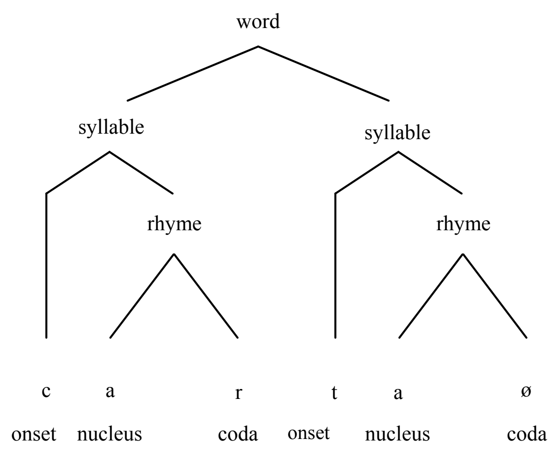

Figure 4. The phonoarticulatory correlative structure

A sound that is made up of various phonemes held together by means of temporal continuity and having this particular structure is a syllable. The correlative structure of the sentence "The dead leaves have fallen on the ground" is shown in Figure 5.

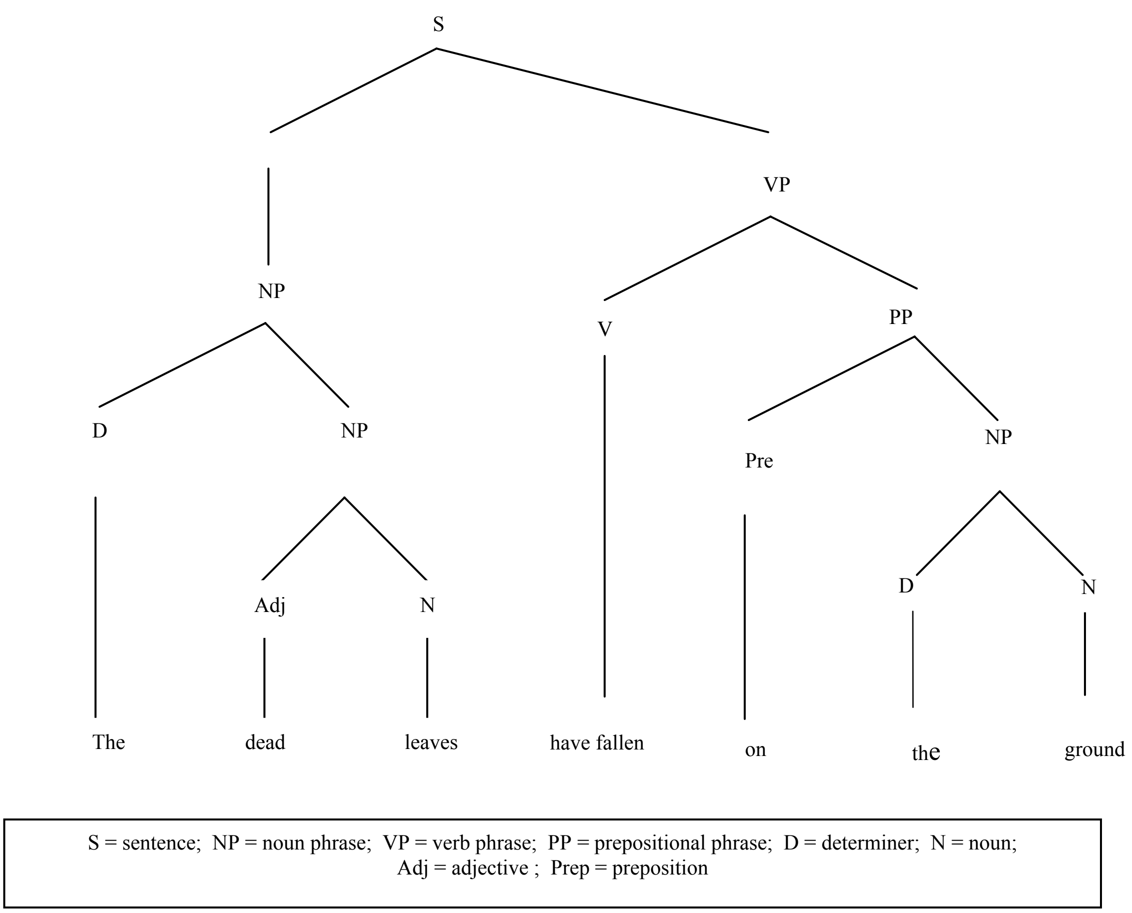

Figure 5. The correlative structure

As we can see, there is a similarity between the structure of the linguistic correlations between words and the phonoarticulatory syllabic structure. The phonoarticulatory syllabic structure is an organization of the phonoarticulatory movement made on the basis of emitted sounds. The sentence structure is an organization of phonoarticulatory movement based on the vocabulary.

We can therefore suppose that all motor systems have this structural organization, that is, a correlative structure also for the spatial relations between the body districts. In this case, when we speak we use two motor levels. The first involves the position of muscles in time. The second involves the structure of syllables, words and sentences.

Our hypothesis is therefore that all the motor systems use two levels. The first organizes, through correlations, the space/time relations of the body districts. The second, integrated with the first, uses correlations to organize the space/time relations of external objects and our body referred to these objects.

2.2 Spatial interrelation and logic-motor correlation

All the motor systems use muscles for movement and neuromuscular spindles for sensory information of the position of the articulation in time. In a simplified way, muscles can be represented by two elements arranged in sequence: a contractile element (represented below by a rack and a pinion, Figure 6) and an elastic element (represented by a spring) (Ghez, 1991).

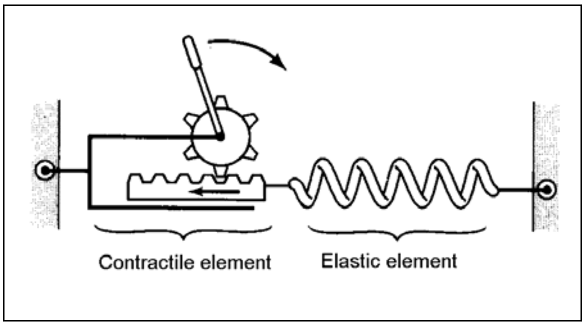

Figure. 6. Mechanisms of muscular contraction

A muscle movement (bending or extension), therefore, depends on the spatial interrelation between the elastic and contractile elements. This spatial interrelation can be represented as in Figure 7.

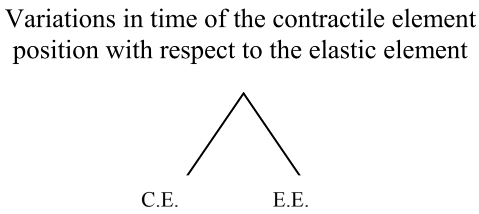

Figura 7. Spatial interrelation between the contractile element and the elastic one

This means that muscle modifications caused by bending or extension are supported by a population of interrelation neurons that register in real time the spatial variations of the elastic element with respect to the contractile element and of the contractile element with respect to the elastic element.

We shall now examine an articulation. An articulation such as the elbow (Figure 8) is flexed through reciprocal innervation or co-contraction. Through reciprocal innervation, the reference value of the biceps, which is excited, is reduced and the muscle gets shorter, while the triceps, which is inhibited, relaxes. The biceps activation increases its rigidity and lessens its value or reference length, whereas the relaxation of the triceps leads to the reduction of its rigidity and the increase of its value or reference length. The concomitant variations which occur in both muscles set a new balance position of the arm, so that the elbow bends to assume this new articular angle.

The elbow's bending requires the coordination of two muscles. While one bends the other relaxes (during the co-contraction both bend) (Ghez, 1991). This movement, which involves two muscles, also depends on the spatial interrelation of the contractile and elastic elements, but of both muscles as well.

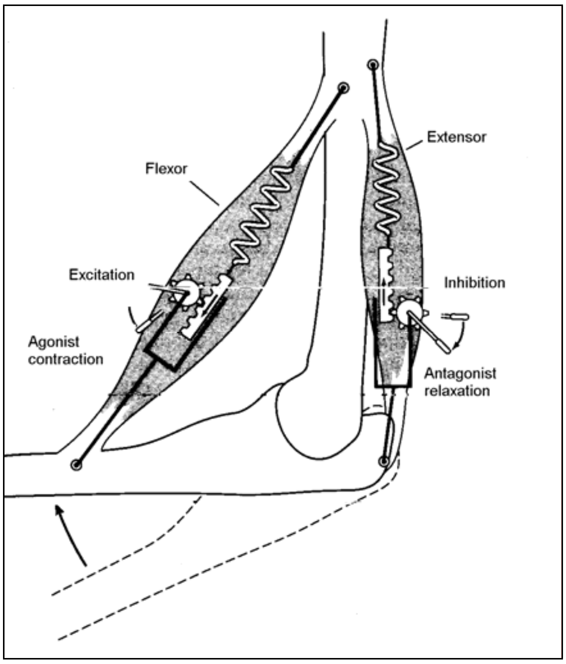

Figure 8. Elbow's bending mechanism

The information on spatial interrelation, which comes from the neuromuscular spindles, reaches the posterior parietal cortex through the primary somatosensory cortex (Figure 9). The parietal cortex memorizes the movement that has taken place through the interrelation between the space of the arm and forearm. This depends on the fact that movement is relative. We can say that something moves if we can verify the relative position of the object in movement with another object that is present in the scene.

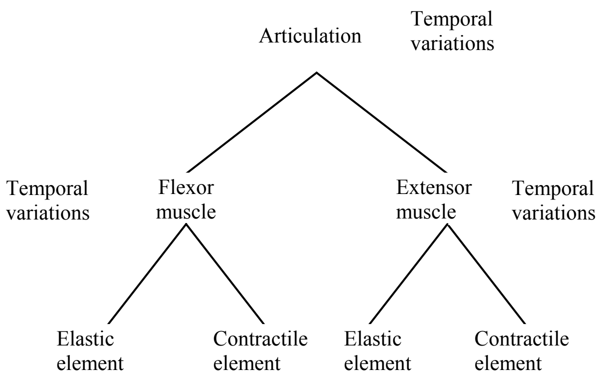

Figure 9. Spatial interrelation of an articulation memorized in the posterior parietal cortex

2.3 Perceptual and organizational interrelation

The spatial interrelation of articulations, and muscles, but also of the elastic and contractile elements, must be seen as an input organization of perceptual space. A single perceptual act can concern the interrelation between two simple elements such as the elastic element and the contractile one, whose interrelation makes us perceive the muscle. A single perceptual act can involve more than two elements. In this case also, perception must be organized. The organization is always the same. Starting with simple interrelations, our mind builds complex interrelations.

In other words, the spatial information which is perceived through a single perceptual act is structured in interrelations (the organization of the perceptual inputs can be formed not only by interrelation but also by "relations" or "associations". The "interrelations" are characterized by the fact that the "interrelated" elements change concomitantly in time, on the contrary the "relations" and the "associations" refer to the relationship between two separated elements).

No destructured information has access to consciousness. The organization of incoming data is double and concerns "space" and "duration". If we listen, with a single perceptual act, the word "slides", which has a certain "duration", the sounds (vowel and consonant) that make up this word, are organized in correlations.

The interrelational organization doesn't involve incoming elements (inputs) only. It is a general organization of the brain and also involves outgoing elements (outputs). The anterior areas of the cortex deal with the organization of the outputs. The premotor cortex has a complementary function with respect to the parietal cortex. It organizes the temporal variations of the motor outputs directed to motoneurons (Figure 10).

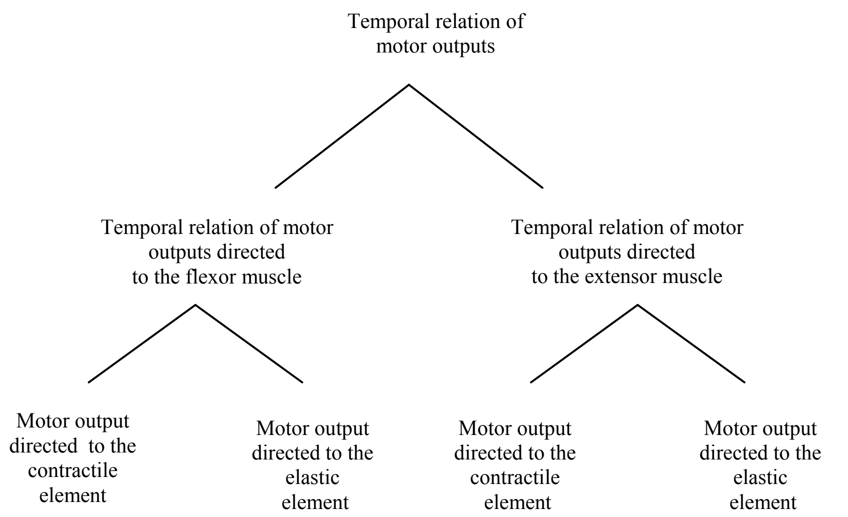

Figure 10. Motor interrelation of an articulation

2.4 The logic-motor correlation

We have seen how various cortical and subcortical areas help to perform a movement (as we will see further on, the prefrontal and temporal cortex also take part in the movement with particular functions, which, for the time being, we shall not explain). These areas, together with the basal nuclei, form a logic-motor circuit, which performs the basic cognitive function. The logic-motor circuits are characterized by a process which anticipates what will occur after a movement. The temporal relations of the motor outputs are organized by the premotor cortex which determines them before the movement is performed. After the movement, the neuromuscular spindles, which are somatotopically organized, send their information to the primary somatosensory cortex and within this information there is also a piece of information about the spatial relations between arm and forearm which change in real time. This information is about space in input, that is, the information registered by the neuromuscular spindles. This spatial information arrives from the parietal cortex to the premotor cortex which, on the basis of this knowledge (the fact), anticipates (if this… then) the new spatial interrelation between the two muscles after the movement (hypothesis). The movement is organized and performed on the basis of this positional hypothesis. After the movement, the "real" interrelation of the two muscles (parietal cortex) functions as the "verification" of the hypothesis, thus becoming the new starting data for the new hypothesis (premotor cortex)

The correlative logic-motor structure has the same structure as the basic cognitive function. It doesn't apply only to the motor circuits, but to all the cerebral circuits, whose function is to generate "logical correlations" (Figure 11).

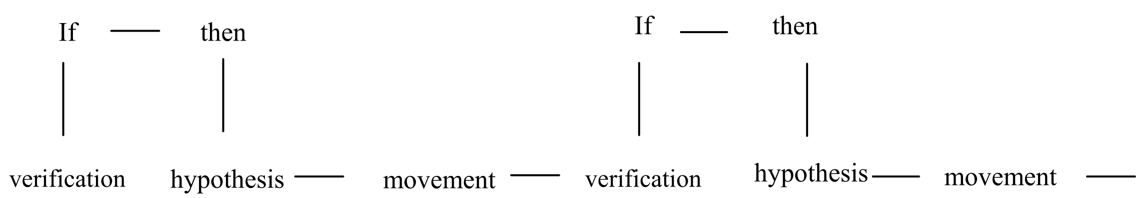

Figure 11. Correlative logic-motor circuit

The logic of this circuit is determined by temporal sequences. The positions are not simply recorded in a temporal before/after relation. The anticipation enters within this temporal relation generating the logic structure (Figure 12).

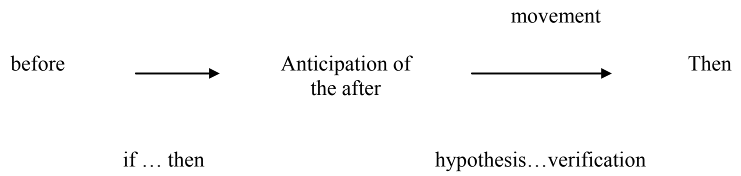

Figure 12. Temporal relations in logic correlation

The parietal cortex memorizes how one muscle interrelates with the other before and after the movement. The premotor cortex memorizes the times of the motor output. The only thing that this logic circuit lacks is the memory of "what" is in these circuits. This is the awareness which allows us to differentiate one element from another but we will deal with this cognitive component later on. The premotor cortex and the parietal cortex interact in a circuit that also includes subortical areas.

The logic correlative structure of the articulation is shown in Figure 13. Figure 13 shows, on the left, the spatial interrelation before the movement, and, on the right, the hypothesized spatial interrelation. The link between the two interrelations represents the logic circuit, which, on the basis of the first interrelation, hypothesizes and verifies the interrelation after the movement.

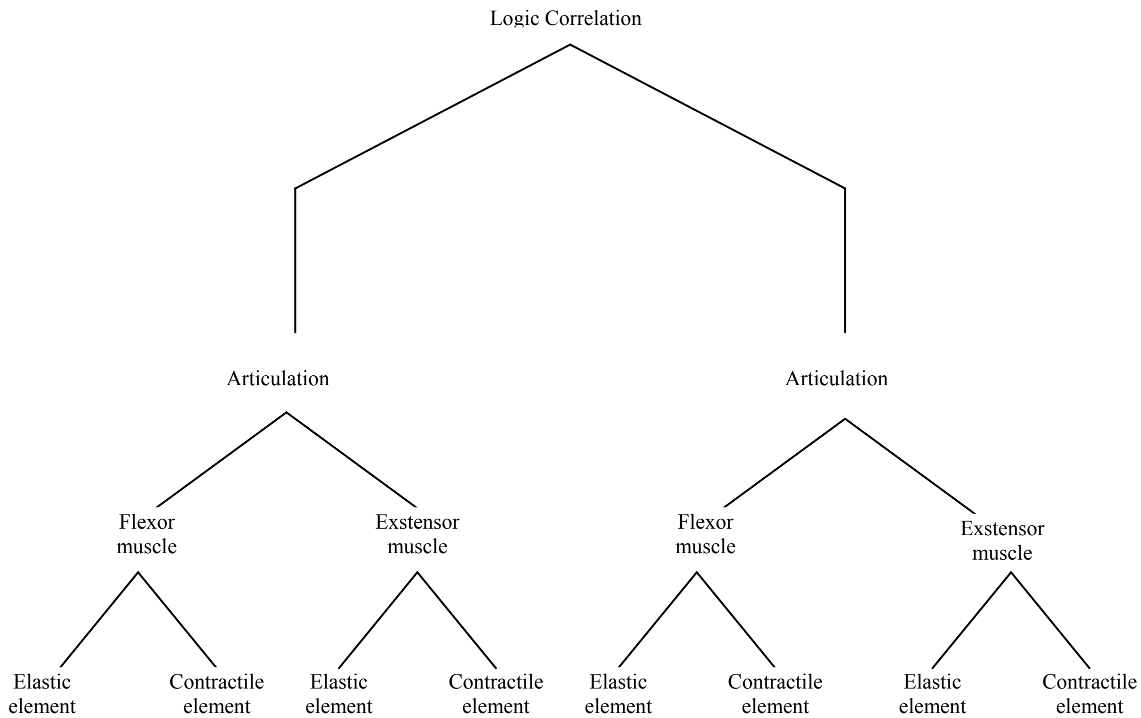

Figure 13. Logic correlation of an articulation

The logic-motor correlation is a continuous process. Hypothesis and verification occur in real time, second after second, for as long as the movement continues. On the basis of what has been stated, there is a hierarchy of interrelation neurons. Some process the interrelation between the elastic element and the contractile one; others encode an articulation or can be in charge of the movement of more than one articulation.

The information about the position of limbs, to which the articulation contributes, is given not only by spindle receptors but also by skin mechanoreceptors and articular receptors (Ghez, 1991).

In brief, when discussing about motor systems we have noticed that there are two kinds of interrelations (input and output), and one kind of logical correlation (circuital), which, being formed by a circuit, we have called: logic-motor circuit. Simple interrelations are found in specific cerebral areas where the possible presence of interrelation neurons is decisive for the interrelation. Simple interrelations related to movement concern the spatial interrelations in time of body districts (muscle articulation, etc.) memorized in the parietal cortex and the temporal relations of motor outputs memorized in the premotor cortex.

The hypothesis is that movements are made through a circuit that “anticipates” the movement and subsequently verifies it is not new. With reference to this, Heilman, Barret and Adair (1998), in order to explain the anosognosia for hemiplegia (the patient doesn’t realize that he can’t move a limb), have suggested that this depends on defective intentional mechanisms (feed forward hypothesis). According to these authors, in order to achieve the awareness of a limb movement, the subject must have the intention to move it. If this intentional mechanism is damaged the patient will not try to perform the action and therefore will not be aware of his own hemiplegia. The lack of programming hinders the expectancy of the movement, the movement itself, and the awareness of the inability.

2.5 Relation, association, interrelation

At this point of the discussion one should distinguish between interrelation, relation and association. And for each of these, between the constitutive function of the circuits which create interrelation, relation, and association, and the memory of interrelations, associations and relations which can be perceptual and functional.

Relation as a circuital function occurs through the action of the prefrontal areas, and consists in “shifting” from the first to the second element of the relation, while keeping the first element present (Figure 14).

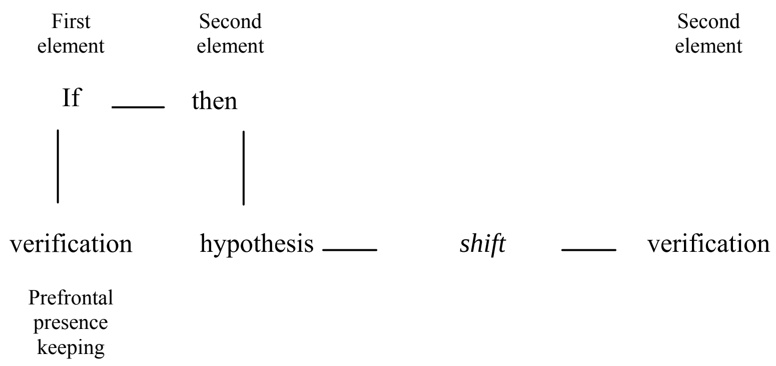

Figure 14.The "relation" circuit

In the posterior areas, the activity of this circuit generates a relational structure that connects the two elements related by the circuit. In the anterior areas a similar structure of a functional kind is generated. When we perform the "soft couch" or "left/right" relation, the relational structure of the two elements is memorized in the posterior areas. In order to reproduce the relation, the prefrontal cortex (functional memory) must intervene by activating the circuit which establishes this relation.

Association as a circuital function differs from "relation". When there is an association, the shift between the two elements occurs without presence keeping (Figure 15).

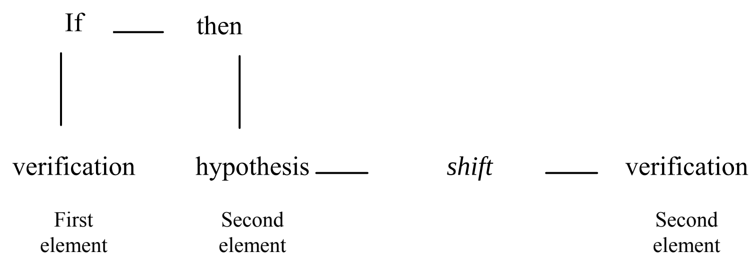

Figure 15. The"association"circuit

Here, the associative structure that is created by the circuit is memorized in the posterior areas as perceptual memory, and in the anterior areas as functional memory.

The interrelational circuit has a different structure, as illustrated in Figure 16.

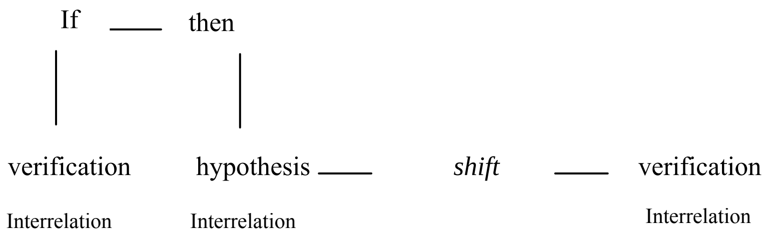

Figure 16. Tthe"interrelation" circuit

In the interrelation circuit, the relations between the two elements are modified instant by instant. The "shift" is therefore a continuous process. This circuit is used when we perform movements in which the articulations work together. Moreover, if we perceive with a single stare two or more elements that as a whole form a "significant object", the interrelation circuit registers the concomitant variations of the elements as a whole. An example is the face, composed of eyes, mouth, nose, etc., or a scene.

After a relation, association or interrelation has been performed, the posterior areas memorize the structures (with an interrelation, it is likely that interrelation neurons will be involved). In order to obtain the relation, association or interrelation again, our mind retrieves these structures in the posterior area, then it "shifts" from one element to another. When there is a relation, there is also presence keeping. One example is when the relational table-brown structure has been memorized in the temporal cortex. To reactivate this relation, the cognitive circuit belonging to the prefrontal cortex retrieves the table from the temporal cortex and keeps it present while the attention moves from "table" to "brown". The procedure is almost the same for an association, with the only exception that there is no presence keeping.

To simplify matters, the term "motor correlation" has been used to indicate the circuit in charge of movement even if it consists of interrelations and/or associations, and the term "logic correlation" to indicate circuits that create the association, relation and interrelation without any movement (Figures 17a and 17b).

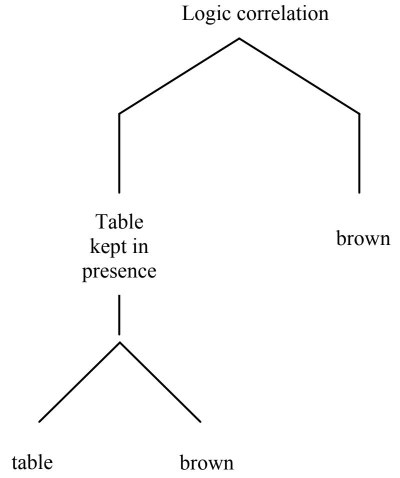

Figure 17a. Reference/referred relation

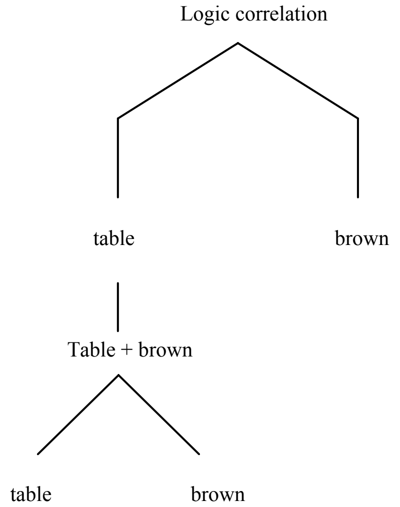

Figure 17b. Association

2.6 Motor sequences

The logic-motor correlative structure of Figure 11 can be related in time to another logic-motor correlative structure, thus giving origin to a motor sequence. In fact, motor sequences can be defined temporal associations between two logic-motor correlative structures. Once again, this kind of structure is created by a cognitive circuit in which each motor correlation that follows is hypothesized before being performed. In this case, the cognitive circuit "passes" from one movement to another (Figure 18).

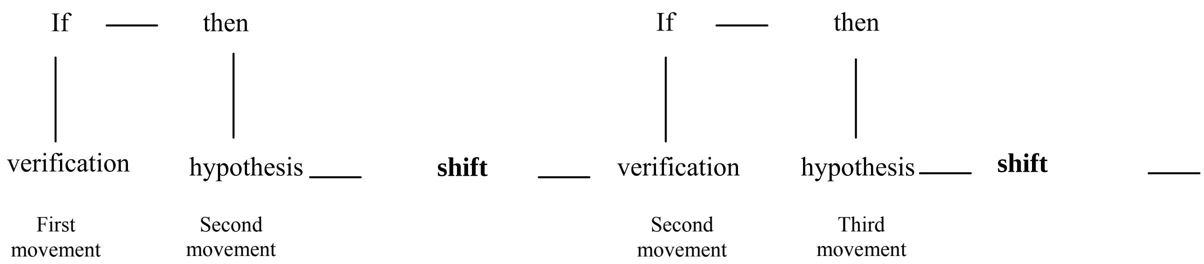

Figure 18. Motor sequences circuit

The activity of the cognitive circuit sets a temporal relation between the spatial interrelations, which is memorized in the parietal cortex as perceptual memory, in the motor cortex as executive memory, and in the premotor cortex as organizational memory.

Figure 19 shows the temporal relation between two articulatory movements performed in sequence. The fixation in memory of the motor sequence allows for its execution without the repeated activation of the circuit.

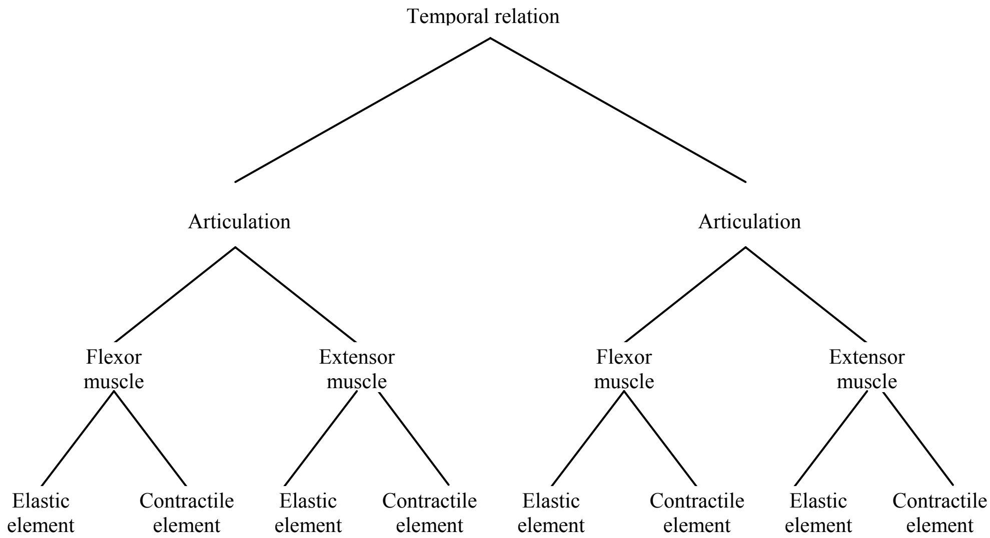

Figure 19. Temporal relation between two spatial interrelations of two articulations

What has been said about the interrelations also applies to motor sequences which can also differ according to the extent of their complexity. The neurons involved in motor sequences have a hierarchical organization. Some specific neurons memorize simple motor sequences in premotor and parietal areas, others encode complex motor sequences consisting of simpler motor sequences.

2.7 The two levels of movement organization

When we are watching two objects in succession: the ocular movement depends not only on the reciprocal position of the eye muscles (as well as of the muscles moving the head), but also on the spatial *relations* between one object and the other, and between both objects and our body (Figure 20).

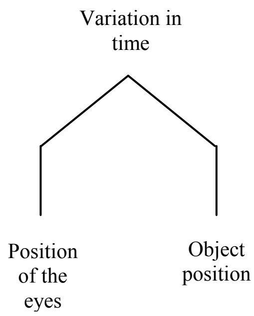

Figure 20. Spatial correlative structure of the position of the eyes with respect to the object

The logic cognitive circuit that is activated during the perceptual visual shift from an object to another can be considered a motor circuit in every respect. It is, in fact, functional to an ocular movement. This circuit differs from the circuit that organizes the temporal relations of the body districts and allows us to move our eyes and head in the external world.

We can state therefore that movement occurs on the basis of two logic circuits, the first dealing with body districts, the second (which is a cognitive one) dealing with external objects and with the variation of their spatial position in time.

2.8 Changing objects in dreams and imagination

Stephen M. Kosslyn (1983) shows, in a convincing way, that we can elaborate our mental images exactly in the same way in which perceived objects change in time. An imagined object, similarly to what happens with the perceived object, can get larger, smaller, closer, farther away, can be rotated, moved, etc. Thanks to imagination we can, for example, compare two shades of green on a perceptual level. The same phenomenon occurs during dreams. The events we dream, even if they can sometimes be considered absurd and unusual, are absolutely similar to what we experience daily while awake.

The faculties of imagination and dreaming can be explained only if we assume that our mind has the ability to modify objects without touching them. But, if it possesses these faculties, how does learning occur? In other words, how do we learn to "make a man walk", "make a lion run" or "modify a chameleon's skin" etc.?

This involves circuital processes, namely those based on a logic cognitive circuit. When we observe a cat moving in front of us (the perception and recognition of the cat implies mental activities that we will deal with later. For the sake of simplicity, we will not consider these functions now), the movement modifies the spatial relation of the animal with respect to external objects. If there is also a tree on the scene, the spatial relation between the tree and the cat changes in real time and it is recorded instant by instant by the interrelation structure belonging to the parietal cortex.

One can obviously assume that this *interrelative structure* depends on the cat's movement as it is perceived (the tree doesn't move). Actually, things do not go exactly in this way. On a mental level, while the cat moves, the premotor cortex "organizes" the logic cognitive structure related to the cat's movement, *anticipating* its moves. It *organizes* this movement by using the variations of the spatial relations stored in memory that refer to the movements of cats as they were previously experienced by the subject.

The spatial interrelations are, therefore, encoded in the correlative-cognitive circuit, inside which they provide "data" and function as a "verification" of what has been anticipated on a premotor level (the "hypothesis"). In other words we can state that some milliseconds before the cat moves, the cognitive circuit belonging to the premotor cortex, supported by the parietal perceptual spatial memory, moves the cat anticipating its moves.

The validity of this operation is verified some milliseconds later, when the spatially ordered information coming from the sensorial receptors arrives in the parietal cortex. This information is the verification and starting data for a new hypothesis.

The ocular movement which allows us to follow the cat's movements is the product of a dual anticipation process at a first and second level. The premotor areas move the cat in space and move the eyes on the basis of the expected movement of the cat and of the position that the eye muscle will assume (anticipation). This process of hypothesis/verification is a general process of cerebral functioning: the anterior and the posterior cortex areas interact on this basis.

The same mechanism was also found in sensory modalities, for example, when we observe the colour of an animal whose skin is changing, such as a chameleon. If we have already seen this animal while it changes its color and we see it again, our mind anticipates the colour changes, verifying them subsequently. This is a learning process in which all the cortical areas inside the cognitive circuit are involved, with each playing a role.

This mental procedure may appear paradoxical, nevertheless there is no difference between moving one's own body and moving a cat (without touching it). In order to move our body, an output organization of the motoneurons determines the contraction and relaxation of the various muscles. In order to move a cat, there is a similar output organization of the sensorial receptors. This output organization also exists to process the changes in a chamaleon's colour, the shape of a rotating object, facial expressions, etc.

The organization of the nervous system is such that ordered information flows from the periphery to the centre and from the centre to periphery. The "thalamus" has a numbers of subcortical nuclei, which relay the sensorial information, the proprioceptive one, etc. coming from the periphery toward the cortex areas. These relay nuclei are organized so that for each fibre which sends information to the cortex, there is a fibre which sends information from the cortex to the nucleus (Kelly, 1991).

Something similar happens in the primary sensory areas. These areas are structured in "columns", each of which is divided into six layers. Each piece of sensorial information coming from the sensorial receptors arranges itself inside these layers and interconnects with others. Some areas project to superior visual areas, and others (those of the VI layer) project back to the geniculate lateral body (a nucleus of the thalamus) (Mason and Kandel, 1991).

The anticipation of the cat movement is a mnestic function where the mind "retrieves" what it has learnt. The function of *retrieving* information from the "memory store" takes place inside the logic structure of the cognitive circuit. This is called "anticipation". In other words, the cognitive circuit, in addition to being a logic circuit, is also a "mnestic circuit". Learning keeps pace with anticipation and therefore with mnestic retrieval.

Mental representation involves activating circuits other than those involved in perception. The two kinds of circuits are similar however. The anticipation process is, in fact, the same for both circuits. What changes is the way sensory information is retrieved: in perception, it occurs by means of processes at the "input", in mental representation it occurs by means of processes at the "output".

2.9 The modularity of motor circuits

The correlative motor circuits and correlative logic circuits are countless. If there was a single system to deal with all these processes, it wouldn't be able to perform its function. In order to handle this complexity our brain employs "modules". Each module deals with a specific function, which involves spatial and temporal interrelations, as well as motor and cognitive circuits. For example, the visual spatial information projects into more than one area of the parietal cortex. Each of these modular areas processes specific mental functions.

Let us consider, as an example, the seemingly simple function of reaching and grasping an object lying within our *peripersonal space*. This function is divided in two subfunctions: the first involves adjusting the hand to the (visual) space of the object to be grasped; the second one involves moving the limb toward the object. Two modules take part in the first function, a parietal one (intraparietal anterior area, called AIP), and a premotor one (F5 area). In F5, the movements are divided into simpler modules which encode movements of *prehension with precision*, movements of *prehension with all fingers*, movements of *prehension with the palm*. In this area, a percentage of the motor neurons also responds to visual stimuli. A similar division between motor neurons and visual motor neurons occurs in an area connected to F5, that is, the anterior intraparietal area. While the neurons are predominantly visual in this latter area, in the F5 area there are no visual neurons. The two modules, F5 and AIP, are part of the cognitive circuit in charge of moving the hand articulations to adjust the hand to the object to be grasped (Rizzolatti and Gentilucci, 1988).

We do not always grasp a motionless object, often circumstances compel us to grasp an object in movement, because it is being pushed by the wind or because it is falling. Here, the movement modifies the shape of the object to be grasped, which can vary in time, instant by instant. In order to grasp it, a "double anticipation" process is needed: that is, a visual anticipation, for the external object, and a somato–sensory anticipation, for the hand conformation. The F5-AIP module deals with anticipation related to the hand conformation. The visual anticipation is performed by another module, which probably belongs to the frontal ocular fields.

3. Dorsal system and ventral system

3.1 Attentional selection

Attentional selection is a cognitive process of attentional circuits, characterized by the fact that information coming from the sensorial receptors is spatially and temporally delimited. In order to show the cognitive function of attentional selection during perception, let us deal briefly again with the visual sensorial system.

Even if colour, shape and movement move in parallel during the elaboration process of retinal images, in the primary visual area (V1) information about shape, movement, size and colour merges. Shape and movement fit into the same columns, arranging themselves into different layers. Colour is encoded in structures (known as blob) which are arranged near the V1 columns (Mason and Kandel, 1994).

Since the columns have a retinotopic, and therefore spatial organization, the circuits in charge of the selective function can select a portion of space occupied by a specific sensory figure. Therefore, in attentional selection, the direct selection of a colour, shape, or "something hard" is not necessary. It is sufficient to select the portion of space occupied by a certain colour, shape, etc., in order to indirectly select these sensory components.

The spaces, which, as a consequence of attentional selection, become virtual spaces of the "objects" we perceive in our daily life, are projected in the inferior parietal lobe. The virtual space of an object is determined by the somatotopic and visuotopic organization of the sensorial systems and corresponds to the space occupied by the object that is perceived after attentional selection.

Just like the object, which has a background, virtual space also has its own virtual background, which corresponds to the spatial context of the object. Something similar occurs with “virtual time”. With time, the “duration” of a perceived action depends on the attentional system which keeps the attention on the scene for a certain period of time (cfr. Marchetti, 2007). For all this time, the sensory neurons transmit information gathered from the “external world” and the duration of this information is recorded as an input process, that is, of a sensorial kind.

The first mental function is to circumscribe the object of perception in space and time. Only through this primary function does the spatial-temporal order of primary areas change from an undetermined order into an order of objects, which are such because they are limited in space and time. We call “figure” a “mental entity” of the primary areas which has been circumscribed in space and time. The figures therefore have a temporal “duration” and a “virtual space”.

Attentional processes are performed by two systems: the dorsal system, for space and time, and the ventral system, for the “what” pathway. Let us start from the dorsal system. In order to circumscribe the spatial-temporal delimitation of “external objects”, the subject must move the “attentional focus” from the scene to the object, or from the object to one of its details. The movement of the attentional focus and the spatial-temporal delimitation of the object therefore go hand in hand. Movement occurs by means of logic anticipation; the whole circuit therefore acts on logic correlative bases. A series of examples can explain how the attentional correlative circuit fucntions, using as a term of comparison the visual dorsal system, which is the most studied and the most known.

For example, we enter a room, observe it as a whole and, soon after, see a cat that, as soon as we arrive, moves away. The perception of the room as a whole makes us perceive the objects with their background. Let us call this perception “scene” and start from this. The scene is the “fact” on the basis of which the “dorsal system” hypothesizes the size and the position of the cat compared with the scene. On the basis of this hypothesis, the dorsal system organizes the ocular movement. Its performance is followed by the parietal verification of its accuracy. The ocular movement includes the movement that restricts the attentional focus to the selected cat. The attentional selection concerns the figure/background interrelation. What is selected is indeed the figure with its background. Without a spatial interrelation, in fact, no perception would be possible. The figure is separated from the objects present in the scene, but a portion of the background that delimits it, remains present and inconspicuously accompanies the figure that stands out against it.

3.2 The figure/background interrelation

For example, if we select the weight of an object, in the figure/background interrelation the specific feature of the figure is “heavy/light”. What we actually select is something that belongs to this feature. Most probably, the background also belongs to the “heavy/light” feature. In fact, the elaboration of the information of the sensory receptors is such that it emphasizes any contrasts detected within each specific featural field.

If we extend this consideration to all the features of stimulus elaborated by all the sensorial systems, we realize that the countless figure/background interrelations involve contrasts within the same typology of stimuli. The selected shape stands out against a background which is in contrast with what has been perceived. Likewise, the selection of the “yellow” separates this colour from a background of a different colour. The “transparent” feature stands out against an “opaque” background, etc. The close interrelation between figure and background is evident if we consider colours. Edwin Land (inventor of the Polaroid camera) proved that objects which reflect light of the same wavelength may appear of a completely different colour if projected on different backgrounds. Moreover, it is common knowledge that a grey object, on a green background, is seen as red (Gouras, 1994).

As regards shapes, some experiments in psychology show that figure and background interact during perception. The Danish psychologist Edgar Rubin created a famous image, representing a vase or two profiles, in which figure alternates with background during perception (Figure 21).

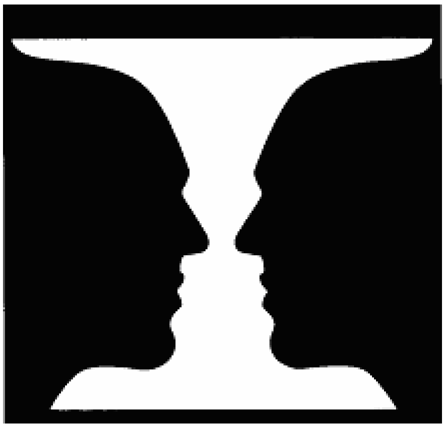

Figure 21. Alternation of figure and background

From what we have said, we can infer that in "attentional selection" two perceptual components interact: figure and background. These components have a definite spatial relation which can vary in time. If we blow a balloon we also modify the spatial relation between figure and background. Going back to the previous example: when the attention moves from the scene to the cat, the scene, as much as the cat, are constituted by a figure/background spatial interrelation (Figure 22).

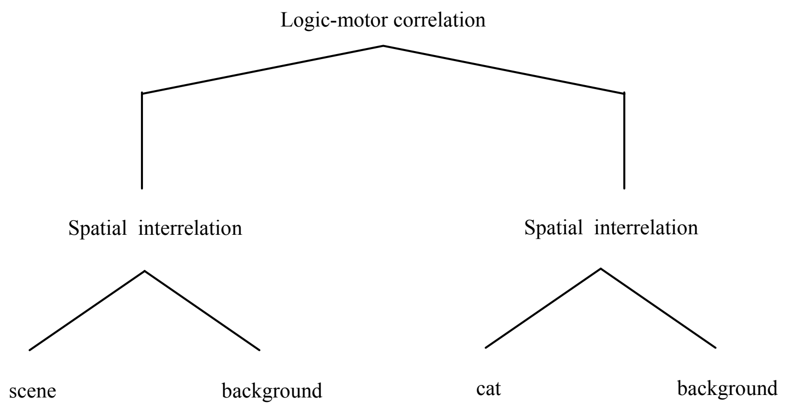

Figure 22.Figure/background interrelative structure and shift from the scene to the cat

The logic circuit of Figure 22 memorizes the temporal relation between the two spatial interrelations in the parietal cortex (Figure 23).

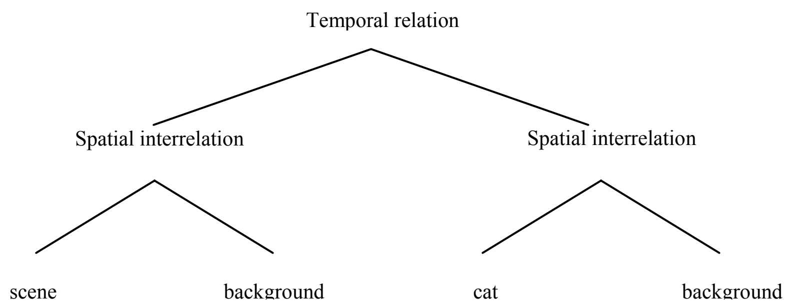

Figure 23. Temporal relation between the scene and the cat

When we observe the moving cat, populations of neurons register the figure/background interrelations which change instant by instant. If, for a moment, we turn our attention away from the cat and then focus again on it, by means of the ocular movement we create a logic-motor correlation that anticipates the figure/background transformation that the cat will undergo after the second perception. It is in this way that our mind learns how to move the cat (Figure 24)

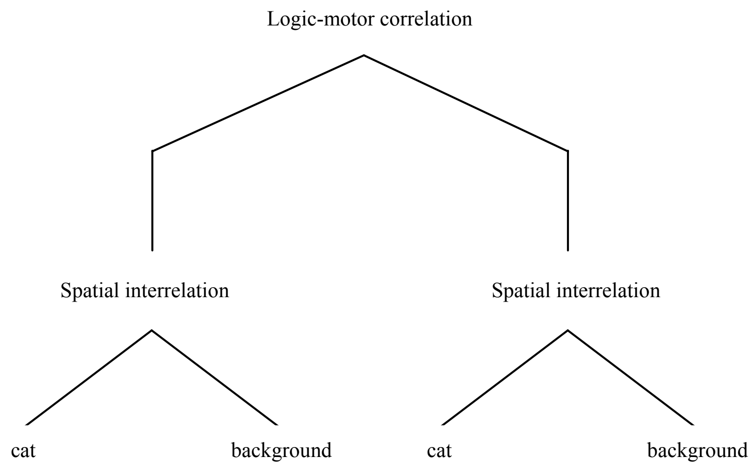

Figure 24. Figure/background correlative structure and logic-motor correlation related to the moving cat

3.3 Interrelation between two "figures"

If, after seeing the cat, we move our attention to a nearby table, this shift is performed by a logic-correlative circuit. In the parietal cortex, outside the inferior parietal lobe, a spatial association of the cat and the table is created. The two elements are in fact perceived in succession. However, we can select both the cat and the table with a single stare. Between the two elements in this case, there is a spatial interrelation. They jointly vary, and the movement of one and/or the other implies a variation in the interrelation. If we perceive them jointly in two different moments, the shift from a first joint perception to a second joint perception is a logic-motor correlation in which the anticipation process occurs. In this way we learn to move in the space of the cat interrelated with the table (Figure 25).

The ventral system is related to the prefrontal cortex and the temporal cortex; its characteristic is the fact that it processes the fine details of objects. The prefrontal cortex, which is also connected to the temporal cortex, is involved in the attentional system with an anticipation process that is more related to "what" than to space. After the perception of the cat and attentional disengagement, and before the new perception of the feline, the prefrontal cortex together with the temporal cortex anticipate the perception of the cat, which is subsequently verified by the temporal cortex.

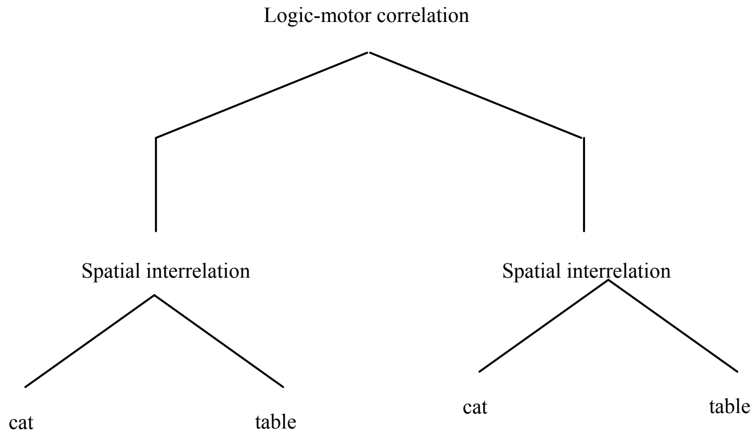

Figure 25. Logic-motor correlation of the cat's movement compared with the table

3.4 The perceptual memory of the dorsal and ventral systems

The most important function of the ventral system is that of allowing us to recognize objects. In order to understand how this is achieved, a simple example is when we use attention to select a table through the dorsal system, the ventral system memorizes the "detailed perception" in the temporal cortex. Moving the attention from the table to the "brown" colour, the ventral system will also memorize this "detailed perception" in the temporal cortex. Moreover, the two "figures" will be related to each other.

The process of relating things is circuital, the result of this process is the relation. The relation concerns figures characterized by fine details. If, at a third stage, we select the table and the colour by fixing our eyes on both at the same time, the interrelation between the table and the colour occurs in the temporal cortex. Figures 26a and 26b show the relation and interrelation.

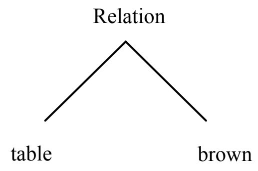

Figure 26a. Table-colour relation

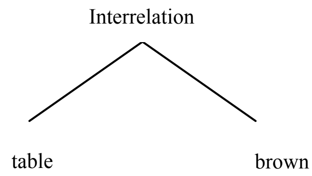

Figure 26b. Table- colour interrelation

When perceiving both the table and the colour with our eyes, the interrelation of the ventral system allows us to see, and recognize, both of them almost as if they were a whole, even if they are separated. Moreover, thanks to the relation, the simple perception of the colour or the table activates the related element.

Figure 27 shows the functions played by the dorsal and ventral systems in perceiving the table and the brown and in their ventral relation and interrelation.

From what has been stated, we can infer that there are associations, relations and interrelations in the two associative parietal and temporal areas. In the parietal cortex these structures concern spaces and times; in the temporal cortex they concern "what". Virtual spaces are memorized in the inferior parietal lobe, while figures are memorized in the primary areas.

We must underline the fact that the associations, relations and interrelations of the ventral system involve figures which are spatially and temporally decontextualized. The act of attentional selection, in fact, separates the figures from the spatial and temporal parietal context. Therefore, the ventral system cannot identify the size and position of an object whose parameters depend on the interrelations, relations and spatial associations of the dorsal system. Moreover we have explained how the dorsal system moves an object or determines its sensory variations, such as colour change. The ventral system therefore cannot perform these functions by itself, but plays a role in these functions, dealing with meanings.

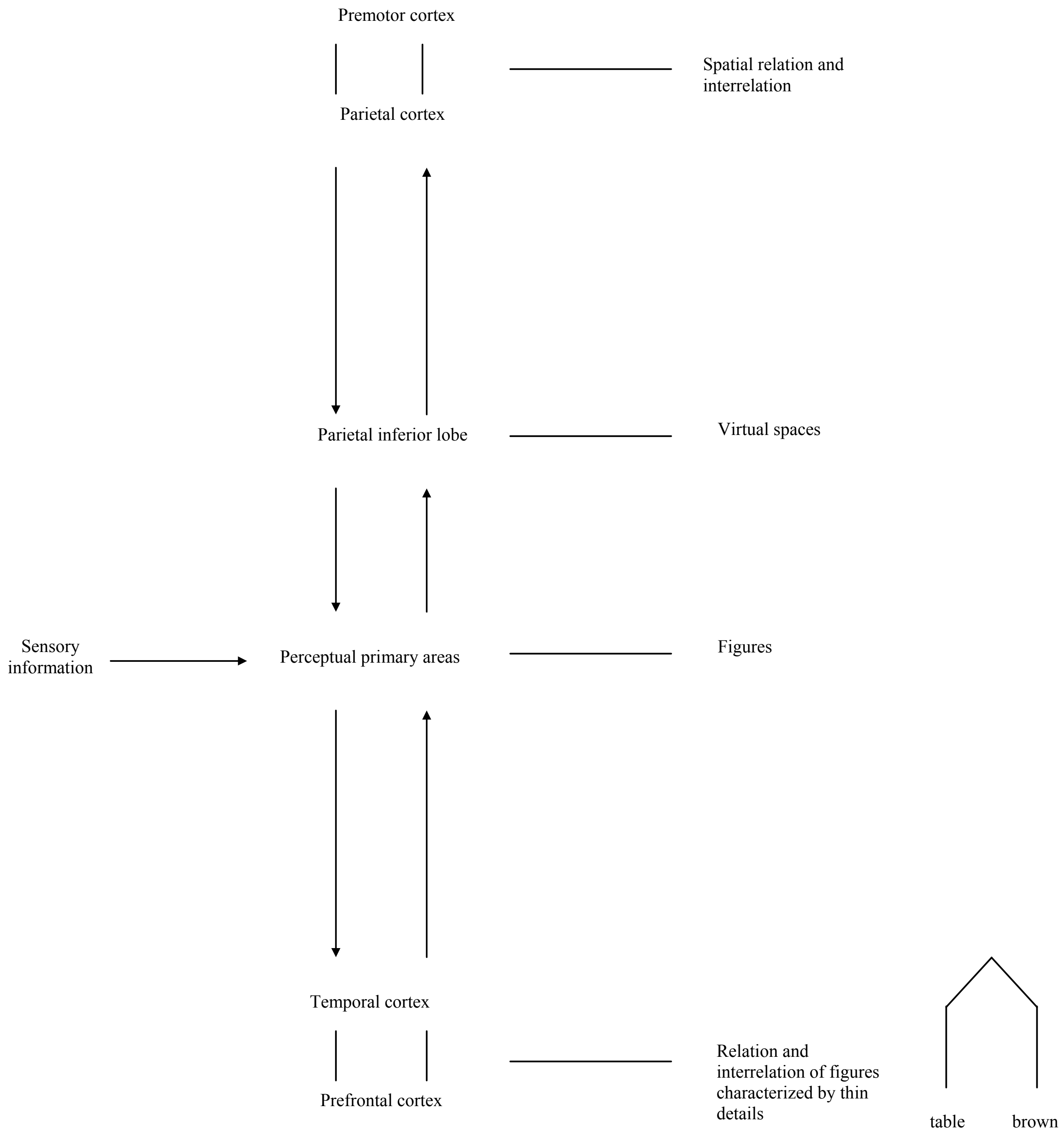

Figure 27 Scheme of the dorsal and ventral systems

3.5 Figures, categories, concepts

We have already stated that, in visual field, the kinds of figures that can be selected are: a scene, an object, a movement, a colour, a brightness, etc. Each of these selections corresponds to a specific area of the visual primary cortex where "figures" are memorized. These areas are organized on the basis of the selected contents. For example, in a scene that includes objects, movements, colours, brightness, etc., the visual areas related to colour and movement are independent, while the area concerning the object includes movement, colours and brightness. This involves an accurate anatomic configuration of these areas. The V1 area that memorizes the scene is the area on which the information of the retinal receptors converges. The V2 area that memorizes objects is the projection area of the V1. The MT area, in charge of the memorization of movements, and also the V4 area, in charge of the memorization of colours, are projection areas of the V2 (Figure 28).

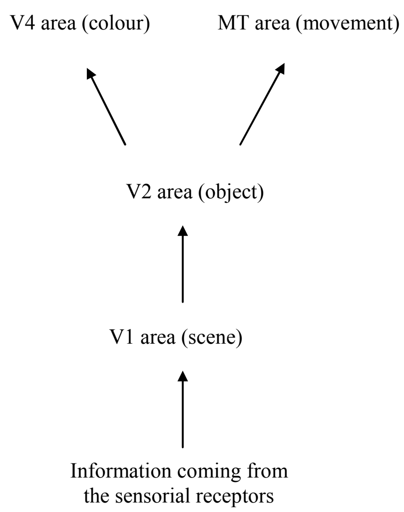

Figure 28. Organization of the visual primary cortex

Let us try to clarify what a "figure" is. When we walk on the seashore and then observe the footprints, they have a precise shape and some well-defined spatial relations. Before we started our walk, how many possibilities were there of producing footprints with exactly the same shape and spatial relations? I think that this possibility can be estimated as one in several billion. Even if it is nearly impossible for that specific sequence of footprints to occur, nevertheless some sequence must occur. By walking and leaving footprints, we move from the potentially unlimited to a "fact". The same can be said about the relationship between all the potential images that can be created by our sensorial receptors and primary areas, and the specific image that we perceive. The figure is a "fact" versus the almost countless potential possibilities. Our mind, selecting various objects, moves and acts through the dorsal and ventral systems that encode the relations between the figures present in the spatial and temporal context.

This example allows us to differentiate *performed movements* from *organized movements* and *figures* from *concepts*. We could also define *organized movement* as a "motor category". Let us consider quite a frequent movement, such as signing a document. We are able to sign a document because the population of neurons in the premotory and parietal area, in charge of the "writing" function, organize the logic-motor *correlative structure* for this purpose. This organization is the "motor category". It turns into the specific series of movements that determine our signature. But if we carefully observe some of our signatures, we will notice that they differ, even if only in a tiny detail. This happens because *the organization of movement* cannot be such as to allow us to perform the same movement more than once in a perfectly identical way. The "motor category" is an "a priori" that can have countless and various results. Among the numerous potential possibilities, at least one must be performed during the motor act. In the same way, among the countless series of potential footprints on a floor, at least a series of specific footprints must occur.

What we have stated about the relationship between *motor category* and *performed movement* also applies to the relationship between *concept* and *figure*. The figure is the "white", "hard", "hot", and "chair" that we actually perceive and mentally represent in a spatial and temporal context. The concepts of "white", "hard", "hot", and "chair" are "a priori" potentialities: they imply the mental faculty of perceiving and/or mentally representing a given figure. A "figure", in its a priori status, cannot be specific because it has not been made yet. It is precisely a concept.

We can therefore consider the dorsal and ventral systems, as systems that can potentially construct movements, images, colours, etc. These constructions, before being made, are categories and concepts; after they have been performed, they are specific figures and movements. Let us think about when a fertile couple conceives a child. Before the baby's birth we can state that this couple is able to make children (concept). After the baby's birth, we can state that they have been able to conceive exactly that child (figure).

When we compare the physic world with the conceptual world we consider mental constructions (whether figures or concepts) as external elements that are independent of our mental activity.

3.6 The explicit logic-cognitive circuit

The basic cognitive circuit "*given that* → *then …hypothesis* → *verification*" (perception/recognition → anticipation (retrieval) → movement → perception/recognition) requires a "shift". This shift can be a movement or a shift of attention from one space to another. The circuit begins with perception/recognition and ends with perception/recogniton. As we have already said, the circuit is based on logic since the verification is a hypothesis that has been formulated on the basis of a fact.

The internal components of the circuits: "hypothesis … movement … verification (perception/recognition)" are not completely conscious. A conscious "perception" occurs when the perceived object is, "somehow", hypothesized and recognized. When we move our eyes at random and we see an object that we do not expect to find in that place, we are surprised and have another look to be certain of what we have seen. While reading we are not aware of the *anticipation* process (for experimental evidence of the anticipation process see Rugg, 1995). Moreover we are not conscious of the hypothesis/verification process that allows our mind to learn. If we are in a room in the dark, we press the switch *anticipating* that the light will turn on. The anticipation process is unconscious. On the contrary the "given that" is conscious. The latter, in fact, is the starting point of a new circuital activation but also the closing act (verification) of the previous circuit and for this reason it is conscious. In other words, the perception/recognition process, which follows hypothesis and movement, is conscious because it is supported by all the circuital elements. Hypothesis and movement are unconscious since they do not complete the cognitive circuit by themselves. A final step is necessary to close the circuit: that is, the perception/recognition process.

The perception/recognition process, which makes the result of the circuital process conscious, is a ventral system function. With the dorsal system, instead, it is plausible that all the logic-cognitive circuit is unconscious.

In order to make *anticipation* conscious, it must be *mentally represented*. In this way the hypothesis is made explicit by the representational circuit. This represented hypothesis can be verified after the movement. In order to verify a represented hypothesis we activate two circuits, the first of which mentally represents the hypothesis, the second of which performs the movement that is followed by the verification. Figure 29 shows the activity of the two circuits when we consciously hypothesize the turning on of the light before pressing the switch.

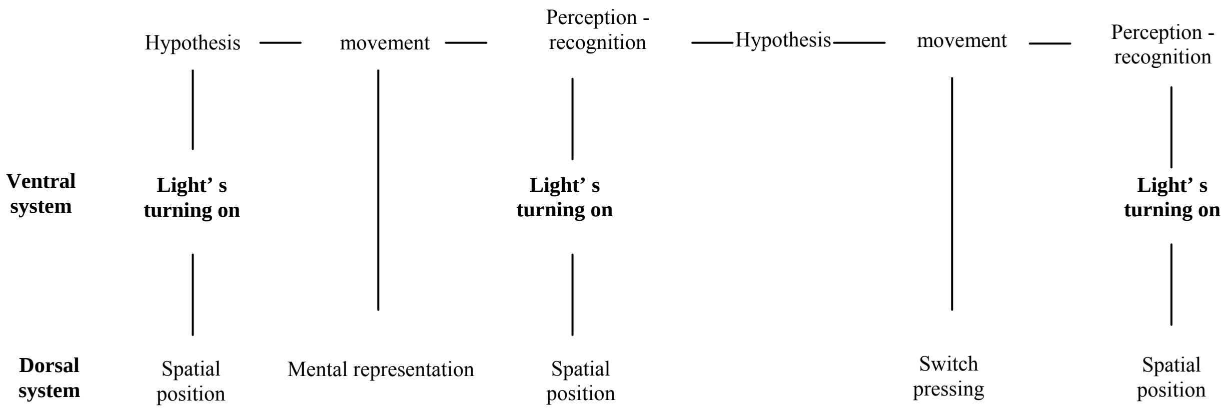

Figure 29. Verification of a represented hypothesis

Let us now insert the "given that" in this circuit, that is, the starting point. We have a first level explicit logic circuit (Figure 30).

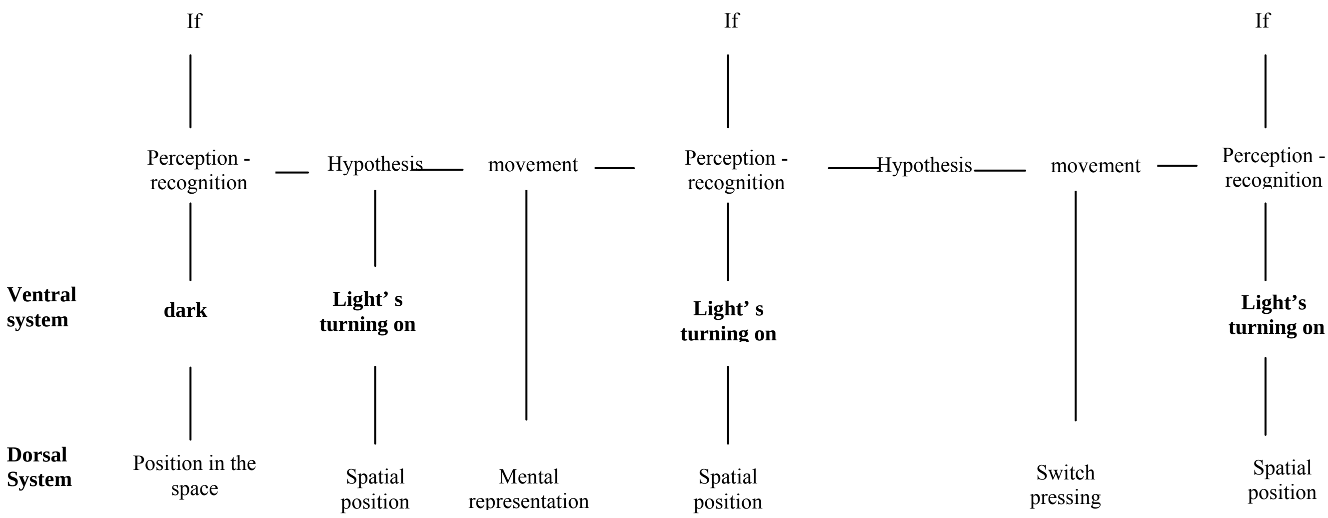

Figure 30. Explicit logic circuit

The first level explicit logic circuit consists of three conscious elements: starting point, represented hypothesis and verified hypothesis. This circuit is certainly common to mammals who are able, on the basis of a given situation, to consciously anticipate something that will occur after a given movement. They are therefore conscious of something that has not happened yet but that has only been imagined. A mouse is surprised when it doesn't find food once it reaches the platform. In doing so, it almost certainly anticipates the food perception by representing it mentally. The limits of this circuit derive from the fact that the starting point (the initial "if") is perceptual. The animal must be in a given "real" situation, before being able to mentally represent the hypothesis to be verified.

A more complex circuit is the *second level logic-cognitive circuit*. This is similar to the first level circuit with the only exception of the initial "given that", which, instead of being perceived, is represented. This circuit allows us to formulate hypotheses on facts that are not present in the experienced scene. By means of it we move from a real level to a theoretical level. I believe that anthropomorphic monkeys are able to use second level circuits, by mentally representing the "given that" and the hypothesis. That is, they are able to make simple abstract thoughts.

The mentally represented "given that" and the "hypothesis", that is also mentally represented, can be motor acts. The second level logic-cognitive circuit, when the "given that" is a represented motor act and the hypothesis also is a represented event, builds a logical link between the action and the ensuing fact. For example, I can represent to myself the gesture of pressing a switch as a starting event and the light's turning on as an hypothesized and verified event.

Every conscious process is a circuital process that contains unconscious elements. The consciousness of "pressing the switch" derives from a mental representation in which the dorsal system unconsciously moves the attention to the mental representation. Anticipation is also unconscious. We don't even realize the shift from a mental representation (the gesture) to another (the light's turning on). The time spent by anthropomorphic monkeys in observing and exploring objects and environments, makes me believe that these animals are able to use circuits where their own gestures, mentally represented, can be also used as starting data or as a hypothesis to be verified.

3.7 From conscious to unconscious

Learning a sequence of actions occurs through a process which, by using conscious processes, makes them automatic and therefore unconscious. In other words, a sequence of gestures that are originally consciously performed becomes automatic. When we are learning to drive, we realize that the car is slowing down so we decide to change gear, to shift from third to second gear. The change of gear implies a sequence of three movements: we have to declutch, change gears, and then press the clutch. "Realizing that the car is slowing down" means being fully aware (conscious) of an event, that is, perceiving and recognizing it. "Changing gear" is a fully conscious action and differs from a simple muscular contraction. While we can also become aware of a muscle contracting, this usually doesn't happen.

Awareness originates from perception through one of the five senses or through the so-called "internal sense", which makes us perceive hunger, thirst, etc. Let us go back to the previous example, that is, when we shift from third to second gear, and consider the activity performed by our motor cognitive circuit when we declutch. At first, we are fully aware of the "clutch engaged", the movement of "declutching", and the "clutch disengaged". All three elements are hypothesized, perceived and recognised (Figure 31).

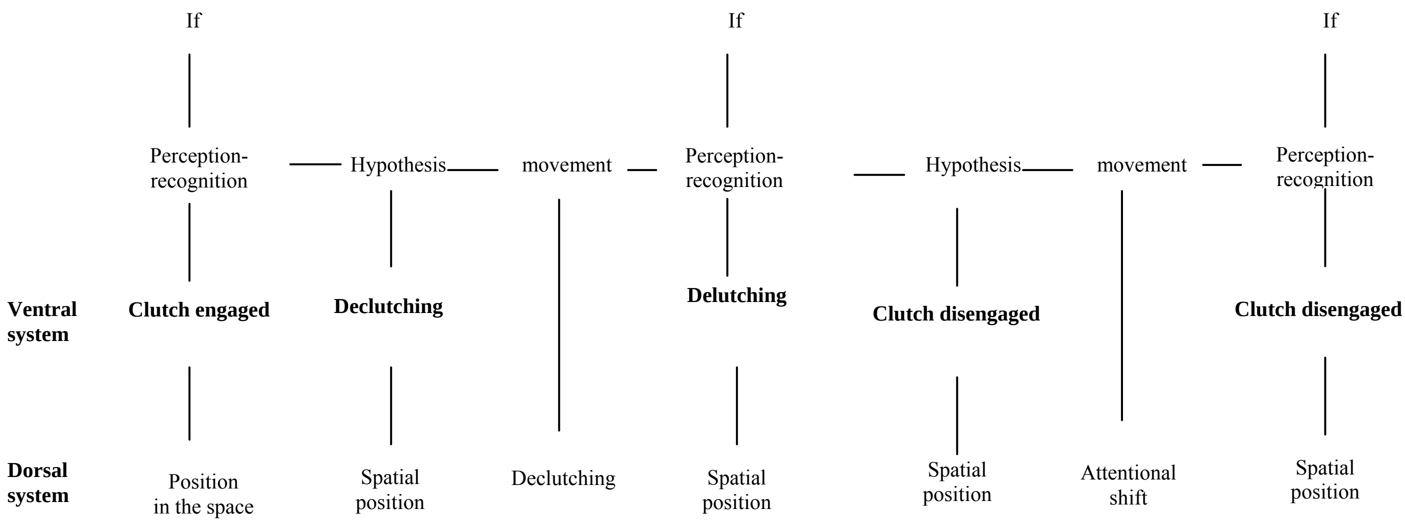

Figure 31. Conscious elements during declutching

Subsequently, the declutching movement is not perceived and recognized, but occurs automatically; we are only conscious of the clutch position before and after the movement (Figure 32).

With practice, this circuit becomes automatic, and we are conscious only of the lever position, which is automatically moved at the same time as declutching (Figure 33).

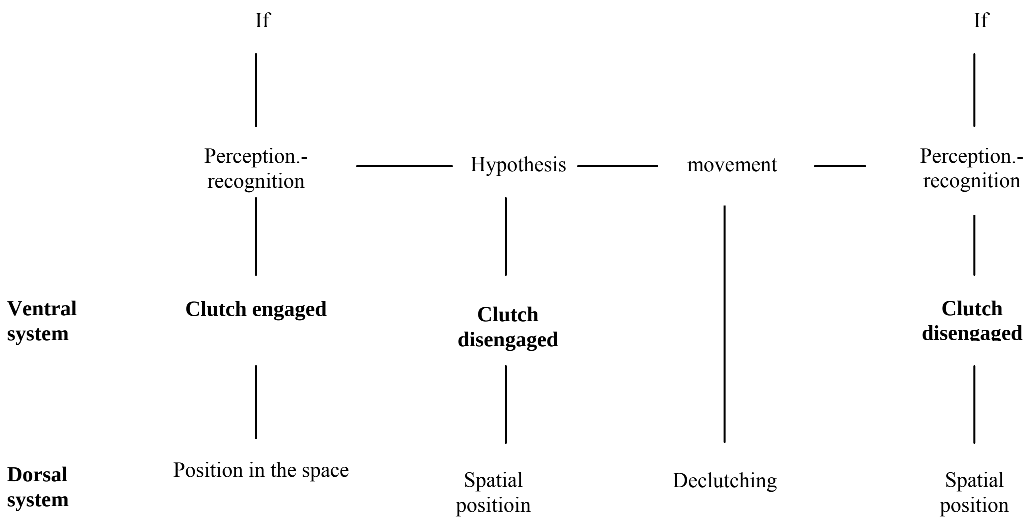

Figure 32. Automatization of the declutching movement

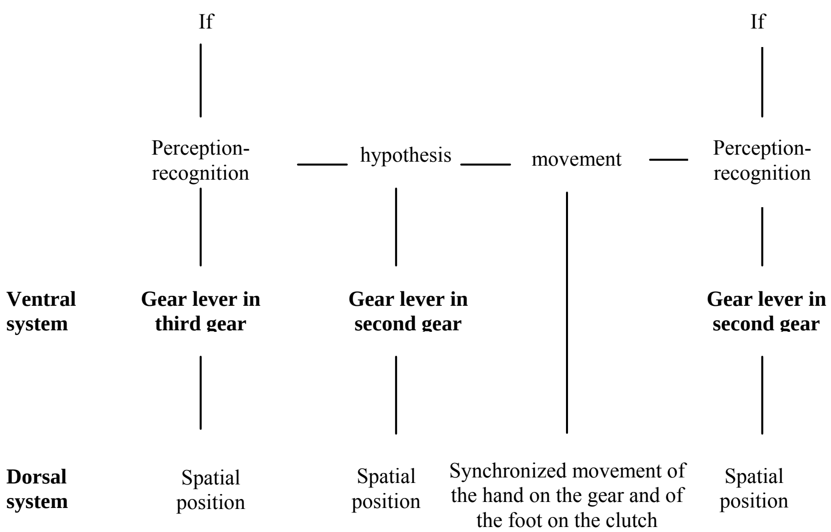

Figure 33. Automatization of the declutching and shifting the gear stick movements

When we are still learning, the conscious perceptions during the gear shift – apart from those dealing with movement – are: clutch engaged, clutch disengaged; gear stick position in third gear,

gear stick position in second gear; clutch disengaged, clutch engaged. We can represent them in their correlative structure (Figure 34).

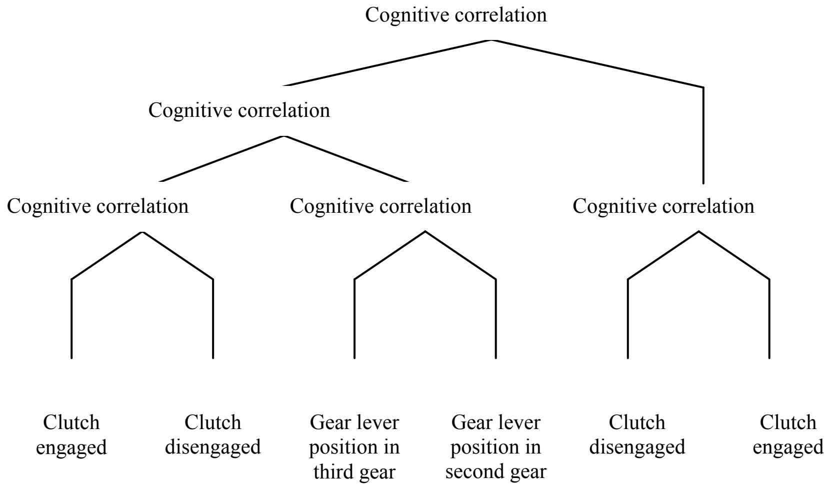

Figure 34. Correlative structure for gear shifting

This complex circuital scheme derives from the fact that the motor sequence has not been memorized and the logic cognitive circuit that performs the new hypothesis is activated at each step, after having verified the previous hypothesis.

Once memorization has occurred, a single structure of spatial interrelation is built up for the variation in time of the spatial positions of the clutch, gear stick, and the temporal relations between clutch and gear stick (Figure 35).

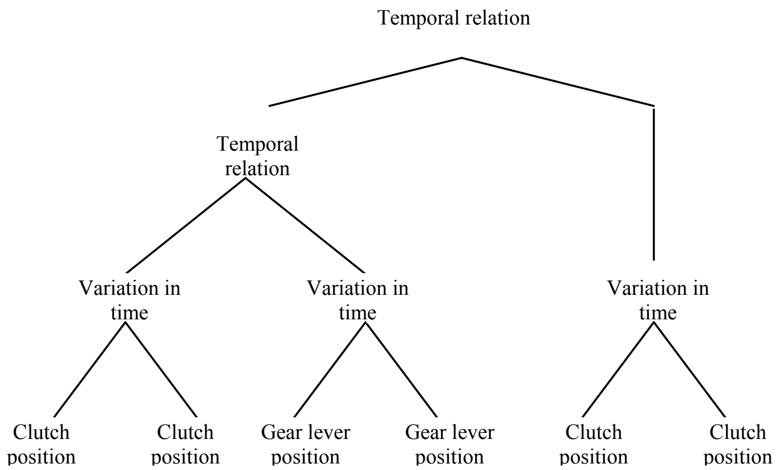

Figure 35. Interrelative and associative spatial structure of the position of the clutch and gearstick

With this structure memorized in the parietal cortex, the premotor cortex organizes the movement of the specific articulations, whose memory is stored in the primary motor cortex. Before learning, in order to perform a gear shift, the logic cognitive circuit was activated five times. After learning, the whole sequence is automatic. The move from the initial position, when the gear stick is in third gear, to the final position, when the gear stick is in second gear, is achieved by activating the logic cognitive circuit only once. The ventral system is also involved in the parietal structure of interrelations and associations by specifying "what" is found in a given position compared with "what else". With experience, in order to perform a sequence of actions, each of which is linked to a circuital operation, only a single circuit is activated, in which the temporal relations between the spatial components become more and more complex.

This mental procedure allows us to learn. At a mental level, learning is performed through logic circuits of a motor and cognitive kind. They "outline" the experience in the anterior, posterior and subcortical areas of the cortex. This experience is reflected in spatial, temporal, modal and "functional" networks of interrelations (and associations) that can be embedded in increasingly complex circuits.

3.8 The attributive relation

Before dealing with the attributive relation, it should be pointed out that the cognitive circuit includes both the dorsal and ventral systems, since the firstdeals with movement and spatial/temporal relations, and the second deals with relations between "figures". From a cicuital point of view, the attributive relation involves the dorsal system, which concerns spaces and times, as well as the ventral system, which concerns "what" (detailed figures). As far as the attributive relation is concerned, it is the ventral system activity that plays the most important role since it deals precisely with *attributes*, *objects*, and their "recognition". The attributive relation is a circuital connection between the two "mental entities", where what acts as an attribute is a "feature" of the other. We can define the attributive relation as the connection between an "object" and its components. The term *components* is used for the information which is gathered by the sensorial receptors from the object and then sent to the cortex along parallel pathways through the various relay nuclei. Examples of such attributes are: yellow, light, big, bitter, hot, sad, etc. The ventral system, in order to relate "object" and "attribute", acts on the figures selected from the spatial and temporal context by the dorsal system.

An example of the simultaneous functioning of the two systems in the attributive relation is when we observe, one after the other, an object (a leaf), its colour (green) and its brightness (light). The selection of the leaf is performed through a process of fragmentation of a wider space, for example that of a leafy branch. The leafy branch is therefore our starting point, the fact. On the basis of this fact, the ventral system hypothesizes "what" will follow this perception. The dorsal system hypothesizes, on this basis, the position of the leaf on the leafy branch. The ocular movement is then performed on this hypothesis. Both systems verify their hypotheses, which become the starting point for a new circuital activation. The ventral system first hypothesizes which colour will be perceived and then which brightness will be perceived, by keeping present first the leaf and then its colour. The dorsal system hypothesizes the relevant positions and organizes the movements; after which the verifications follow. Figure 36 shows the activity of the circuit, beginning after the perception of the "leaf".

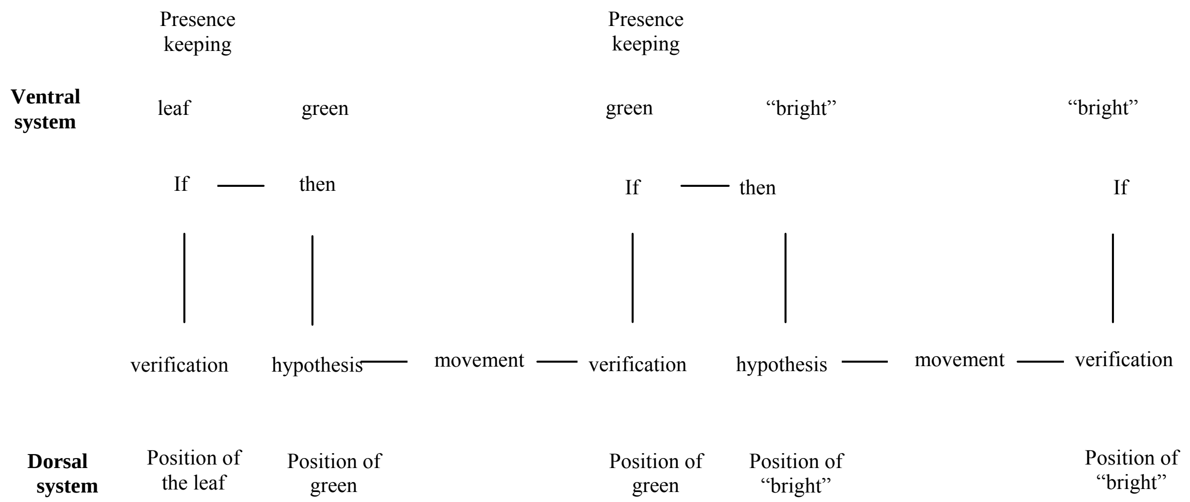

Figure 36. Simultaneous activation of the ventral and dorsal systems in the attributive relation

The attributive relation of Figure 37a is memorized in the temporal and prefrontal cortex. In the temporal cortex as input perceptual memory; in the prefrontal cortex as output memory. The spatial relation of figure 37b is then memorized in the parietal cortex (input memory) and in the premotor cortex (output memory).

Figures 37a and 37b highlight not only the attributive relation between the leaf, green, and bright, but also the interrelation between leaf and colour, green and bright, and the relevant spaces.

The interrelation and the attributive relation are mental constructions: both are performed at independent moments and differ because, during the interrelation, the two elements change simultaneously with respect to each other, while in the attributive relation there is a shift from one to the other. In the interrelation, as we have already said, the components are perceived and retrieved at a singleglance. After these memorizations, the cognitive circuit can retrieve, on the one hand, through the prefrontal cortex, the leaf, colour and brightness memorized in the temporal cortex; on the other hand, through the premotor cortex, the parietal spaces. This double retrieval allows for the mental representation of each element. The retrieval process is performed by a cognitive circuit which uses the memorized data more than the sensory information. As already stated, these memorizations promote perception. The perception of the leaf by means of a single glance automatically activates the spatial and attributive associations without "shifting", with the circuit, from a perception to another.

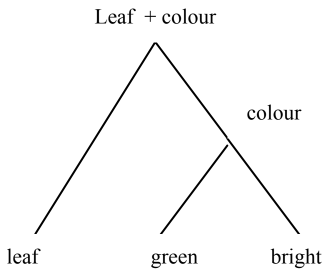

Figure 37a. Attributive relation

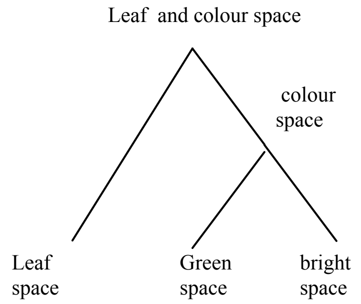

Figure 37b. Spatial/attributive relation

3.9 Posterior Attentional System (PAS) and Anterior Attentional System (AAS)

Posner and Petersen (1990) distinguish two attentional systems respectively called: "Posterior Attentional System" (PAS) and "Anterior Attentional System" (AAS). The PAS refers to the dorsal system, while the AAS refers to the ventral system. In the visual field, the dorsal system (or Posterior Attentional System) selects the leaf, colour, and brightness, dividing each from the spatial context and moving the focus of attention from one to the other. When it selects the "leaf" it also divides the figure from the background (meant as spatial context). This means that the leaf is separated from the spatial context together with a portion of background against which it stands out. After the disengagment of attention, it selects the colour (shade + brightness) separating it from the background (also meant as spatial context). This mental function, that is, the separation of colour from background, involves the "leaf" object and the "colour" object. In fact, the separation of the colour occurs on a background that is represented by the leaf itself. In other words, the leaf acts as background during the selection of the colour. The PAS attentive processes occur in still or in movement spaces. The leaf is selected by splitting up the scene space. A part of this space, that is, that belonging to the leaf, is separated from the scene space, which acts as background. The selection of the colour occurs on the leaf space, which acts as background. If more colours occupy this space, it is divided and we say that the leaf is "yellow and green". In this case, two spaces belonging to two colours are separated from the leaf space (background). The attentional process of separating the colour from the background of the leaf, which is kept present, produces the attributive spatial relation. This is memorized as an "act" in the circuit and as a perceptual and functional "fact" in the premotor and parietal cortex.

The tiny detailed figures project from the primary cortex to the temporal cortex. The prefrontal cortex acts on this projection. These two cerebral areas (temporal and prefrontal cortex) are parts of the Attentional Anterior Process or AAS (the ventral system). The attentional anterior system creates the relations of the tiny details, in charge of recognition, which can be considered to all effects relations of "objects" and "attributes".

We should highlight the fact that whereas the leaf is separated from the spatial context (the scene), the colour maintains its own spatial relation with the leaf. For this reason the spatial relations that the leaf has with other objects are excluded from the attributive relation while the spatial relations with the colour are preserved. Therefore, leaf size cannot be determined using temporal memory, because it is outside space and cannot be related to other objects; but we can determine its colour, since it is spatially related to the leaf.

This also applies to shade and brightness. The separation of brightness occurs on the shade space, creating a spatial relation in the parietal cortex and a modal relation in the temporal cortex.

3.10 The spatial and temporal relations of the dorsal pathway

Before analysing the spatial relations, we should point out that each physical object has its own "virtual space" because of how the sensorial systems are organized. This "virtual space" is the space occupied by the object itself. It projects into more than one module of the parietal cortex and performs more than one function. Virtual spaces of our body, in the angular gyrus for example, are involved in the process of determining the spatial "right"/"left" relation (damages in these areas can provoke the "Gerstmann syndrome"). In other projection areas (left parietal lobe), virtual body spaces are involved in determining the spatial relations between the body districts (damages in these areas can cause "autotopoagnosia"). The virtual space is one of the object features, like colour, shape, weight etc. It too is generated by an attentional act of selection when the "figure" is separated from the "background". The virtual space (as a figure) therefore has a virtual space as a background. Each "virtual space" can be selected after the object is perceived and in this way becomes what is referred to the object, which represents the reference.

"Virtual time" is determined in the same way as visual space, which corresponds to perception time. This is also a feature of objects and as such can be referred to the object, which is the reference. In order to understand how our mind creates spatial relations let us observe Figures 38 and 39.

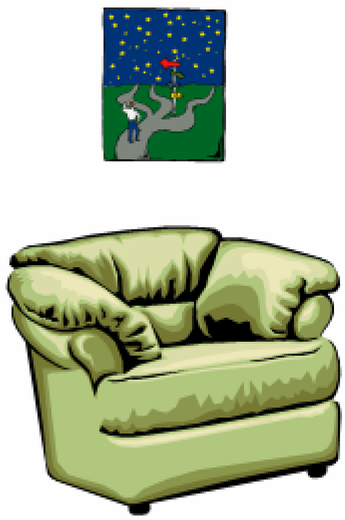

Figure 38. two objects

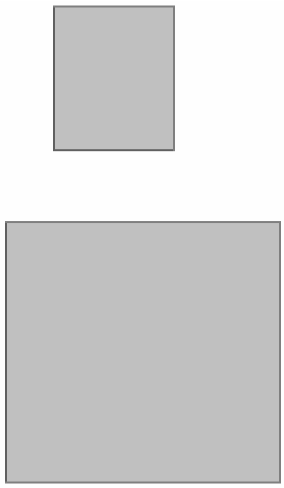

Figure 39. Two virtual spaces

Figure 38 shows two "objects": an armchair and a painting. Figure 39 represents two virtual spaces. They are the virtual spaces of the armchair and of the painting.

Our mind can create the reference/referred relation between the two virtual spaces. Thanks to the visuotopic organization of the retinal receptors and of the visual cortex neurons, this function generates the relation "over/under" (or "under/over"). This spatial relation concerns "virtual spaces" (Figure 40a). If we use, in order to perform a similar relation, an "object" such as an armchair, and a virtual space, we have the relation "over the armchair" (Figure 40b).

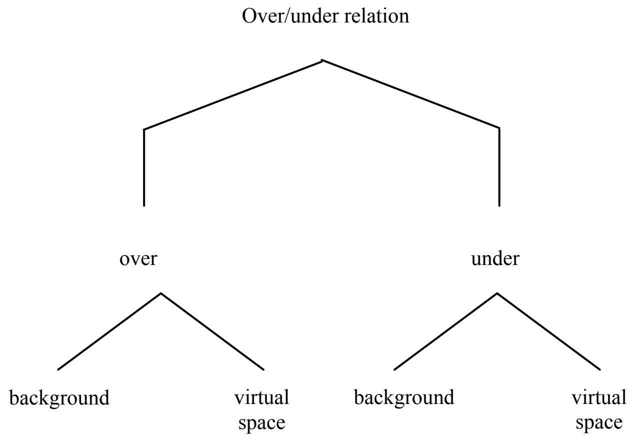

Figure 40a. Over/under relation

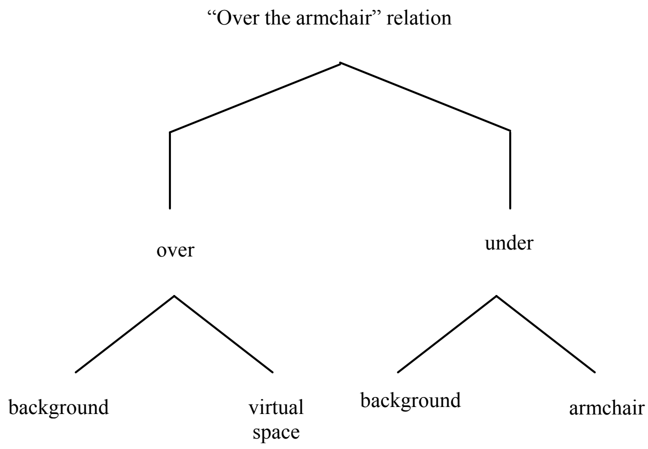

Figure 40b. Over/the armchair relation

This relation can be, in turn, inserted in an attributive relation that includes the object "painting". In our mind, the position expressed by the phrase "over the armchair" is an attribute of the painting. We have a double spatial relation: the first is of an attributive kind ("the painting over the armchair"), and the second generates the correlative structure of spatial origin ("over the armchair") (Figure 41)

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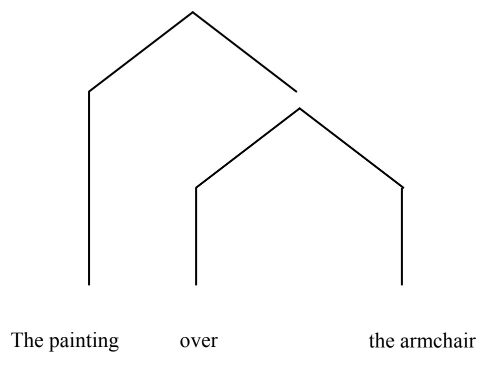

Figure 41. Ternary correlative structure "the painting over the armchair"

Ternary correlations of time are built similarly. For example, the correlation "a walk after dinner" originates from the correlation of two virtual times, "before/after". From here, the binary correlation "after dinner" arises. With the insertion of the construction "the walk" we have the ternary correlation: "The walk after dinner".

4. Concepts and semantic areas

4.1 Comparisons

Another important perceptual function is "comparison". During comparison, the dorsal system selects a first figure, which is kept present by the prefrontal cortex, while the second figure is selected. The alternate selection of the two figures, kept alternatively present by the prefrontal cortex, generates the reference/referred relation several times. Sometimes, figure "A" is referred to, other times, it is figure "B". This double referring process is what we call "comparison". It is used to distinguish two "objects" by differentiating them.

As with the attributive relation, during comparison, keeping present an "object" while we perceive another gives rise to a relation in which the object that is kept present is the reference, and the perceived one is the referred item. These comparisons yield relations of sameness, difference, etc. We say, for example, that object "A" is the same as object "B", where "A" is the referred item and "B" the reference.

The relation structure, where a population of neurons encodes the first figure, second figure and their relationship, is generated in the temporal cortex. So, when we compare two colours, such as green and yellow, we use them sometimes as a reference, other times as a referred item. This function allows us to achieve the *relations* of sameness and difference between two objects and/or features, and to memorize the relation structure in the temporal cortex, which will be used during recognition and retrieval.

Figure 42 shows the operation of comparison. The dorsal system separates the yellow and the green, alternatively, from the background (the dotted line stands for the discarded background). At the same time as the attentional selection of the green colour takes place, the prefrontal cortex keeps the yellow colour present; likewise, while the attentional selection of the yellow colour takes place, the prefrontal cortex keeps the green present. The comparison is achieved between the colour that is kept present and the colour that is selected. This activity brings about a relation of diversity between the two colours, memorized in the temporal cortex.

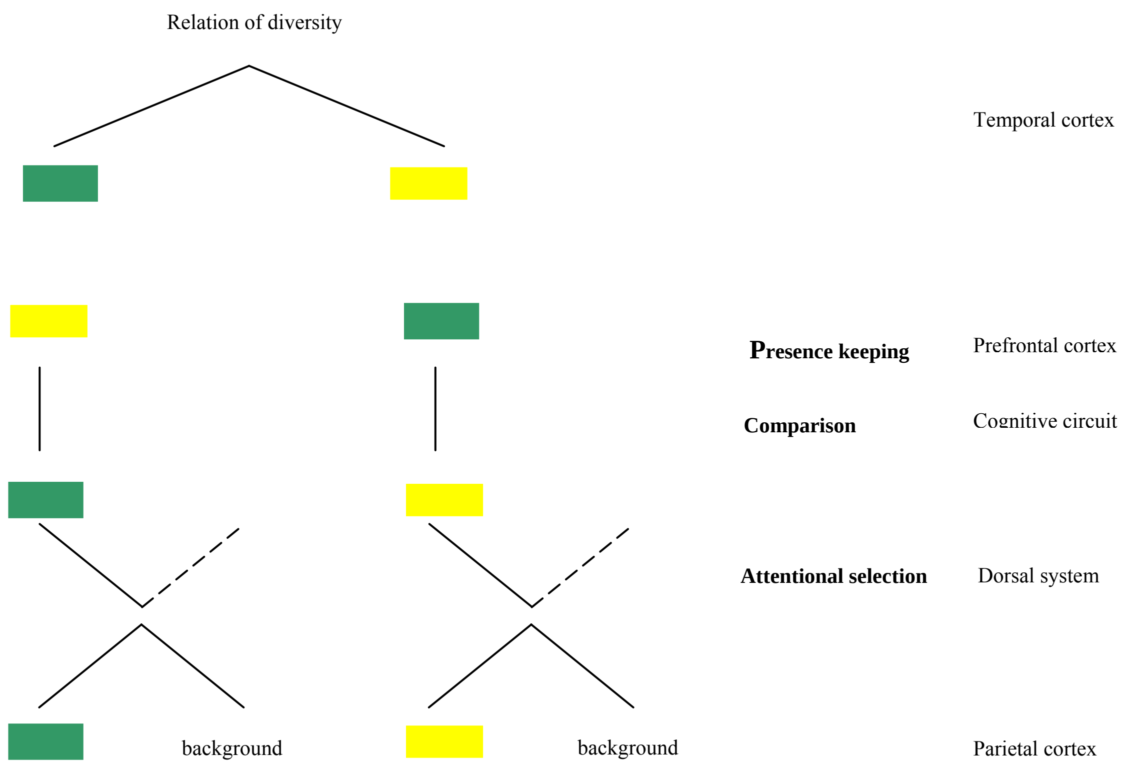

Figure 42. Comparison between two colours and their association

Words such as equal, different, similar, same, identical, etc. derive from the operation of comparison. Moreover, comparison allows us to distinguish objects and their attributes. In order to be able to distinguish two or more objects, they must be made up of associations, relations or interrelations. It is just the difference between two associations or interrelations or relations that allows us to distinguish objects. In other words, an object cannot be recognized as equal or different from another if we observe them "separately". Differences derive from variations in the associative, interrelation, and relational structure that the two objects have. The recognition between two colours is possible by analysing the different interrelation figure/background. Green is different from yellow since their relation figure/background is different.

The comparison is made between mental entities that cannot be attributively associated. In fact, in this case one entity can never be a feature of the other. It is not possible to compare a colour with an object or a position with an object. It is possible to compare two colours, two objects, two movements, etc.

When comparisons are made, the involvement of the "working memory" is required in order to alternatively keep the two figures present, which are memorized in the cortex while they are produced. Associations are memorized in the temporal cortex, while the associative *function* and the comparison *function* to be activated with the dorsal system are memorized in the prefrontal cortex.

4.2 Conceptual areas

By "conceptual areas", we mean mnestic areas of the temporal cortex where figures are *associated, related* and/or *interrelated* to each other in order to make recognitions and comparisons, the latter by the prefrontal cortex and the dorsal system.

Conceptualization is a memorization process of the relations originating from comparisons. A simple example of modal conceptualization is the conceptualization of colours. Berlin and Kay (1967) found that in every culture, colours are perceived following categories based on the level of language development. In more linguistically poor cultures there are only two categories (and related nouns) that distinguish the bright area (known as white) from the dark area (known as black). As the colour vocabulary gets richer, the areas become more and more narrow. So a more advanced culture will have a noun for "red"; another culture at an even higher linguistic level will have a name for "green", and so on, according to a given progression.

A possible way of conceptualizing colour could be the following. If we are observing some objects for the first time, the simple alternate selection of the "bright" figure and the "dark" one produces a relation structure of comparisons. The working memory, which keeps the figure present for the short fractions of time that elapse between one perception and the other, is involved in creating such a relation structure of comparisons. In this way in the temporal cortex, which is the V4 projection area (in charge colour construction), a relation area of the previously perceived black and white is formed. This area, together with the prefrontal cortex and the dorsal system, is involved in reactivating the discriminative comparison in the output.

This capacity of achieving an output function is what we call a "concept". The concept of "white" is the double functional capacity of perceiving and recognizing the figure as well as of generating the "white" figure in output.

It is important to highlight that colour is also recognised because, at the output, we can compare it with another colour by using the association memorized in the temporal cortex. Of course, the comparison at the output involves the intervention of the dorsal system, which operates in the space/temporal context where comparisons take place.

With practice, colour relations that are functional to the output processes increase. Practically speaking, this means that also on the level of mental representation we can compare and distinguish shades of red, shades of green, etc..

Conceptual areas of hot/cold, smooth/rough, dry/wet, sweet/salty, transparent/opaque, light/heavy, dull/loud, hard/soft, motionless/in motion, etc. are formed in a similar way to that of colours. The conceptual area of heavy/light is created by the association of a "figure" corresponding to "heavy" with a "figure" concerning "light" and with a series of intermediary "figures" concerning the different degrees of heaviness/lightness memorised by the subject (Figure 43a). The conceptual area concerning hot/cold develops in a similar way (Figure 43b). These relation structures can bring about comparisons at the output by means of the intervention of the prefrontal cortex and the dorsal system.

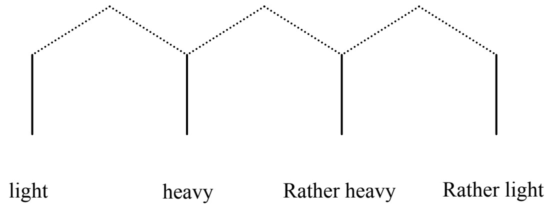

Figure 43a. Light/heavy conceptual area

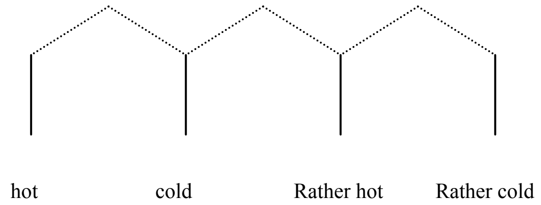

Figure 43b. Hot/cold conceptual area

4.3 Complex concepts

Conceptual areas concern *simple figures* like heavy/light. One must distinguish conceptual areas from *semantic areas*, which are associations of "complex concepts". Let us consider the *complex object* "orange" (which we perceive at a single glance). Figure 44 shows the set of the attributes related to this object, which are in turn related to other attributes equally necessary to make comparisons. It is a star-shaped structure, with the object at its centre, and the specific features of that object all around it. Each of these features is part of the conceptual area. Such a structure, memorized in the temporal cortex, shows the attributive relations of the "complex concept".

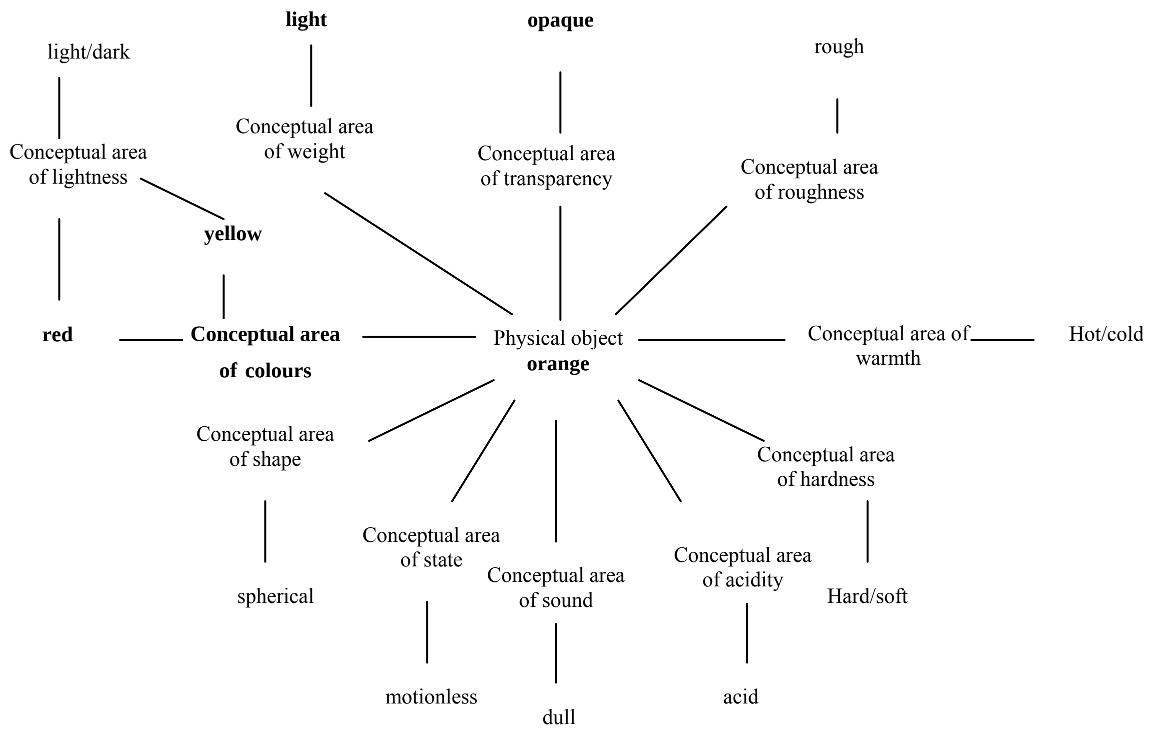

Figure 44. Attributive relatios of the "Complex concept"

Figure 44 shows a scheme which is only partially complete. For auditory perception, in fact, only the (dull) noise produced by an orange that falls on the ground is considered. Other sounds can be added such as an orange being squeezed. As for the orange taste, the scheme only shows the attribute related to the conceptual area of acidity. It lacks the smell attributes. Moreover, each of these attributes can change in time.

The "complex concept" is not only made of attributive relations. It is, above all, a net of *interrelations*. The visual perception, with a single glance at the orange, allows us to simultaneously perceive shape, colour, size, and state. This structure of visual interrelation is associated with similar interrelation structures of the other senses. Moreover, almost all the physical objects that we perceive and recognise have a complex structure at the spatial and/or temporal level. Faces, for example, include the eyes, chin, forehead, hair, ears, nose etc. Each of these "objects" includes other objects in turn: the eyes, for example consist of the iris, pupil, lashes, etc.

These objects are spatially related in a specific way and are all interrelated, so that perception and unitary recognition are possible. The position of the eyes with respect to the nose, the ears, etc. can vary within a specific "range", outside of which a face loses its characteristics and becomes something else. Another complex physical object is spoken words (phonological lexicon). Spoken words are made up of some sounds which are both interrelated and temporally related in a specific way.

In order to memorize complex objects and their "components" our mind divides spaces and/or times and relates objects to the components and components to components, such as when we see the Italian word "legno" ("wood") for example. When we look at it with a single glance, it corresponds to a single figure separated by the background (considered as spatial context), and is therefore spatially decontextualized. This figure's space can be divided into two significant units: le-gno, where the figure itself is the background of the two units. We can create a relation between the object and the component, an association between the two components, while the object and its components can be interrelated. These mental activities produce the following structures memorized as "figures" in the temporal cortex and as spatial relations in the parietal cortex (Figures 45a, 45b, 45c, 45d).

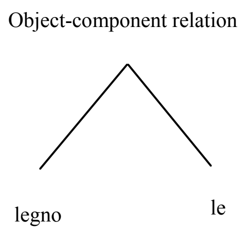

Figure 45a. Object-component relation

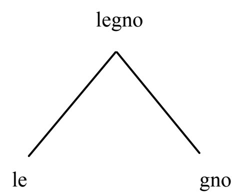

Figure 45d. Interrelation between the syllables and the word "legno"

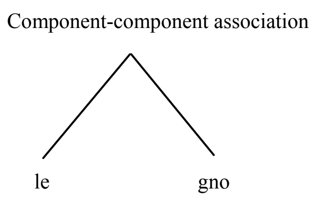

Figure 45c. Component-component association

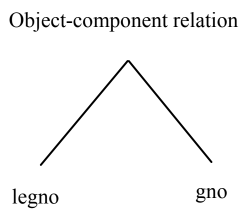

Figure 45b. Object-component relation

By using the same process with the syllables "le" and "gno", we have the interrelations, associations and relations represented in Figure 46.

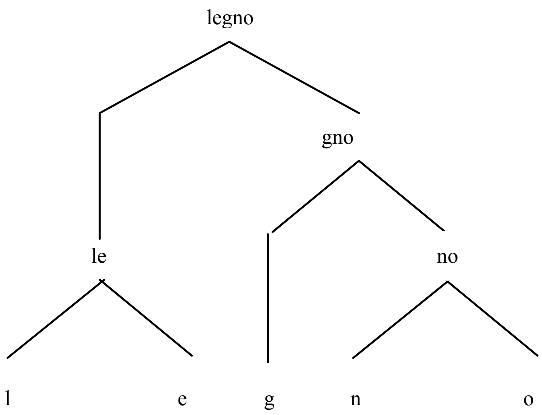

Figure 46. Interrelations of letters and syllables in the word "legno"

The relation, association and interrelation structures of the posterior cortex are two: one is part of the ventral system, the other is part of the dorsal system. The *object-component* attributive relation, the *component-component* association, and the *interrelation* determine the relation structure of the "complex concept": this relation structure is used for recognition and mental representation. In order to understand how these relations integrate with the *attributive* modal relations, let's take the Italian word "legno" again. The structure of this word, which represented in Figure 46, is memorized in the temporal cortex as far as "what" is concerned; and in the parietal cortex as far as the spatial relations are concerned.

The colour attribute can be related attributively to the different "nodes" (see below), which represent the whole word or just syllables, or can be related to a single letter; moreover it can be related to one or more components. The written word: "legno" produces an attributive relation of "red" at the superior node (Figure 47a). The written word "legno" produces the attributive relation of "red" at the node of the syllable "le" and of "black" at the node of the syllable "gno" (Figure 47b)

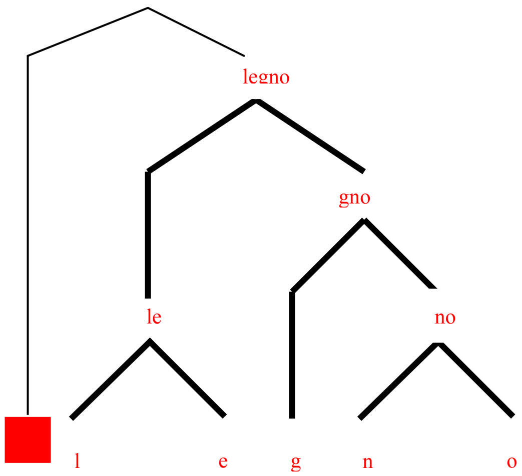

Figure 47a. Relation, association and interrelation structure of the written word "legno"

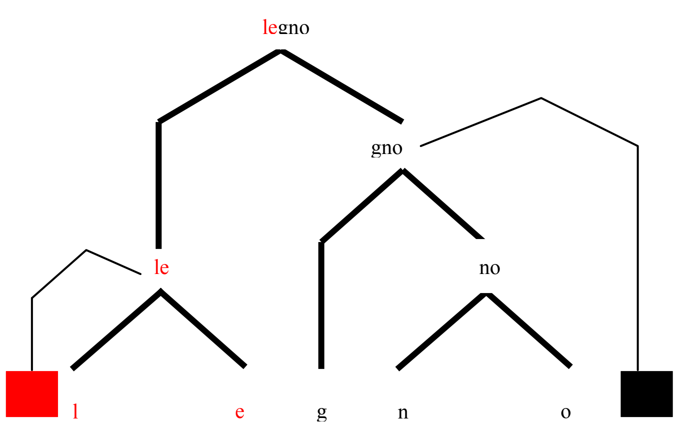

Figura 47b. Relation, association and interrelation structure of the written word "legno"

4.4 Semantic areas

Every "complex concept" is related to analogous "complex concepts". This is due to the fact that these relations arise from comparison operations and we, like all pluricellular animals, are led, in daily life, to compare objects that are similar, so that we can recognize them by differentiating them. If I compare two tables (separated by the background) that I see for the first time, without dwelling on the colour, shape, size, components etc., I notice that they are similar or different, since the figure/background relation varies. The observation of the details creates attributive structures. Each table is associated with its shape, size, colour, hardness, roughness (if we touch it) and components. A table attribute can be *compared* with a similar attribute of another table. In this way, the two tables are differentiated on the basis of their attributes and their components. These mental processes give rise to the *semantic areas*. Figure 48 represents the attributive relations only. In particular, the object/attribute relations are represented by a continuous line, the attribute-attribute relation by a dotted line.

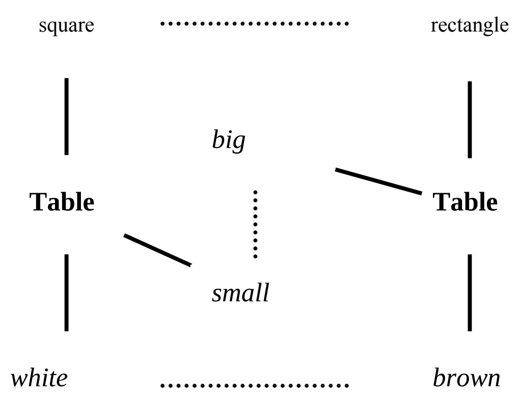

Figure 48. Semantic area of two complex concepts (tables)

All complex objects are inserted in a great semantic network that connects them in the most various ways. The recognition of an object activates, first, those objects that are closely related with it, and then those which have only a weak relation with it. The prefrontal cortex retrieves various objects from this semantic area. The ventral system connections cannot be cut from the system itself. If the prefrontal cortex retrieves a face from the temporal cortex it cannot divide the components (eyes, ears, lips, etc.). This is a function of the dorsal system that operates after semantic retrieval. The dorsal system inserts the object in the space/temporal dimension turning it into a specific figure with its own size, specific colour, etc. This figure can then be subjected to comparison, selection and association activities. It is the dorsal system that allows us to see the object with the "mind's eye". It is able to retrieve the spatial and temporal relations between the components of an object and modify them. In other words, the two systems work in perfect synchronism. The ventral system retrieves and recognizes; the dorsal system performs selections, associations, and comparisons, using the motor system and the memory of space/temporal relations. We call "*cognitive synthesis*" the more or less complex ventral system construction that can be retrieved and recognized at a single glance.

4.5 The activation nodes

As far as recognitions and the organization of "what" are concerned, the basic element is the "figure" separated from the background. This figure can be a "scene", a "complex object", a "simple object", or a "feature". We talk about "figure" because we refer to what is selected by the dorsal system. The memory of the figure is the "cognitive synthesis". When we read the Italian word "pane" ("bread"), because of attentional selection we can separate the following *significative* figures: "p", "a", "n", "e", "pa", "ne", and "pane" from the background. Moreover, for each of these figures we can separate features such as colour and shape from the background. When we select the whole word "pane" with a single glance, we activate the organization of relations and interrelations concerning the "what" of the whole word (cognitive synthesis) and all the attributive features of the word (black, big, etc). If we select the syllable "pa", we activate the organization of relations and interrelations of the syllable and its attributive features.

The *activation nodes* are the components of a mnestic structure (cognitive synthesis) that are involved in recognition when we perceive something with a single glance. These activation nodes depend on the performed attentional selection and on the semantic memory of the perceiving subject. Figure 49 shows the mnestic *activation nodes* for the word "pane". The attributive relation with the black colour, identified by thinner lines, is shown only with relation to the whole word; obviously, it occurs with whatever attentional selection.

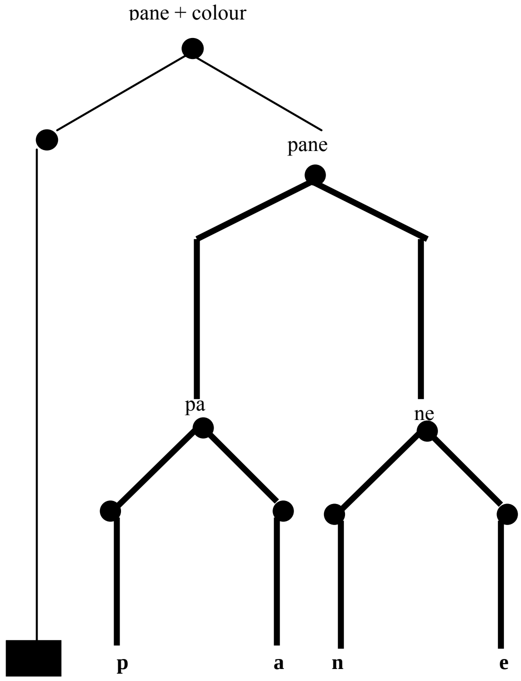

Figure 49. Activation nodes

If we read the whole word with one single glance, we automatically recognize the syllables, letters and colours. The recognition of the word is *conscious*, while the recognition of the syllables, letters and colour is *unconscious*. The perception and the following recognition are *conscious* when they are performed through the basic cognitive circuit. When reading the word, the cognitive circuit is applied to it. The whole word is selected, hypothesized, and perceived. As regards the conscious perception and recognition of syllables, letters and colour, attention must be focused on these through circuit intervention.

4.6 The concept

Previously, talking about motor categories and concepts, we defined these as input and output processes "a priori". An object, which is constructed through complex parallel processes involving colour, shape, movement, hardiness, taste, components, etc., is, before the perceptual act takes place, a "conceptual a priori"; after the perception we have the specific *figure* with that colour, shape, size, etc. This definition is a bit simplistic, since it doesn't consider the functions of mnestic areas and the "mnestic activation nodes". The latter can be useful in better differentiating the *figure* from the *concept*. For example, the face is a very complex object that is made up of many components and attributes. The activation node of a face includes a great number of associations and relations which are automatically activated as soon as we perceive the face. These associations and relations concern the components and the attributes and they are unconsciously recognized when perceiving the face.

Unconscious recognition depends on the frequency with which components and features are first perceived and then memorized. In fact, for a European it is more difficult to differentiate Chinese faces than Western faces. This is due to the unconscious recognition which is more accurate in the latter case than in the former one. If we consider one component of the face, for example the lips, they are unconsciously recognized when we perceive the face as a whole. From this point of view, the lips are a "concept", being a potential figure which can be perceived by focusing the attention on it.

Activation nodes can explain the paradoxical fact why two "objects" can be both "similar" and "different". If we take a single look at two faces that we have never seen before, we will unconsciously recognize the lips. They are *similar*, being "concepts", that is, *potential figures*. But if we dwell on the lips of the two faces, we will grasp what *distinguishes* one from the other, since they have become "figures" in every respect.

4.7 Classifications

The complex object, with its network of interrelations and relations (between object and attribute, attribute and attribute, object and component, and component and component), relates with other complex objects creating "classes". Classes originate from comparisons too.

The comparison between two objects, as we have already said, is made by comparing relations or associations (object-component relation, object-feature association) or interrelations (figure-background interrelation, object-components interrelation). On this subject, let's analyse which mental functions are performed when comparing a phoneme with another through some features that distinguish them. We can define a phoneme as a complex object characterized by its distinctive features, even if some of its distinctive features do not pertain to the whole phoneme but only to part of it (such as, when we refer to green as being the colour of the eyes, while this colour is actually a feature of the iris, which is part of the eye). When we compare two phonemes, the comparison may not concern the whole structure (figure/background), but only one or more distinctive features, which are, with respect to the phonemes, attributes. For example, if the comparison between the phonemes occurs on the consonantal or syllabic distinctive feature, we have consonantal phonemes and syllabic phonemes. Figure 50 shows the comparison of the phonemes “p”, “a”, “d”, and “e”. The comparison is made on consonantal distinctive feature, which is an attribute of these very phonemes.

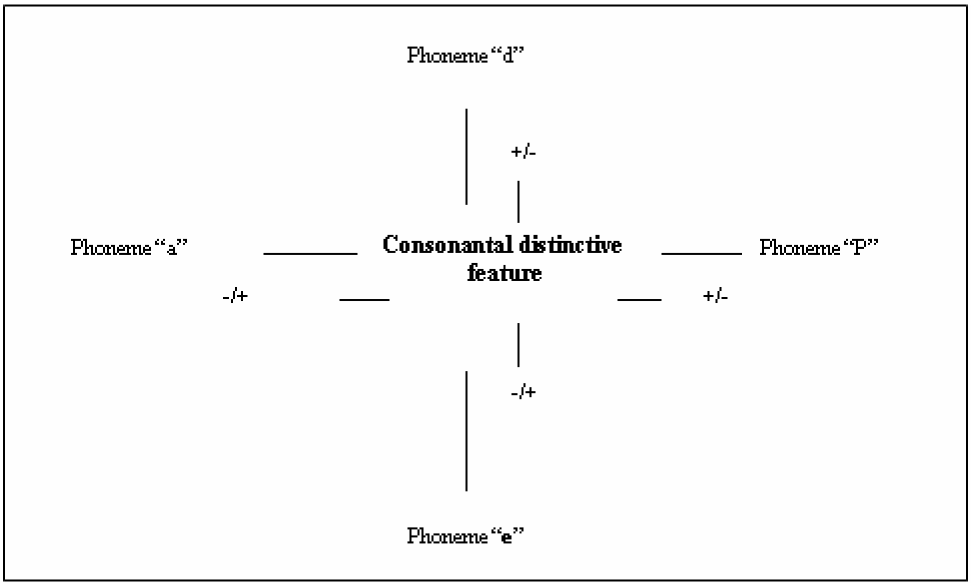

Figure 50. Comparison between the phonemes “a”, “d”, “p”, and “e” at the consonantal distinctive feature level

After this comparison, the phonemes “d” and “p” are similar since they have the same consonantal distinctive feature “+”; phonemes “a” and “e” also appear to be similar, since both have the consonantal feature “-”. The two pairs are different because of their different consonantal distinctive feature. As one can see, the comparison of the distinctive features of the two figures allows us not only to differentiate them but also to notice their similarities. The comparison creates a relation between the compared phonemes. In this case also, the relations are of identity and difference.

The phonemes that possess a consonantal distinctive feature form the consonantal *class* to which our mind can relate the single consonants p, d, r, (elements). However, the operations which lead to a classification can create a class only if the classified “elements” are spatially and/or temporally circumscribed by the attentional selection. In order to clarify this statement, we should recall the linguistic distinction between countable and uncountable nouns. The first group includes nouns that refer to people, animals and things that can be counted and that have a plural form. Instead, the group of uncountable nouns includes those nouns that refer to “entities” that we cannot count and that do not have a plural form. Uncountable nouns are also known as “mass nouns”. Examples of countable nouns are “dog”, “table”, and “computer”. We can say “dogs”, “two tables”, and “five computers”. Examples of uncountable nouns are “money”, “blood”, and “patience”: we cannot say “three moneys”, “bloods”, or “patiences”. The uncountable noun’s group includes, in addition to “mass nouns”, names (Salvi and Vanelli, 2004).

Countable nouns have two main features. The first is that of designating, making reference to two or more “entities”, the same “class”. For example: cat + cat = two cats; cat + feline= cat + feline (in this case numeration is impossible since they belong to different classes). The second feature is that of designating something which could be spatially (chair) or temporally (hour, instant) circumscribed. Abstract countable nouns such as “idea”, “thought” etc. can also be related to spatially and/or temporally circumscribed events. I can say: “I have two ideas about Thursday’s party: we can buy some snacks and decorate the ceiling with balloons”. The two actions expressed by the ideas can be mentally represented and are spatially and temporally circumscribed.

We can define classification as the act of spatially and/or temporally circumscribing (achieved by attentional selection) entities that can be grouped together on the basis of attributes and/or common components.

4.8 Individualization

If one or more features refer to a single “entity”, and they cannot refer to any other entity, we have individualization. Francesco, Luigi, and Sicily are “unique entities”. In order to construct them, our mind selects and gives them some special features. These could be a smile, a tone of voice, a strange way of walking, a particular shape, etc.

The “unique entities” can be recognized through a single, particularly developed sense. Many animals use, for example, the sense of smell. Each of us has a particular smell that a dog is able to perceive and recognise among many others. This smell, which can be assigned to a single “entity”, allows the animal to individualize human beings.

5. Numbers

5.1 Cardinal numbers

The fact that entities expressed by countable nouns can be circumscribed in time and/or in space leads us to think that numbers are the product of mental activities related with space and time. In my opinion, numbers are virtual spaces and/or virtual times with virtual backgrounds. Since numbers are virtual space or time they can *refer* to the object, or to the objects, of which they are a feature.

Numbers are organized in correlative structures. They are constructions of the logic-cognitive circuit. Their memory is therefore circuital. Figure 52 shows the circuital constructions from number "one" to number "four".

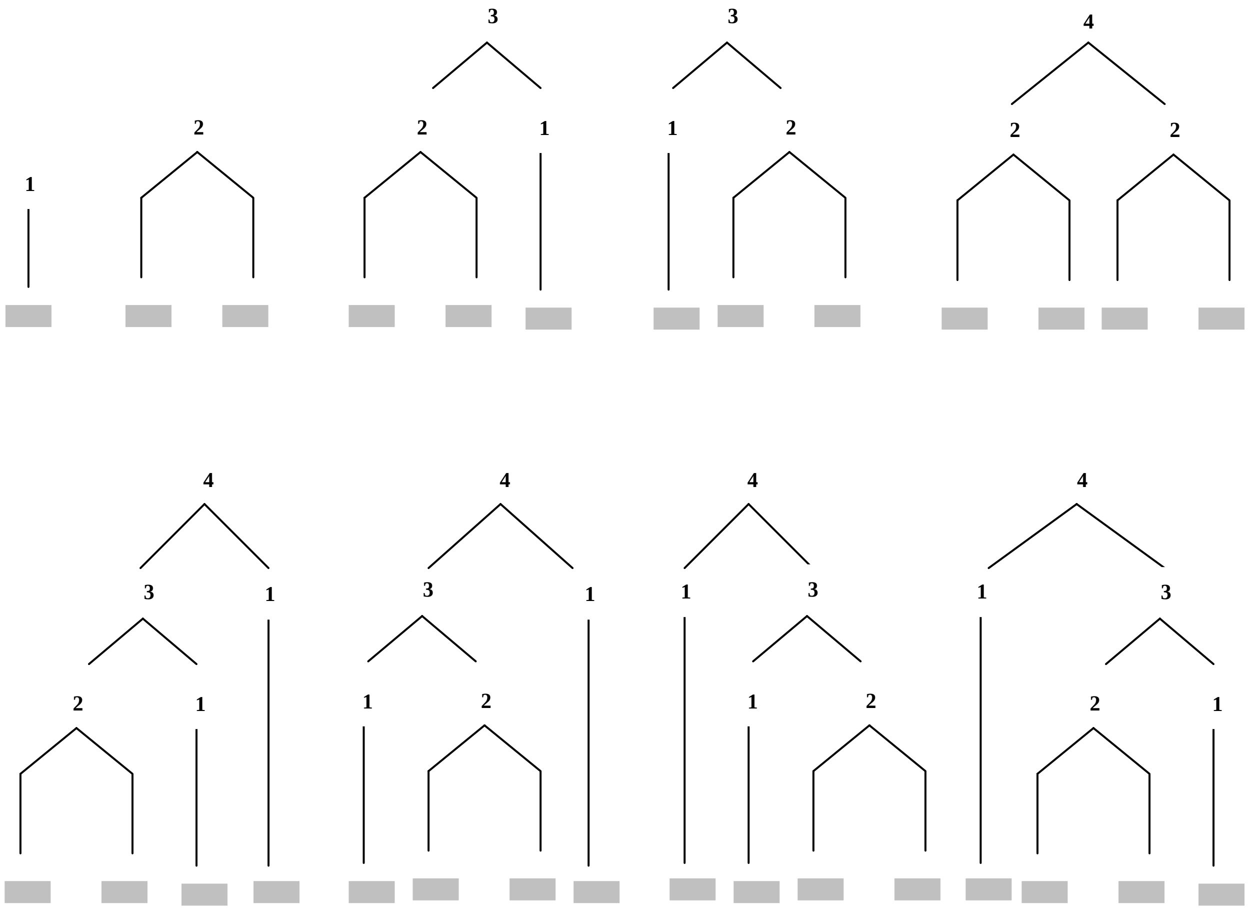

Figure 52. Correlative structures of numbers 1,2,3,4

Observing the two structures of number three and the five structures of number four, we can infer the commutative property of addition. Addition is the act of mentally associating. Subtraction corresponds to the selection which separates. Addition: 1+1=2 and subtraction: 2-1=1 are shown in Figures 53a and 53b.

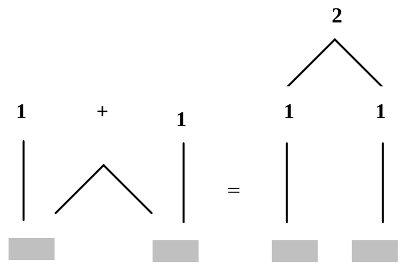

Figure 53a. Addition

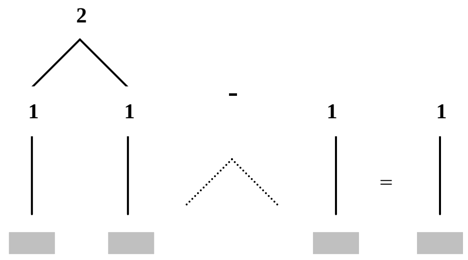

Figure 53b. Subtraction

Figure 54 shows the commutative property.

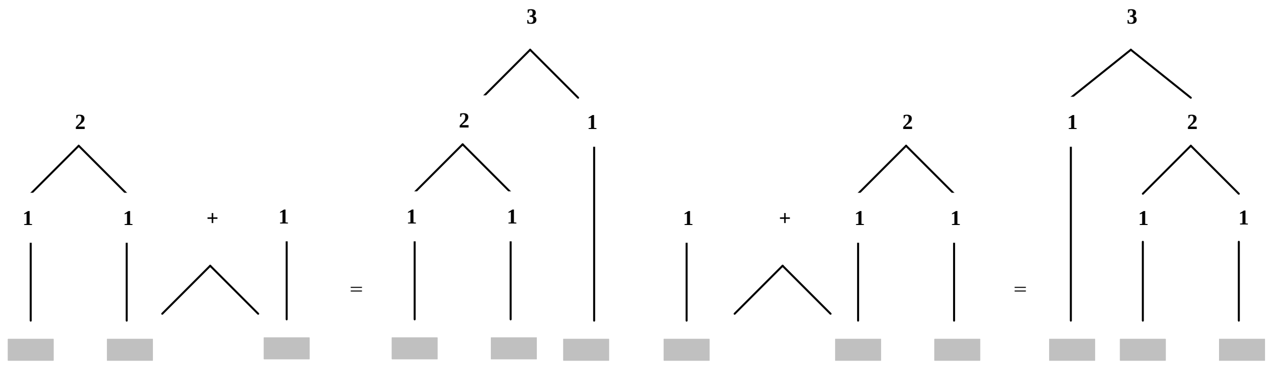

Figure 54. Commutative property

The different ways in which numbers can be correlated allow us to create correlative structures that can be used for multiplication and division. Figures 55a and 55b show the correlative structures of 3x2 and of 2x3.

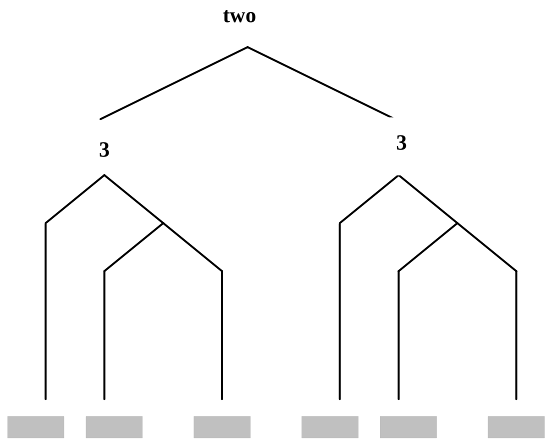

Figure 55a. Correlative structure of 3x2

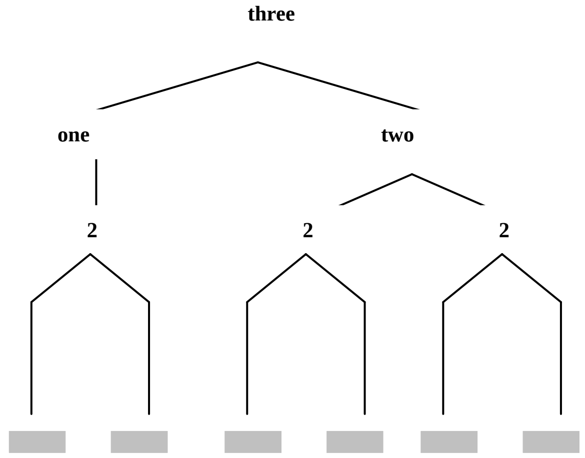

Figure 55b. Correlative structure of 2x3

Figure 56 shows the correlative structure of 2^3.

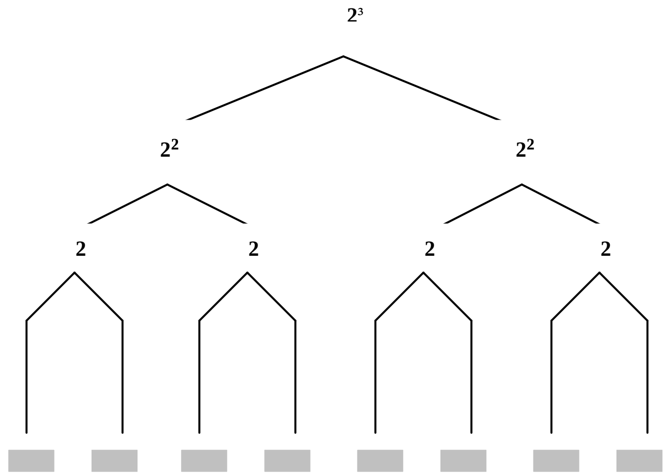

Figure 56. Correlative structure of 2^3

The analysis of the correlative structure of numbers allows us to highlight the importance of language for cognitive uses. Let us consider the correlative structures of number "four" (Figure 57).

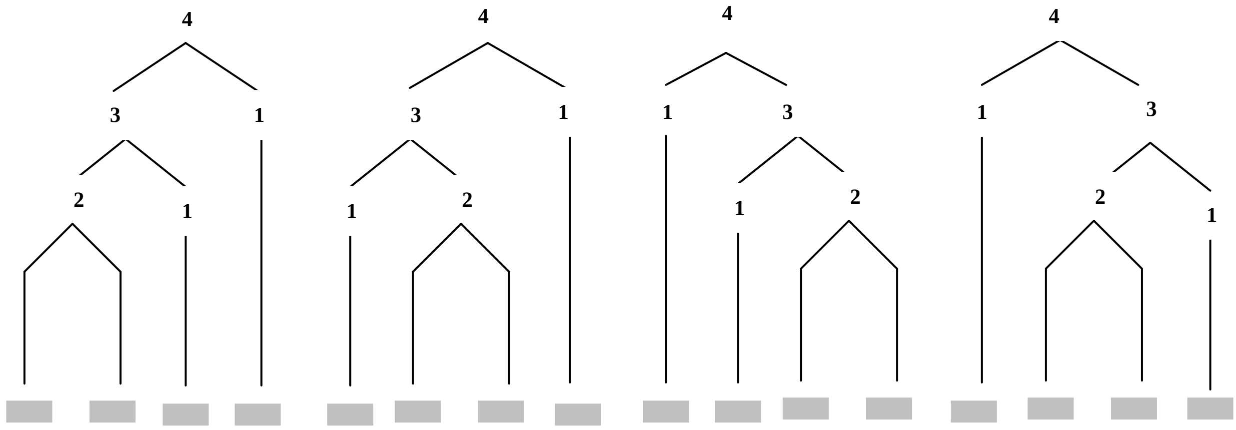

Figure 57. Correlative structures of number 4

It shows the circuit activity, which can also be indicated with brackets:

{[(■+ ■) + ■] + ■}, {[■+ (■+ ■) +] + ■}, {[■+ [■+ (■+ ■)]}, {■+[(■+ ■) + ■]}

It is an activity in which the prefrontal cortex keeps the constructions present as the circuit performs the associations.

If an association is replaced by a number written in Arabic numerals, the operations of the prefrontal cortex are easier since it is less difficult to keep a number present than an association. Mental activity is in fact easier with numbers rather than with virtual spaces and/or time. For example, instead of the [(■+ ■) + ■] circuit, we can activate the easier numeral circuit: (2+1); in the same way, instead of {[(■+ ■) + ■] + ■} it is possible to activate (3+1). Numbers written in Arabic numerals, moreover, can be memorized in the parietal cortex. The three symbols "2+1" have definite spatial relations that can be memorized. Moreover, in the temporal cortex, each number can be conceptualized and memorized (as words are).

5.2 Ordinal numbers

While cardinal numbers can have different structures, ordinal numbers only have a single one. This reflects the "orderly" progression (one after or behind the other) in space and/or in time, achieved through a spatial and/or temporal ternary relation: “second *after* first”, “third *after* second”, etc. (Figure 58).

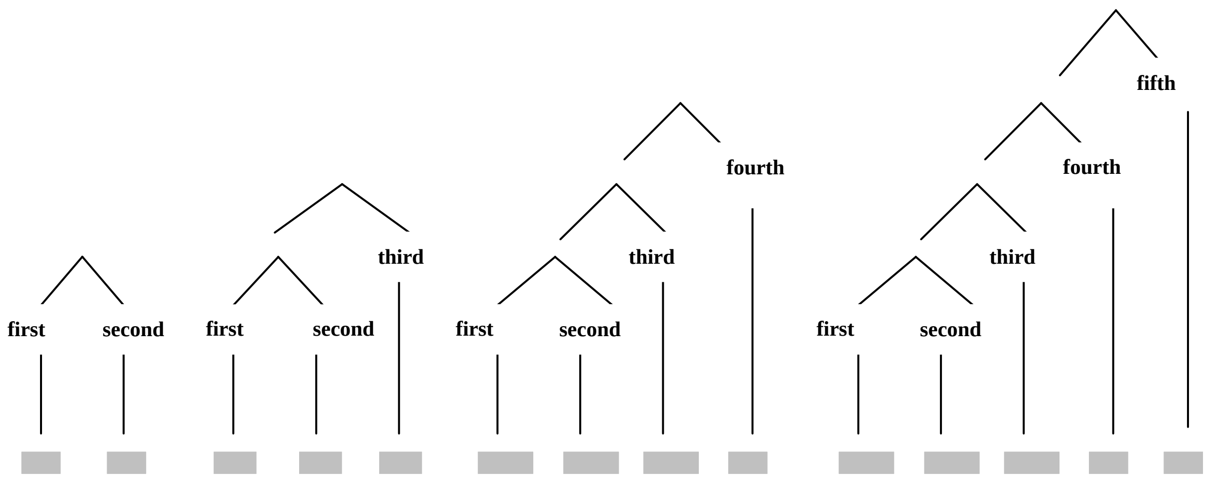

Figure 58. Correlative structures of ordinal numbers

5.3 Arabic numerals

Arabic numerals are simpler and make calculations easier than Roman numerals. This can be explained by the fact that units (from 0 to 9), tens (from 10 to 99), hundreds (from 100 to 999), thousands (from 1000 to 9999) are expressed by given correlative structures. With Roman numerals this was impossible. At the lowest level, we have the single units separated from the background, at the second level the tens, at the third level the hundreds, at the fourth level the thousands, etc. Among the potential structures that can be achieved, the numerical one follows a given configuration (Figure 59). Each number can be read at a single glance, separating it from the background. If the number is made up of several digits, it activates, in memory, the higher node with the whole underlying structure and then recognition occurs. If the number is rather big, such as “2345678”, our mind selects three units at a time from right to left: 2/345/678. The number 345 consists of “thousands” after the reference with the “678”. The latter in fact consists of three digits. Number “2” consists of millions after the reference with “345678” composed of six digits. After this process we can understand and read the number.

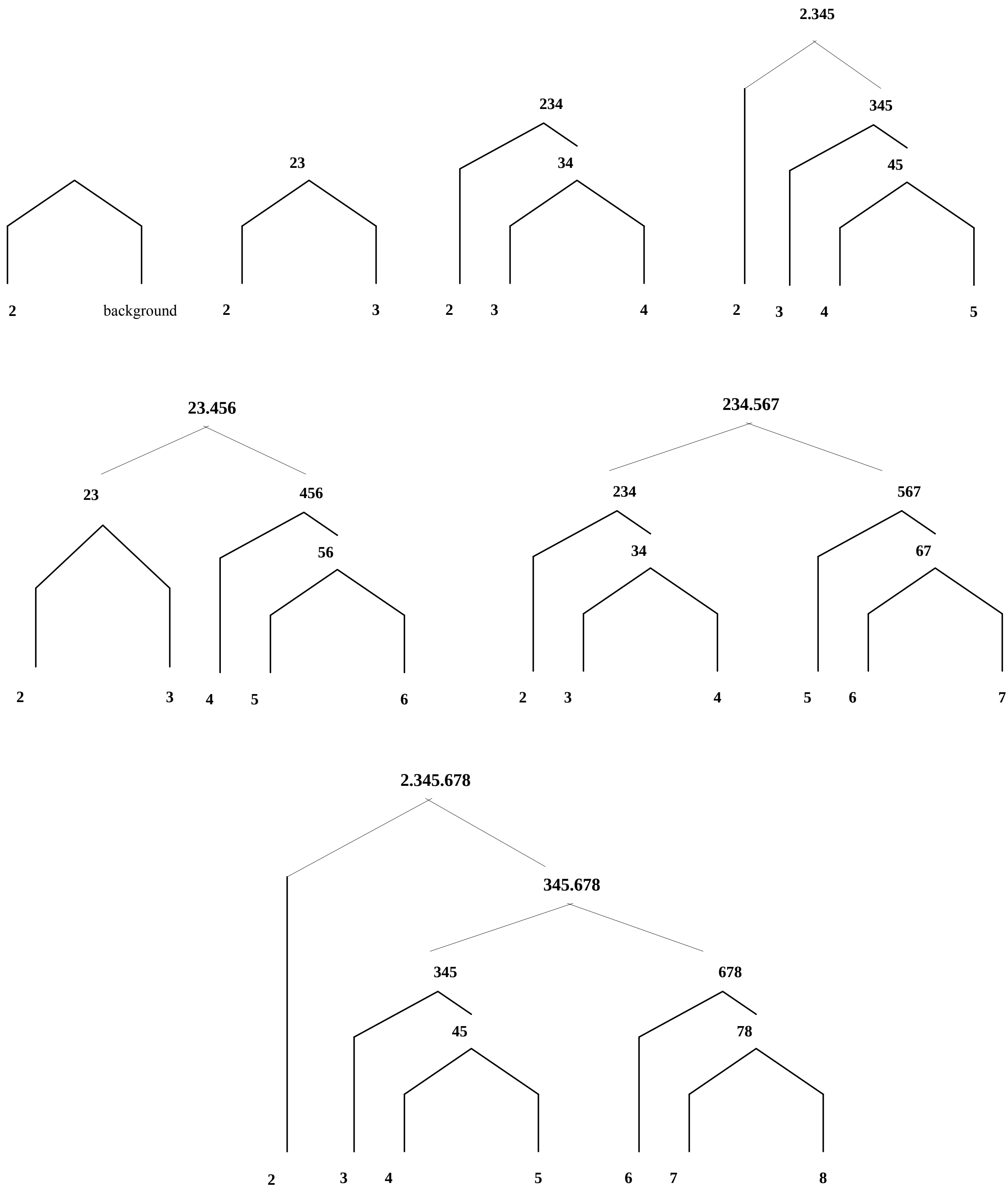

Figure 59. Correlative structures of Arabic numerals made by one or more figures

5.4 Polygons

Figure 60a shows one of the two correlative structures of the angles of the equilateral triangle; Figure 60b shows the right-angled isosceles triangle; Figure 60c shows the correlative structure of the square.

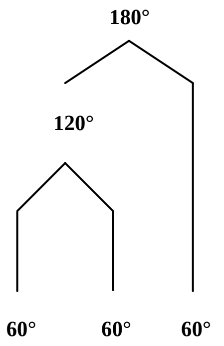

Figure 60a. Correlative structure of the equilateral triangle

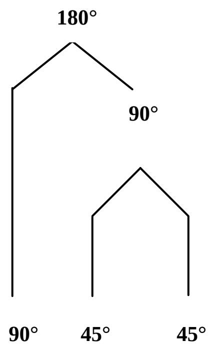

Figure 60b. Correlative structure of theright-angled isosceles triangle

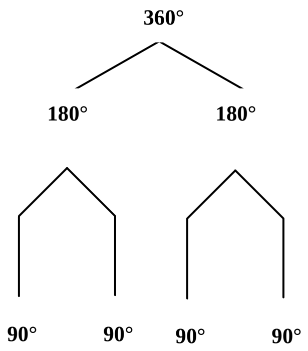

Figure 60c. Correlative structure of the square

The square (Figure 61a) can be considered equivalent (Figure 61c) to the correlation of two right-angled isosceles triangles (Figure 61b).

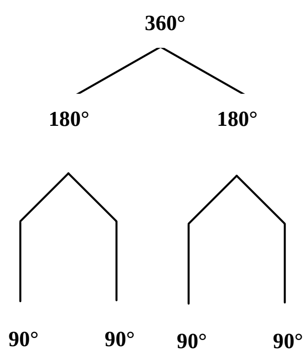

Figure 61a. Correlative structure of the square

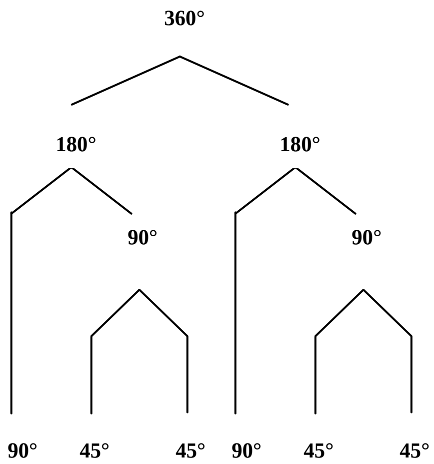

Figure 61b. Correlative structure of tworight-angled isosceles triangles

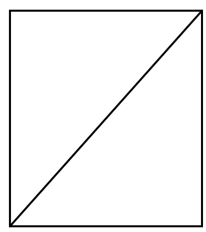

Figure 61c. Tworight-angled isosceles triangles and a square

5.5 The decimal and sexagesimal metric scale

In order to perform measurements, we use specific correlative structures divided into decimal and sexagesimal units. We use the decimal units mainly for surfaces, while the sexagesimal units are more frequently used to measure angles and time (hours, minutes, seconds, etc.). Figures 62a and 62b show the sexagesimal scale of an hour divided into sixty minutes (m). Figure 63 shows the decimal scale from one to twenty.

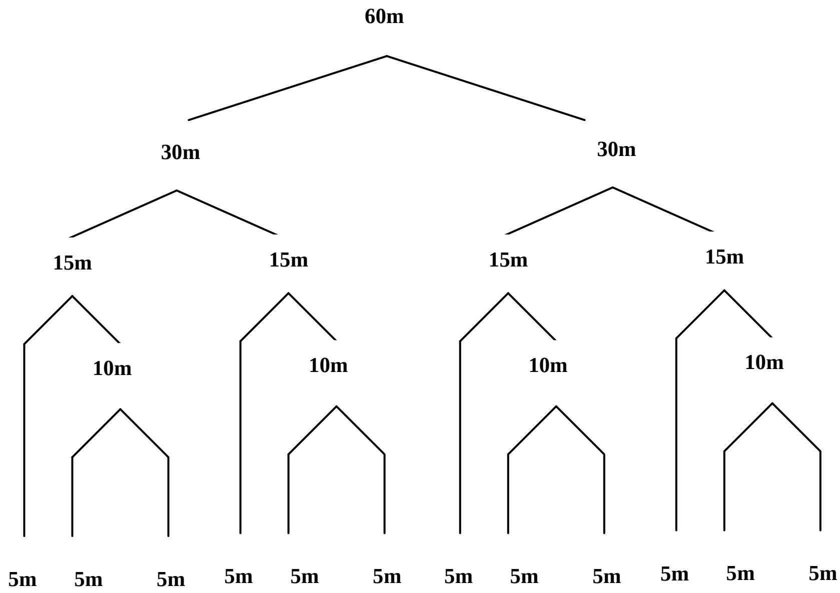

Figure 62a.Correlative structure of the sexagesimal scale of the hour until five minutes

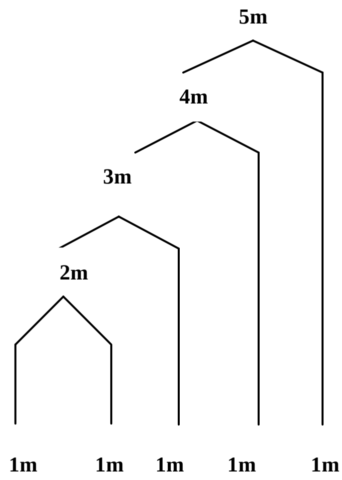

Figura 62b. Correlative structure of the sexagesimal scale of the hour concerning the five minutes

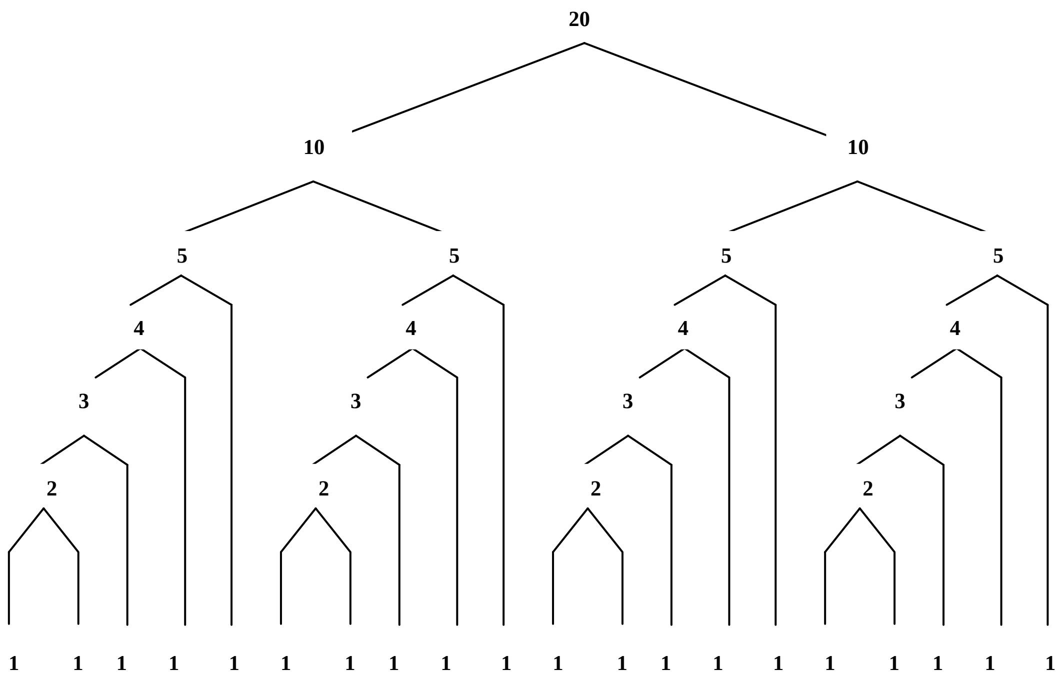

Figure 63. Correlative structure of the decimal scale from 1 to 20.

Also rhythm of music, dance steps, etc. has a correlative structure. Figures 64a, and 64b show the 3/4 and 4/4 rhythms (f = forte, p = piano, mf = mezzo forte).

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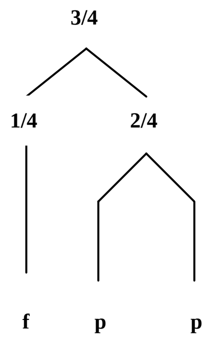

Figure 64a. Correlative structure of the 3/4 rhythm

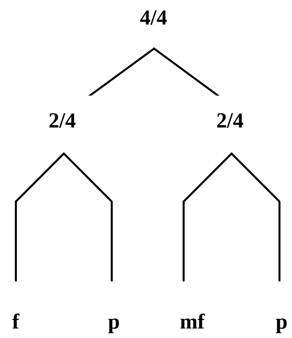

Figure 64b. Correlative structure of the 4/4 rhythm

6. Language

6.1 The two lexicons: phonological and orthographic

Two systems, ventral and dorsal, are involved in language. The ventral system (semantic-conceptual) is in charge of the recognition and retrieval of the cognitive syntheses. The dorsal system is in charge of the movements, the recognition, and the retrieval of spatial and temporal relations, associations, interrelations. The dorsal system is in turn divided into two parts: the first is in charge of the perceptive memory of the spatial/temporal structures of the "elements" that become part of the circuit. The second is functional: it organizes movements on the basis of the memorized structures. The location of the perceptive memory of the dorsal system is the parietal cortex. The location of the functional memory of the dorsal system is instead the premotor cortex.

The ventral system is also divided into two parts: the first is in charge of the perceptive memory of the "cognitive structures" which allow the recognition and assigning of a meaning; the second part is functional. It retrieves and modifies (by means of the dorsal system) the cognitive perceptive structures in order to elaborate meanings. The locations of the perceptive memory of the "ventral system" are the superior temporal cortex (for the phonological lexicon) and the inferior temporal cortex (for the orthographic lexicon); the location of the functional memory of the "ventral system" is the prefrontal cortex.

The lexicon of language can be "phonological" (oral language) and orthographic (written language). Figure 65 shows the two pathways (dorsal and ventral) of the phonological lexicon and their functions.

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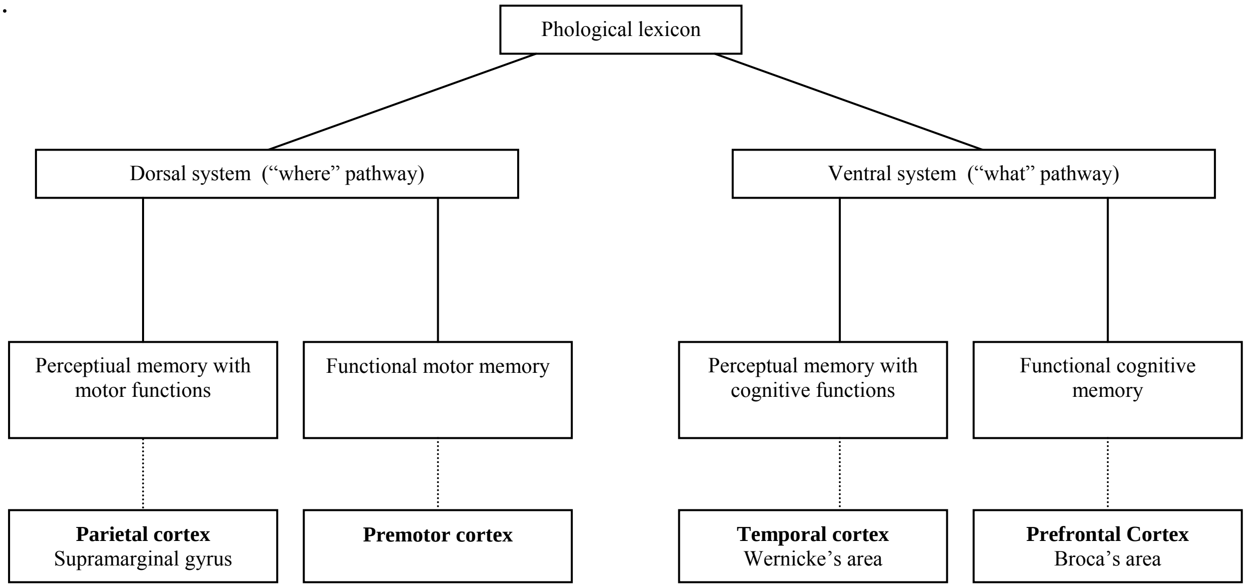

Figure 65. The phonologicallexicon: its two systems and four memory tipologies

As we have already said, the orthographic lexicon (reading, writing, etc.) is divided into two systems: dorsal and ventral. Each of these comprises two memory typologies: perceptual and functional (Figure 66).

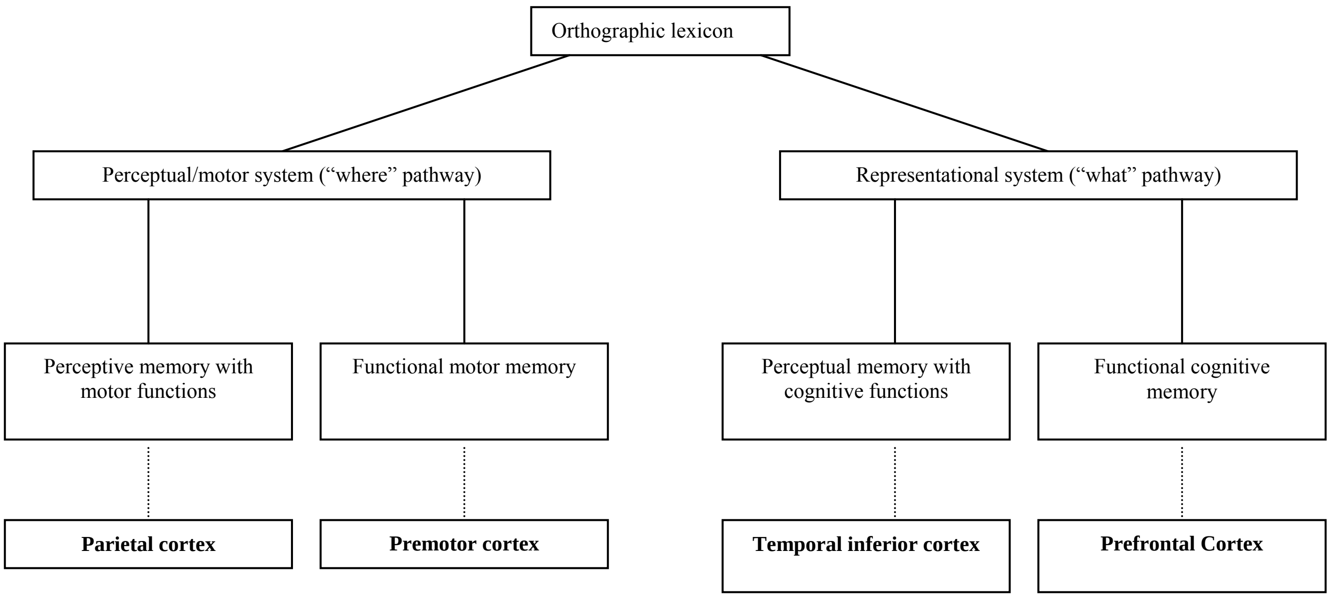

Figure 66. The orthographic lexicon: its two systems and four typologies of memory

6.2 Articulation of sounds and writing

The ability to articulate sounds lies at the basis of language. This ability can be developed by listening to sounds produced by fellow beings. After the perception/recognition of a sound, for example "a", the subject learns to interiorize this experience, recalling the listened sound. In order to do so, the ventral system of the cognitive circuit learns to hypothesize the sound (which it has already heard), and to verify it after the mental representation of the dorsal system. The dorsal system, moreover, hypothesizes and verifies the sound source represented by the person who has uttered the sound (Figure 67).

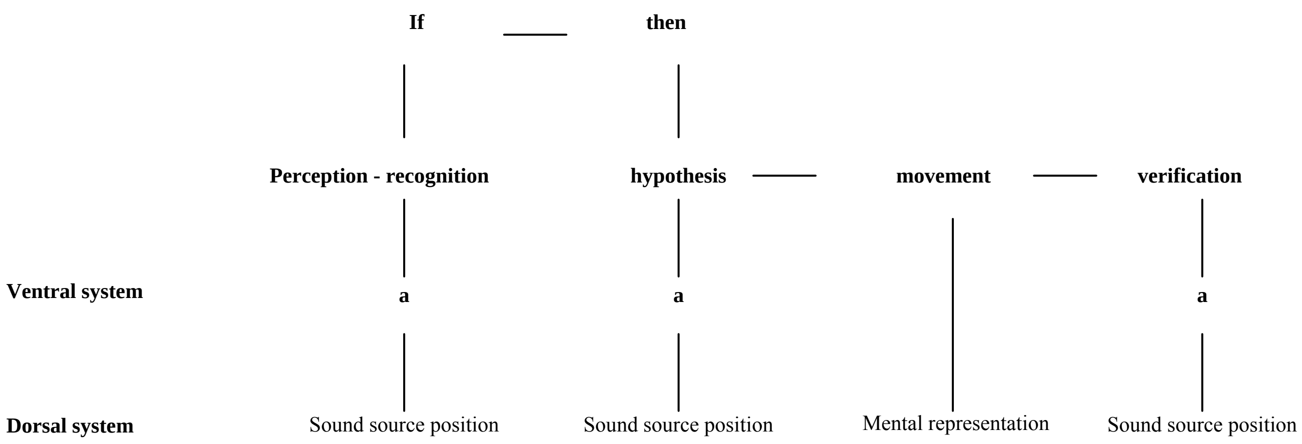

Figure 67. Sound interiorization through mental representation

The following step is to articulate the interiorized sound (which means being able to mentally represent and recognize it when we hear it). Phono-articulation can be represented with a grey rectangle. In this case the dorsal system, beyond performing the phono-articulation, hypothesizes the position of the sound source in the phono-articulatory organs (Figure 68).

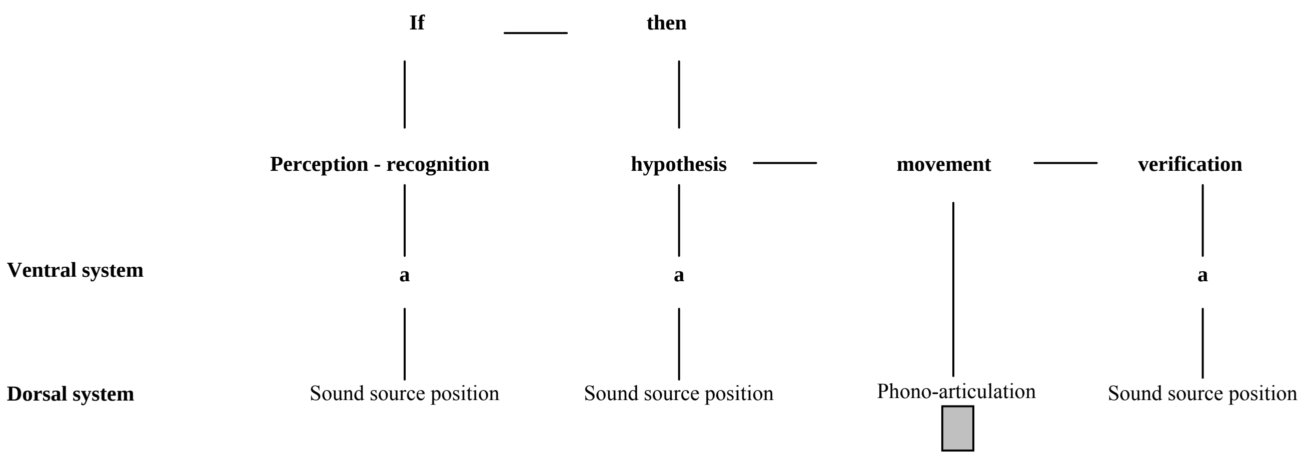

Figure 68. Phono-articulation after recognition

Using the two simple circuits of Figures 67 and 68, our mind learns, through the ventral system, to retrive (hypothesis) sounds and verify them (verification is just perception-recognition); through the dorsal system it learns to articulate sounds and mentally represent them.

An analogous visual circuit allows our mind to retrieve and verify a “grapheme”. If the subject is not able to write, the dorsal system intervenes only with mental representation. When the subject has learnt to write, there are two circuits, one for mental representation and one for writing. In Figure 69, the “underlining” differentiates the written vowel from the oral one.

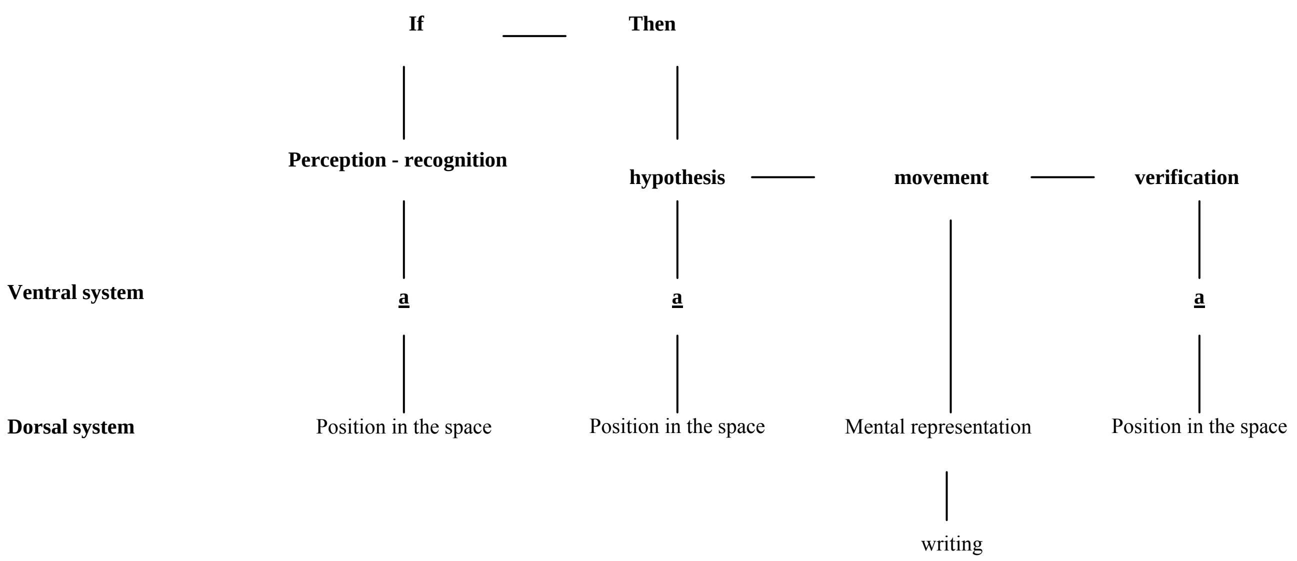

Figure 69. Interiorization, through mental representation and writing, of a grapheme

6.3 Shift from an orthographic lexicon to a phonological one

The process that allows us to shift automatically from the perception of “a” to the retrieval of “a” is performed step by step. Initially, the two circuits work automatically. If we look at “a” and then we listen to the sound “a”, the circuit of the written lexicon, after the perception of “a”, will automatically activate the hypothesis and the mental representation of “a”; whereas the following perception of the “a” sound will automatically activate the hypothesis and the phono-articulation with the mental representation of the same sound. Subsequently the shift from one perception to another is performed (Figure 70).

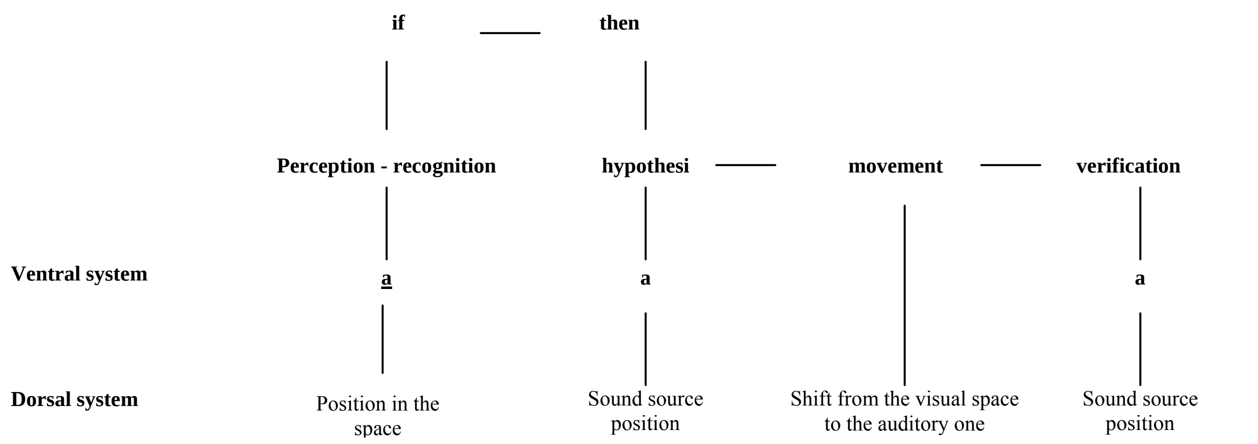

Figura 70. Shift from a visual perception to an auditory one

This circuit allows the ventral system to associate a visual perception to an auditory hypothesis. The association ("a" – "a") made by this circuit is memorized in the temporal cortex. After learning this, the dorsal shift from one space to another is no longer necessary. In the temporal cortex, the perception-recognition of the "a" directly activates the hypothesis "a" and the dorsal system can devote itself to mental representation or to phono-articulation. We have the two following circuits of Figure 71.

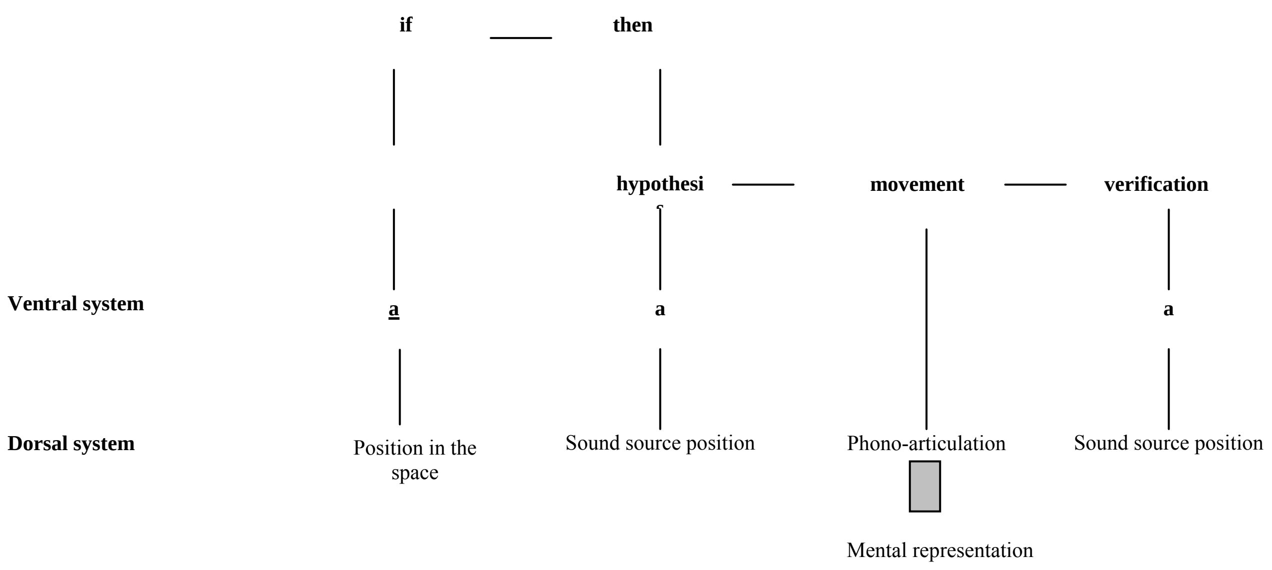

Figure 71.Mental auditory representation and phono-articulation after visual perception

6.4 Occipital alexia and transcodification

Let us consider a pathology of the ventral system, occipital alexia. The pathology is also known as "pure alexia" and is not accompanied by other aphasic disturbances. The disturbances of patients who suffer from "occipital alexia" can range from a total inability to identify single letters and words to a difficulty in loud voice reading and word understanding, nevertheless they are often able to name the letters that compose words. Usually, both the reading of digits and somatoaesthetic reading are preserved. In these cases, writing (both spontaneous and under dictation) is generally preserved. For these patients transcoding operations are rather difficult (shift from the printed to the italics type or from small to capital letters) (Denes, Cipollotti, Zorzi, 1996).

The transcodification process requires the associative memory between graphemes. This associative memory is created when, at school, we learn to switch from a grapheme to another, perceiving the first grapheme and mentally representing the second one, or writing the latter (Ffigure 72). The two graphemes "a" (underlined) and "A" (underlined) are associated in the occipito/temporal area that is responsible for recognition-retrieval (or hypothesis). The perception of the one (or the other) automatically activates associative memory, which allows the immediate writing or mental representation of the second. It is therefore plausible that one of problems associated with occipital alexia is caused by damage to the transcodification circuit.

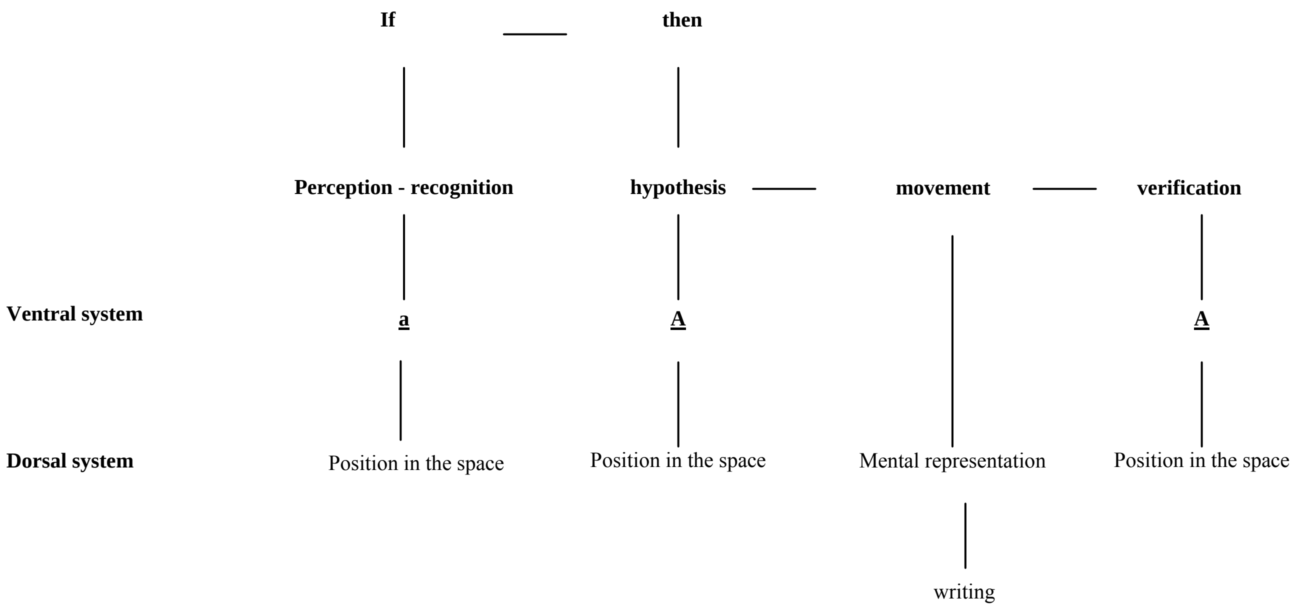

Figure 72. Transcodification from small letter to capital letter

6.5 Perceptual and cognitive synthesis

The issue concerning the reading of syllables is more complex. In order to make this reading possible, our mind needs to activate two perceptive syntheses, a visual one and an auditory one, but also the combination of two articulations through co-articulation. When our visual system perceives the syllable "ca", the visual circuit recognizes it at a single glance. This happens because previously the visual circuit alternately perceived, recognized, and anticipated the "ca", "c" and "a". At each shift, the temporal cortex creates associations, relations and interrelations of "concepts", while the parietal cortex creates analogous structures related to spaces.

Let's try to make the circuit simpler by using only the terms of hypothesis, movement, verification, and by recalling the fact that hypothesis corresponds to anticipation and recovery, while verification corresponds to "if" and "perception/recognition". Let's suppose we are visually perceiving the syllable "pa" then moving to the letter "p", and then from "pa" to "a". Figure 73 shows the activity of the perceptive-motor visual circuit.

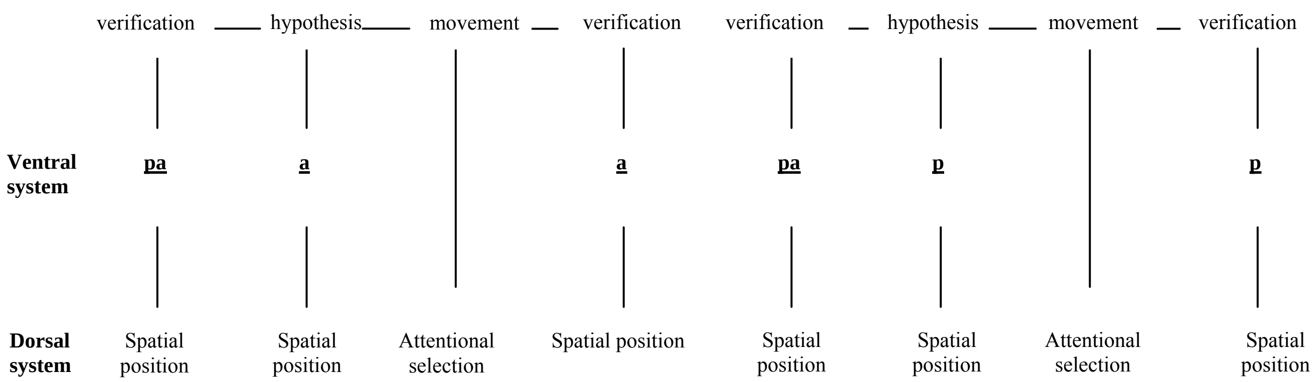

Figure 73. Shift from "pa" to "a" and from "pa" to "p".

The repetition of these shifts creates a "syllable"-"letters" relation in the temporal cortex and a spatial "relation" between the position of the "p" and the "a" versus the "pa". In other words, the mind learns, after perceiving "pa" (interrelation), to move automatically to space "p" and to space "a", as well as from the syllable to each of the two letters. The automatic activation of the two letters after the perception and recognition of the syllable "pa", is what we call "perceptive synthesis". Perceptive synthesis allows us to consciously perceive and recognize the syllable and to unconsciously perceive and recognize the two letters.

What we have said about the written lexicon, also applies to oral lexicon. As soon as the sound "pa" is perceived (interrelation), the unconscious recognition of the sound "p" and of the sound "a" are automatically activated. This process can also be performed through mental representation; in this case, we should talk about "mnestic synthesis", because perceptual activity is absent.

More in general, the term "cognitive synthesis" is used to mean a process which, by means of a single perceptual glance or mental representation, makes a complex object conscious through the unconscious activation of its components.

6.6 Coarticulation

When we talk, the single phones produced by the phono-articulatory system connect to each other through coarticulation. Coarticulation is a mechanism based on the "anticipation" of the "phono" that follows the one already produced. The process of "anticipation" is a circuital process. This means that the ventral system, starting from the produced phono, anticipates the following one and on this basis the dorsal system performs the coarticulation.

Some examples can clarify how the dorsal system performs the coarticulations. Such as the syllable "por". Let us suppose that a child is learning to talk and can produce the sounds "p", "o", and "r" separately (in order to make the example simpler we will avoid dealing with the complex structure of each single phono). The production of a single sound requires the activation of the cognitive circuit that anticipates the phono and verifies it after it has been produced. Figure 74 shows the circuital process during the pronunciation in succession of the "o" and "r" sounds: the rectangle indicates the sound articulation by the phonoarticulatory system.

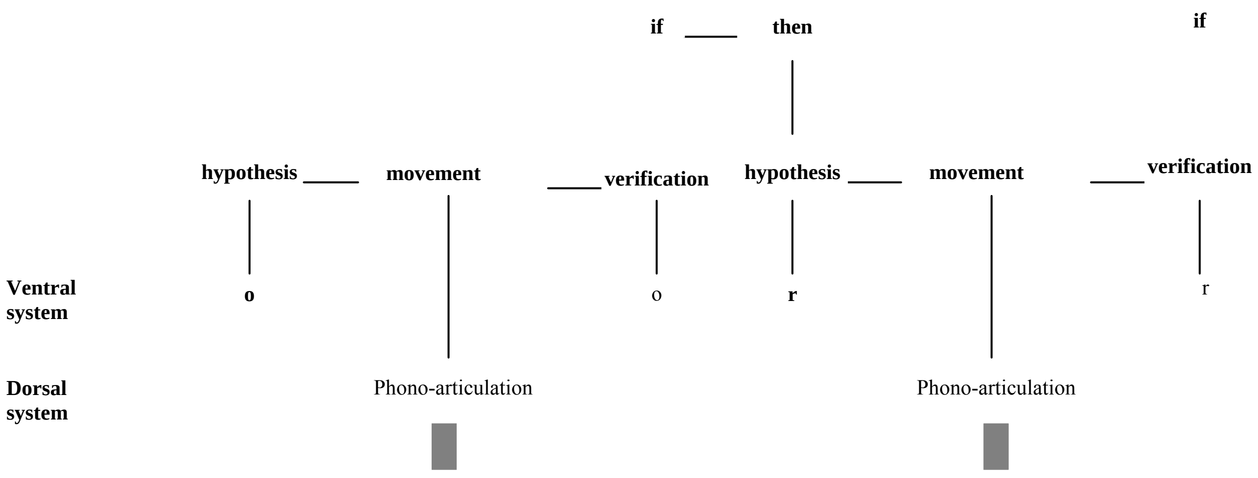

Figure. 74. Production in succession of the "o" and "r" sounds

The ventral system, which involves the prefrontal cortex (Broca's area) and the superior temporal cortex (Wernicke's area), performs the cognitive hypothesis of anticipation and verification of the single phones "p" and "o". The dorsal system, which involves the premotor cortex and the parietal cortex, organises and performs the whole articulation of the "phono". Instant by instant the system hypothesizes and verifies the reciprocal position of the phonatory organs during sound emission (Figure 75).

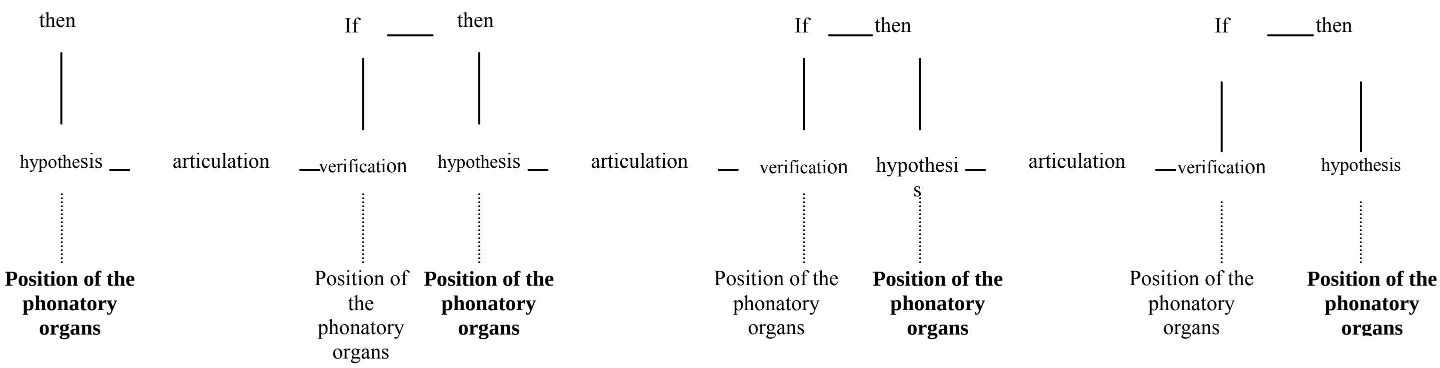

Figure. 75. Correlative logic-cognitive circuit

With practice, the two sounds join and create a "cognitive synthesis" at ventral system level and a "coarticulation" at dorsal level. Figure 76 shows the sound production process; the hyphen represents the "coarticulation".

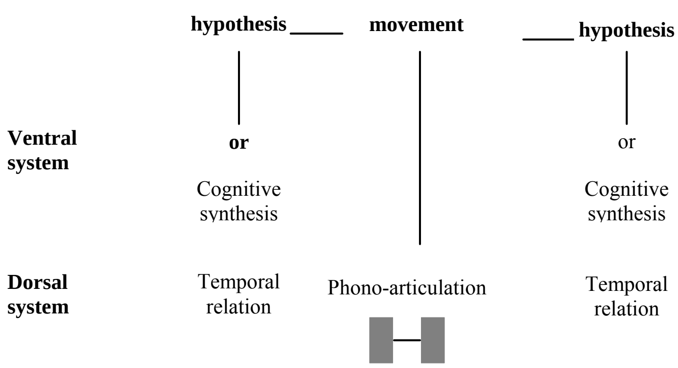

Figure. 76. Production of the "or" sound

The "temporal relation", memorized as perceptive memory in the parietal cortex and as motor memory in the premotor cortex, involves the two phones "o" and "r". The cognitive synthesis and the articulatory movement of "por" are memorized in the same way.

The syllabic structure, consisting of three elements "onset", "nucleus" and "tail", where the "nucleus" and the "tail" are linked and form the "rhyme", shows the way in which the dorsal system performs the coarticulation. The first connection occurs between "nucleus" and "tail", then they will be connected with the "onset".

In order to build up a word articulation, the dorsal circuit first creates the coarticulations within the syllable and then the coarticulations between the syllables. If a word is polysyllabic, the coarticulations are performed inversely to the pronunciation. The coarticulation of a 3-syllable word, for example the Italian word "partenza" ("departure"), occurs by linking the second syllable with the third, and therefore the first with the other two (Figure 77).

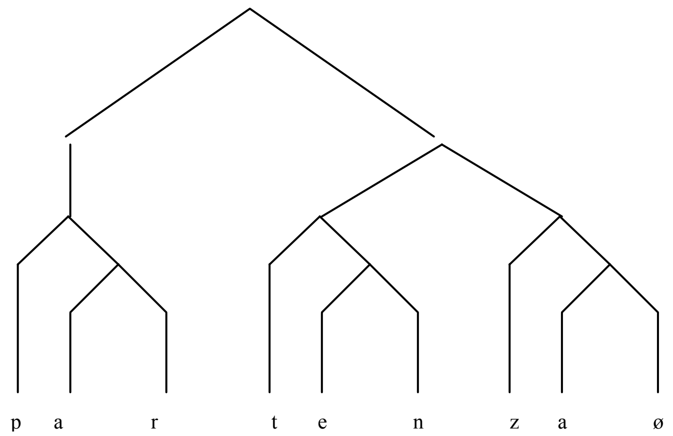

Figure 77. Coarticulation structure of the word "partenza"

After the cognitive syntheses and the coarticulations, the two systems, dorsal and ventral can retrieve - anticipating -, produce and verify by means of specific circuits, the following sounds of the word "language": p, a, r, t, e, n, z, a, ar, par, en, ten, za, tenza, partenza. During speech, this cognitive-motor circuit recovers in the perceptive temporal memory, by means of the prefrontal cortex, the "cognitive synthesis" of "syllables", "words" and "sentences" that are articulated by the dorsal system.

Extensive lesions to the Wernicke area are devastating for language because they damage the "structure of relations, interrelations and associations" (cognitive synthesis) of phones, syllables, words and sentences. Without these structures no speech is possible (spontaneous speech, reading, repetition, etc.). Moreover, since the cognitive synthesis is functional to recognition, these patients do not understand what is said to them. Lesions to the Broca area generate problems above all during speech production rather than during speech comprehension.

6.7 Reading

Once we have learnt to achieve cognitive syntheses for the orthographic lexicon and the phonological one, as well as coarticulations of sounds produced by the phonoarticulatory apparatus, it becomes possible to read not only letter by letter, but also syllable by syllable and word by word. Syllable by syllable reading is called "sublexical reading", which is different from word by word reading which is called "lexical reading".

Reading circuits are characterized by the association of the two lexicons, written and oral, which occur at the retrieval level (hypothesis). This association can be achieved with letters, syllables, words and sentences. Figure 78 shows the association for the word "dog" in the written and oral lexicon.

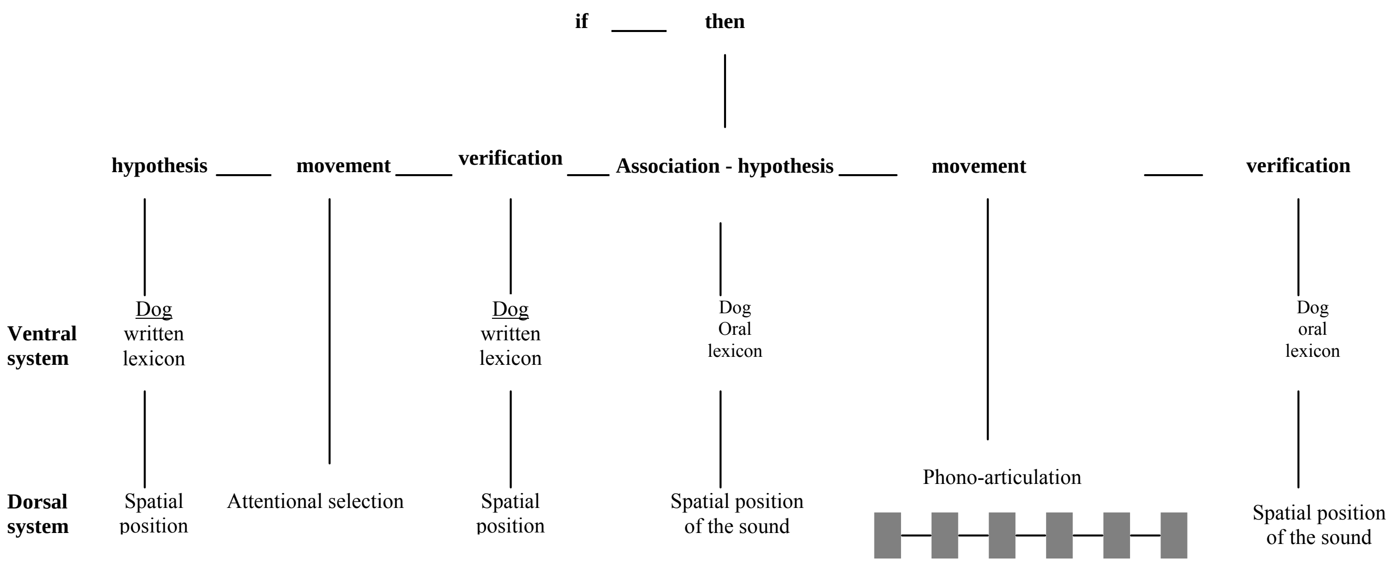

Figure. 78. Reading of the word "dog"

We have recognized three different kinds of readings: letter by letter reading, sublexical reading, and lexical reading. The use of the one or of the other depends primarily on the ventral system which hypothesizes "what" will be perceived and recognized from the visual system. On the basis of this hypothesis, the visual perceptual dorsal system intervenes. This system acts in the spatial/temporal context in which the book, the page of the book, line, word, syllables and letters that we are reading, are placed. Moving the perceptual attention, the dorsal system can select a single letter, a syllable or a word. When we observe the Italian word "rana" (frog), the ocular movements, which make the attention focus on the whole word or on the two syllables, or on each of the four letters, depend on the correlative premotor/parietal structure of Figure 79.

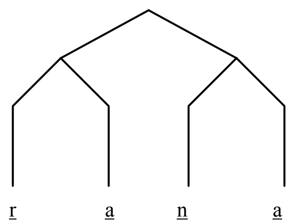

Figure 79. Correlative structure of the dorsal system when reading the word "rana"

This figure represents the potential selective shifts that the dorsal circuit can perform during the reading of the word "rana", its syllables and letters. The dorsal system can separate the following figures of the visual primary cortex: "r", "a", "n", "a", "ra", "na", "rana" from the background. The figure "an", is not selected since it is not a syllable of this word.

The recognition and hypothesis of "what" are performed by the ventral system. The visual recognition of a letter, syllable or word occurs in the same way, by means of the ventral circuit that hypothesizes and verifies. However, recognizing a word is easier because of the semantic/conceptual memory that the word is associated with. The shift from written to oral lexicon occurs in a different way. It can occur through a cognitive synthesis or though spatial/temporal relations. When reading the English word "come" (pronounced "\kʌm\"), for example, the ventral system perceives and recognizes "come" by automatically activating the "\kʌm\" sound, memorized in the temporal cortex, which is the cognitive hypothesis on which the dorsal system works to produce the "\kʌm\" phonoarticulation (Figure 80).

When we read the Italian word "re" (king), which is pronounced in the same way as it is spelled, ("\re\"), there is, of course, a stricter correspondence between letters and sound. This gives importance to the spatial order of the graphemes in the written lexicon as well as to the temporal order of the phonemes in the oral lexicon. The spatial and temporal orders are encoded in the parietal cortex. Since pronunciation depends on the phonological structure of the syllable, the correspondence between the spatial order of graphems and the temporal order of phonemes occurs on a syllabic basis. The cognitive circuit in charge of the reading acts on the syllables passing from written to oral. Reading is therefore syllabic or sublexical. The perception, hypothesis and verification of the position of the sound in space by the dorsal system are not represented in Figure 81. This occurs anyway, even if automatically.

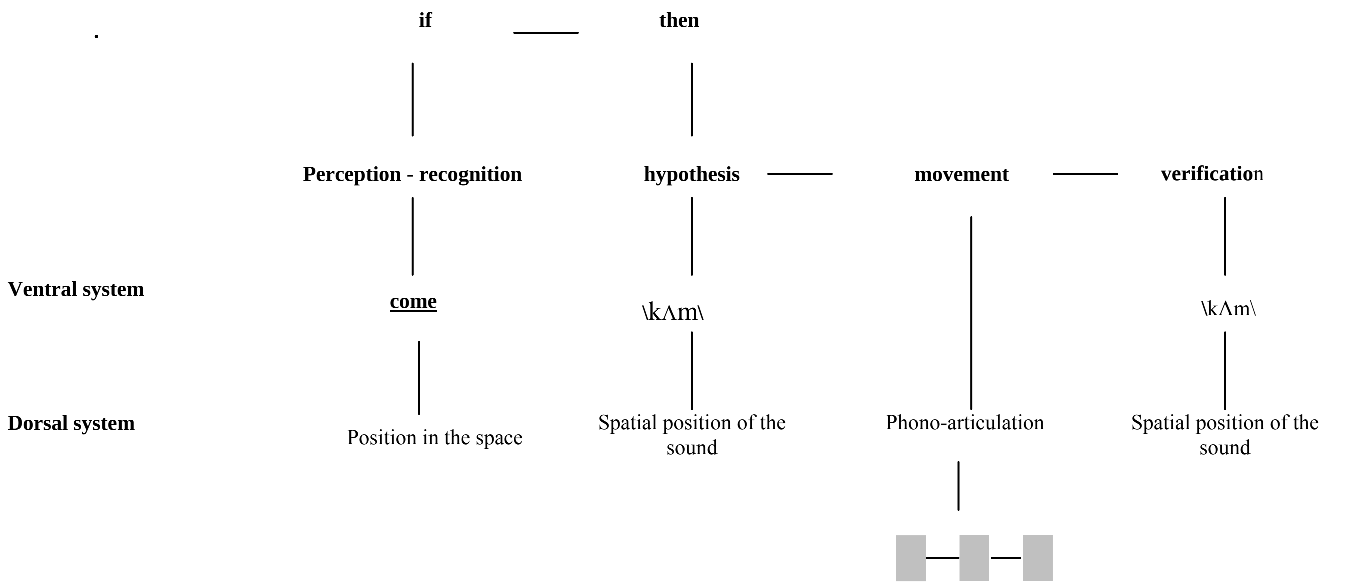

Figure 80. Reading of the English word "come"

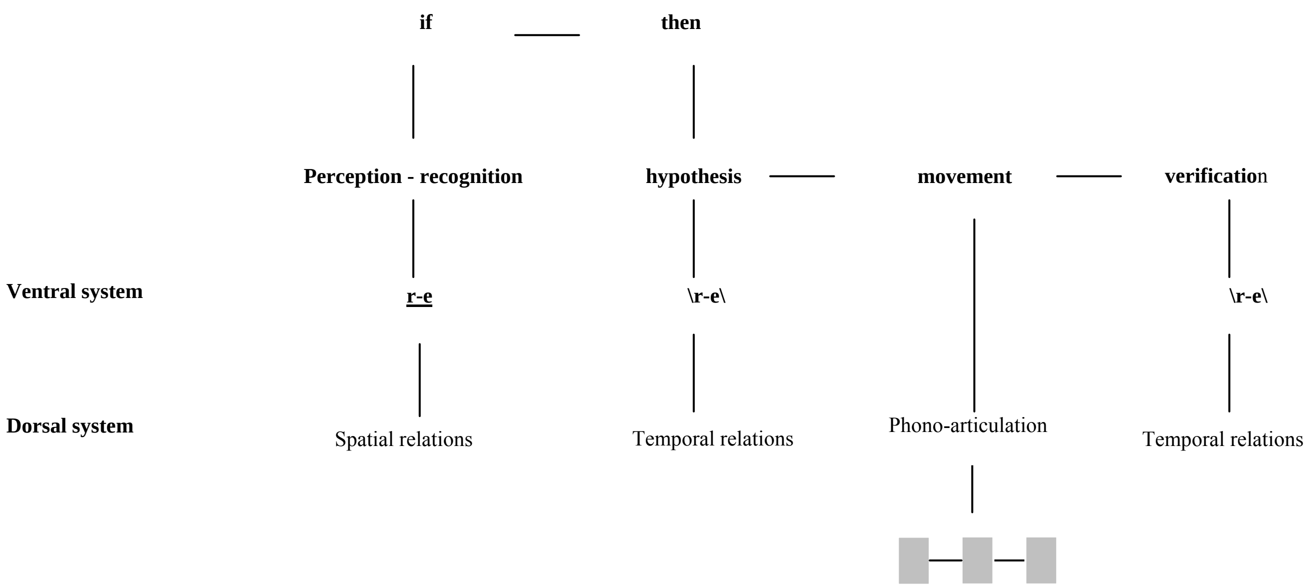

Figure 81. Reading of the Italian word "re"

The associations that link the perception-recognition of a written word and the hypothesis of the sound are important in the reading process. These associations, codified by the experience, allow the automatic activation of the oral hypothesis, after the recognition of the written part. The associations can concern the ventral and the dorsal system.

In lexical reading, ventral association is fundamental. The ventral system hypothesizes the whole word, and phonoarticulation by the dorsal system depends on the ventral system. In sublexical reading, the ventral system performs its cognitive hypotheses, to which the associative relationships established between the recognition of spatial relations and the hypotheses on temporal relations are added.

In other words, in lexical reading the dorsal system anticipates the phonoarticulation of the word that we are about to pronounce on the basis of the ventral hypothesis; in sublexical reading the dorsal system anticipates the phonoarticulation by also taking in consideration the hypothesized temporal relations.

In lexical reading we must associate a proper word of the oral lexicon to each word of the written lexicon. Sublexical reading is made possible thanks to a memorized rule that allows us to pass from a series of letters, ordered in space, to a series of sounds, ordered in time. Lexical reading overloads the ventral memory, and sublexical reading overloads the dorsal memory.

6.8 Spelling

Another mental activity that requires the intervention of the dorsal memory is spelling. Spelling, which is used a great deal by English students, is the action of saying aloud or writing the letters of a word in their correct order. Spelling is important for people who speak and read English since this language contains a lot of words which can be considered "irregular" because they are not pronounced in the same way as they are written. Dictation is impossible if we don't know how words are spelt. Our mind uses two different procedures for spelling, depending on the kind of word we need to spell, that is, whether it is regular or irregular. If we spell a regular word, this is done by using the mental representation of the phonological lexicon (spelling based on sound). If the word is irregular (in the sense that it is not pronounced in the same way as it is spelled), the orthographic lexicon is used (spelling based on vocabulary). If we listen to the irregular word "said" (pronounced \sed\), our mind retrieves the orthographic representation (said), and therefore we mentally go on "reading" letter by letter. If we listen to the Italian word "re" (king), pronounced as it is spelled, the phonological lexicon is used (the phonological mental representation of a word). Vocabulary-based spelling requires us to move from the written word (considering it as a whole) to each single letter. These circuital oprations are possible only if we have the spatial position of the word's letters in our memory. Sound-based spelling requires us to move from the entire listened word to the position in time of each phone. These circuital operations are possible only if we have the position in time of the word's phones in our memory. Roeltgen and Heilman (1984) reported of four patients who could spell word using sound-spelling correspondences, and therefore, had problems in using the orthographic mental representation. They had lesions in a small area that connected the posterior angular gyrus to the parieto-occipital lobe. When we consider patients who spell using an orthographic mental representation only, the regions involved seem to be the parietal regions close to the supramargynal gyrus (Roeltgen and Heilman, 1984).

6.9 Alexia with agraphia

Let's go back to the function of the dorsal system which interacts with the orthographic lexicon. As we have said, this system allows us to move our attention from a letter to another, from a syllable to another, or from a word to another, in order to perform decontextualization. These movements are possible because the spatial relations of the components of sentences, words, syllables and letters are memorized in the parietal cortex. For example the orthographic lexicon of the Italian word "mela" (apple) is memorized in the structure illustrated in Figure 82.

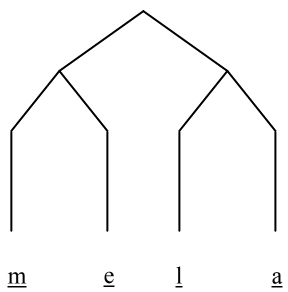

Figure 82. Correlative structure of the Italian word "mela"

This structure is used by the dorsal system to move the eyes along the letters and the syllables of a word. When we write, we need a similar structure. In order to write a word, we have to know the reciprocal position of the letters and syllables. In my opinion, the two structures, for writing and for reading, even if identical are not created by the same population of neurons, but by two different populations in two neighbouring areas of the cortex. However the area where, for motor purposes (ocular movement and writing movement), the orthographic lexicon structures are memorized, is the left angular gyrus. Damages in this area cause alexia (difficulty in reading) with agraphia (difficulty in writing) (Déjerine, 1891).

6.10 Recognition and frontal alexia

Researchers agree that perceptual memory is located in the posterior areas and that damages to these areas cause recognition problems. In particular, damages to the posterior areas of the dorsal system (parietal cortex) can be the cause of apperceptive agnosia while damages to the posterior areas of the ventral system (temporal cortex) can cause associative agnosia (Lissauer, 1890). In general, apperceptive agnosia implies a deficit in the spatio/temporal relations between an object and other objects present in the scene (that is, an object within a specific spatio-temporal context). Associative agnosia implies a deficit in semantic/conceptual relations. Apperceptive agnosia is the agnosia of figures as they appear to us or as we mentally represent them. Associative agnosia is the agnosia of figures that have been separated (after being separated from the background) from the spatio/temporal context. If, for example, we want to compare the size of an animal to that of another animal, we should mentally represent the two images in a spatio/temporal context that allows us to make the "comparison". In order to perform this comparison we must know "what" the first and the second animal are. Before making the comparison, first the ventral system that "knows" the two animals must be activated; then the dorsal system can compare the two animals that we are mentally representing. If we have to recognize an image perceived through unusual points of view, recognition is possible only if we rotate, thanks to the dorsal system, the image in the spatio/temporal context in which it is placed.

The activation of the ventral and dorsal systems in output processes involves the action of the anterior areas of these systems. In fact, in order to rotate an image we need the premotor cortex. This means that we can also have problems with recognition after damage to the anterior area. Even when patients with anterior damage have recognition problems, researchers usually look for damage in the posterior areas that could possibly be responsible for these problems. Here, frontal alexia or "third alexia" could be considered. This is manifested through reading difficulties associated with difficulties in the comprehension of written language. It is present in a great number of "Broca" aphasics, that is, in patients with anterior lesions. Lichtheim (1885) hypothesized that alexia in Broca aphasics could be the consequence of a second lesion in the "angular gyrus" (parietal cortex). However, more recent studies show that third alexia can be noted in patients who "only" have anterior damage (Boccardi, Buzzone and Vignolo, 1984). The difficulty of naming letters, found in patients with "third alexia", can be due to the fact that associative, relation and interrelation structures of decontextualized figures (not single figures) are memorized in the posterior areas of the ventral system. A single figure like a letter can be recognized only for the structures in which it is placed. In this case, recognition is difficult. If we read the Italian word "mare" (see) at a single glance, the separation figure-background (decontextualization) of this figure activates associative structures (between letters and between syllables), relation structures (object/component), and interrelation structures in the temporal cortex. If, instead, we only read the letter "r", the separation figure/background activates structures in which the letter is a component (Figure 83).

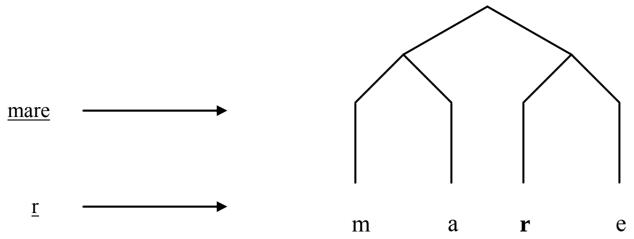

Figure83. Perception of a word and of a letter with the activation of the posterior structures

In order to recognize a single letter, the posterior ventral structures are not sufficient, we also need some cognitive circuits that can act in different ways. By means of these circuits, we can obtain a mental representation of a letter; we can retrieve a letter by getting it from a word etc. Anterior damage can hinder the activation of the circuits devoted to recognition, which consequently will not occur.

As regards the involvement of the anterior areas in recognition processes, a study by Wheeler, Stuss and Tulving (1995) who reviewed a number of cases reported in literature is worth mentioning. They found that in most recognition studies frontal patients performed worse than subjects in control trials.

6.11 Repetition

Repeating words, non-words and sentences that have been heard is a rather complex process. This process begins with the activation of the ventral system which chooses (anticipates) what the dorsal system needs to attentionally scan during the listening. When we listen to the Italia word "gita" (trip), the incoming sounds can be scanned by the dorsal system in two ways: "-gita-" and "-gi-ta-". In the first case the ventral system anticipates and recognizes the phonological lexicon "gita"; in the second case the ventral system anticipates and recognizes the syllables "gi", "ta". Once the lexical recognition is realized, each word activates plurisensorial associations by means of the semantic/conceptual system. The word journey, for example, can be associated automatically to a hotel where we spent our last holidays. Figure 84 shows the cognitive process of the circuit that is responsible for the repetition.

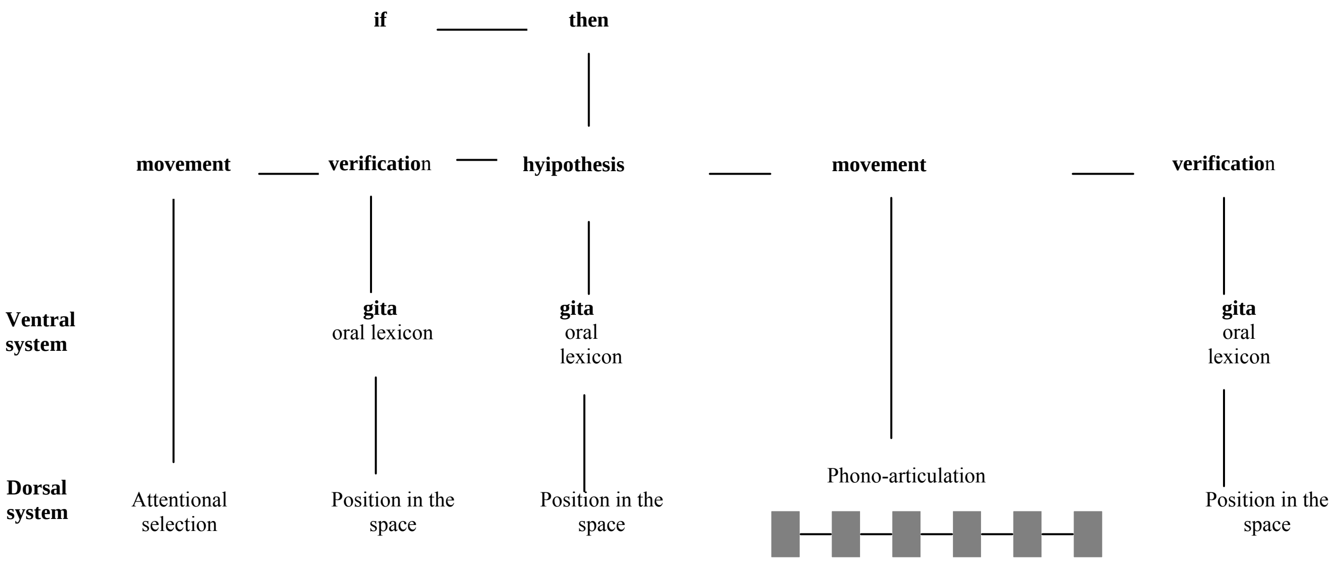

Figure. 84. Repetition of the Italian word "gita"

This figure helps explain the behaviour of some patients who show selective difficulty repeating non-words (Caramazza, Miceli and Villa, 1986). When we repeat a "non-word", in fact, attentional selection divides the "non-word" into syllables. During the listening, each selected syllable is kept present by the ventral working memory (what) and by the parietal one (temporal relation between a syllable and another). The phonoarticulatory movement is performed on two hypotheses, a ventral one for the syllables which form the word, and a dorsal one for the temporal relation of the same syllables. Figure 85 shows the circuit that allows the repetition of the Italian non-word "catevo".

Often, even when we repeat "words", instead of using the lexical pathway, we use the sublexical one, which is effective for "non-words". Compared to the repetition of "non-words", the advantage of the sublexical pathway for "words" is that the parietal cortex memorizes the temporal relations of the syllables that form a "word". This makes the action of the work memory easier.

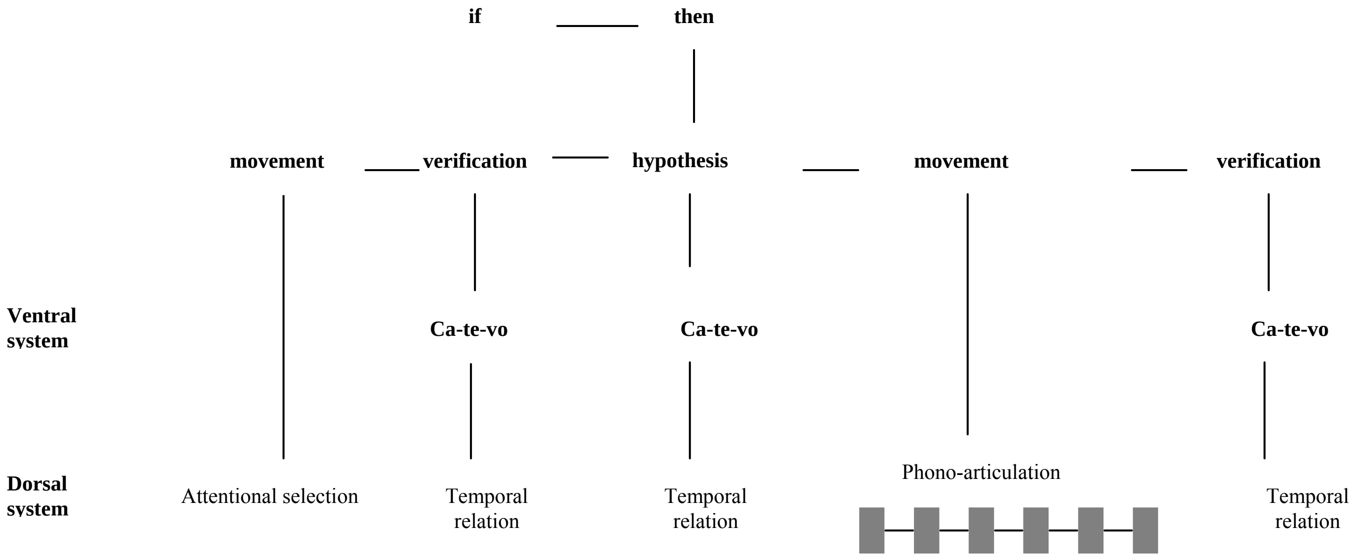

Figure 85. Circuit involved in the repetition of the Italian non-word "catevo"

As regards the repetition of sentences, McCarthy and Warrington (1984) have shown, by examining two patients, that it can be performed either though a semantic pathway or through a non-semantic one. Some conduction aphasics repeat sentences with a high semantic content better than sentences with an opaque semantic content, like clichés (such as: "he is deaf as a post"). On the contrary, a transcortical motor aphasic was advantaged in clichés rather than in other kinds of sentences. The difference between a cliché and a sentence is the fact that in the former its words and the temoral relations between the words are fixed; on the contrary, sentences are more flexible. We cannot replace the cliché: "he is deaf as a post" with the sentence "a post is as deaf as him". We can instead replace a sentence: "he is as deaf as Louis" with: "Louis is as deaf as him". A cliché is like a word, where letters and their temporal relations are not modifiable.

Similarly to what happens in sublexical repetition, in the repetition of a cliché there is an attentional selection of its words, which are kept present by the working memory, with their temporal relations. The phonoarticulatory system operates on the basis of these two hypotheses (ventral and dorsal).

The situation changes when we deal with sentences. The words which compose a sentence install "attributive" relations or linkages that generate meaningful constructions. The sentence "Andrea is deaf" assigns the feature of being deaf to Andrea. In addition to these attributive relations or linkages of a ventral nature there are also temporal relations between words that are not directly applied to the words themselves, but to their categorizations (noun, verb, adjective, etc.). In order to obtain the referred/reference relation, which determines the attributive relation and the spatio/temporal relation, the reference must be kept present while passing to the referred element.

7. Analyses of meanings

7.1 Prepositions

We have already mentioned "prepositions" when dealing with spatial and temporal relation. We have said that the preposition "over" originates from a spatial relation of "virtual spaces". In my opinion every "preposition" designates a relation between "virtual spaces" or "virtual times". An example is the noun phrase "the eyes of Andrea". In this case the relation between the virtual spaces can be defined as a "part/whole relation", since Andrea's virtual space is the "whole" and the virtual space of the eyes is the "part". If we designate the "part/whole relation" by means of "of", we can correlate "Andrea" with "the eyes" in this way: [The eyes → (of → Andrea)].

The preposition "of" is often used to indicate possession. In the phrase: "the watch of Andrea", it is as if the virtual space of Andrea's body has been expanded to such an extent as to contain the objects he is wearing.

The Italian preposition "a" (to) often indicates the relation between two virtual spaces, in which the reference is approaching and the referred is still: "Vado a casa" ("I go to my house").

The Italian preposition "da" (from) is often used to indicate the relation between two virtual spaces, in which the reference is departing and the referred is still: "Vengo dal cinema" ("I come from the cinema").

The Italian preposition "con" (with) often refers to the relation between two movements, that is, between two virtual spaces in motion with respect to a scene: "Passeggio con Giovanni" ("I walk with John").

We attribute movement to an object. At a mental level, however, movement concerns the spatial relation of the "virtual space" of the object. It can be at rest or in motion with respect to the background and it can be at rest or in motion with respect to the virtual space of another object.

7.2 Verbs

In daily life, when we move around our surrounding environment, the "figures" selected by attention change continuously according to how the conditions of brightness, perspective and the psychophysical state of the observer change. If we select and perceive a “figure”, for example the colour of a leaf, we can keep it perceptually present because of the involvment of the premotor cortex which keeps the eyes staring at the object, whether we and/or the leaf move, or we and/or the leaf stand still. If the leaf moves into a less bright area, its colour changes becoming darker (the statement that the “colour changes” should not be understood, from a philosophical point of view, in realistic terms: we say so for explicatory purposes. At the level of mental construction this modification can be either achieved or not. It also depends on how attention is used). In order to “notice” this difference we should activate the circuit which makes the comparison between the first green, which is bright, and the second green, which is dark. This comparison is possible only if the perception is divided into two perceptual temporal unities, the first temporally includes the perception of the “bright green”, while the second temporally includes the perception of the “dark green”. We cannot create two “spatial unities” because the space is always the same. This means that the two perceptions are included in a temporal context from which they are separated by attentional selection.

The green colour is an attribute of the “leaf”, this means that our mind creates an attributive correlation between the “leaf” and the “green” colour. The green colour is perceived twice (in two different temporal unities) and “recognised” by the ventral system as “bright green” and “dark green”. The variation (or non-variation) in time of the attribute is fundamental for verbs (apart from “impersonal verbs” and those impersonally constructed, such as: it is raining, it is snowing, it’s late, etc., where there’s no attributive function).

If we state that the “leaf has become dark green”, we mean that we have recognized a difference between the two perceptual temporal unities of the green colour (bright green ≠ dark green). The verb phrase “becoming dark green” designates a transformation process where the final result, “dark green”, is highlighted.

When differences between two or more perceptions of the same attributes in different times are not perceived and recognized, the verb “to be” is used. In the sentence “the leaf is light green”, we state that in two or more different perceptions of the same attribute, we haven’t noticed any difference.

Previously we saw that the position “over the armchair” is an attribute of an object, for example, a “painting” (that’s to say, between the “painting” and “over the armchair” there is an attributive correlation). The positional attribute “over the armchair” can also be perceived more than once by means of different temporal perceptions. If we do not notice any differences, this non-variation is expressed by means of the verb “to be”: the painting is over the armchair (Figures 86a and 86b).

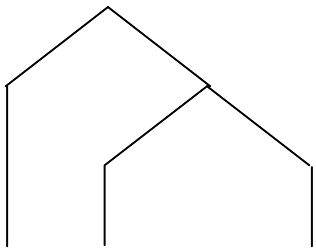

Figure 86a. Correlative structure"the painting over the armchair"

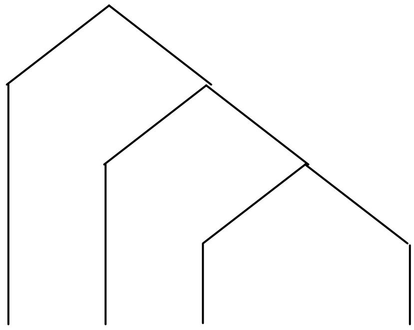

Figure 86b. Correlative structure"the painting is over the armchair"

As regards the tenses of verbs, temporal variations and non-variations occur in a temporal space that is temporally related (referred/reference relation) to the temporal space in which we communicate our experiences. In this relation, the temporal space of communication acts as the reference of the temporal space in which we perceive the variation or non-variation. This relation produces the division of tenses into present, past, future. "Present", "past" and "future" are caused by correlations/relations between two "times". In order to form a sentence in the "present" tense, our mind activates two virtual times, such as those of the speech and of the visual perception. It correlates, and sets up the reference/referred relation between these two times. If the temporal relation between the reference and the referred is simultaneous, we will have the "present". If the relation is "before/after" (reference/referred), we will have the future, if instead the relation is "after/before" (reference/referred) we will have the past. A virtual time can have more than one temporal reference. For this reason a virtual time can be a "future" compared to speech time, and a "past" compared to another time which is, in turn, a "future" compared to speech time. This happens with the "future (with respect to the speech time) perfect" (with respect to another time).

It is interesting to note that through language a series of rather complex mental activities, such as that of determining temporal relations, can be expressed by a single flexional suffix. For example, in Latin, the "future perfect" is expressed by these suffixes: "-ero (laudav-ero = I will have praised), -eris (laudav-eris = you will have praised), -erit (laudav-erit = he/she will have praised), etc.

We have stated that verbs arise from a comparison. This comparison breaks down the experience into more temporal spaces and the verb expresses the variation or non-variation of these experiences. In order to perceive and recognize these differences or equivalences, our mind has to detect variations by means of relations and/or associations. In fact we cannot state that an object is similar to, or different from, what it was before, if we do not associate it or relate it to another object or to another feature. In order to realize that a "bright yellow" lemon has become "dark yellow", the "shade-brightness" relation is needed. This relation allows us to perceive the variation of brightness referred to the shade.

Verbs of movement are divided into unaccusative, intransitive and transitive verbs. The intransitive verbs have no direct object and, in the Italian language, are expressed in perfect tenses with the auxiliary "to have". Examples of intransitive verbs are: "passeggiare" (to walk), "Ho passeggiato" (I have walked), "correre" (to run), "Ho corso" (I have run), etc. Unaccusative verbs have no direct object and, in the Italian language, are expressed in perfect tenses with the auxiliary "to be". An example of unaccusative verb is: "andare" (to go), "Sono andato" (I have gone), "giungere" (to arrive), "Sono giunto" (I have arrived). Transitive verbs have a direct object and, in the Italian language, are expressed in perfect tenses with the auxiliary "to have". Examples of transitive verbs are: "mangiare" (to eat), "Ho mangiato il pane" (I have eaten a piece of bread), "aprire" (to open), "Ho aperto la porta" (I have opened the door), etc.

When an intransitive construction is used, the verb expresses the variation of the relation figure/background which is acheived through movement. In the sentence: "Ho passeggiato nel parco" (I have walked in the park), the park acts as the background of my figure. The act of "walking" modifies the relation between the figure and the background. In the intransitive construction there is an interrelation, that is, a concomitant change in time between an "object" and the surrounding environment.

When an unaccusative construction is used, the verb expresses the positional changes between the subject and a second element which is present in the scene. In the sentence "Luigi è andato a casa" (Luigi has gone back home), the verb expresses the variations between Luigi's position and his house, variations that do not occur instant by instant, since there is no interrelation.

When a transitive construction is used, the verb expresses the variations, instant by instant, of the relation between the direct object and the subject. In the sentence: "Anna opens the door", the relation between Anna and the door changes instant by instant. Once again, there is an interrelation. In the two sentences: "Giovanni ha passeggiato nel parco" (Giovanni has walked in the park) and "Giovanni è andato nel parco" (Giovanni has gone to the park), the position "park" acts as "background" in the first sentence, and as "external reference" in the second one.

Some verbs have a double construction: unaccusative and intransitive. For example, in Italian, the verb "correre" (to run) can be conjugated either with the auxiliary "to be" or with the auxiliary "to have". We can say "Paolo ha corso tutto il giorno" ("Paolo has run all the day") and "Paolo è corso a casa" ("Paolo has rushed home"). In the former case the variations concern the figure of

Paolo with respect to the background which is not expressed: it could for example be the seashore: "Ha corso nella spiaggia" (He has run on the seashore). In the latter case the variations concern Paolo's position with respect to the house.

Let us now consider the derivation of transitive verbs from intransitive verbs due to the correlative shift of the preposition. In the sentence "Manuel è passato sopra l'ostacolo" (Manuel has passed *over* the obstacle), the verb is constructed in an intransitive way since the position "over the obstacle" acts as external reference that verifies the variation of Manuel's position in time. If we move the preposition that is correlated with the name, and correlate it with the verb, we will obtain a transitive sentence: "Manuel ha *sor*passato l'ostacolo" (*sor*=sopra) (Manuel has *over*taken the obstacle). Here, rather than designating the variation of Manuel's position with respect to the obstacle, the verb designates the variation of the spatial relation between Manuel and the obstacle instant by instant (interrelation).

Verbs, as we have already said, usually designate whether one or more features of a complex figure change or do not change in time. A leaf, for example, is a combination of shape, colour, size, state, etc. Each component can change or cannot change in time. Verbs are used to express the variations (or non-variations) of the leaf's attributes and how they occur (Figure 87)

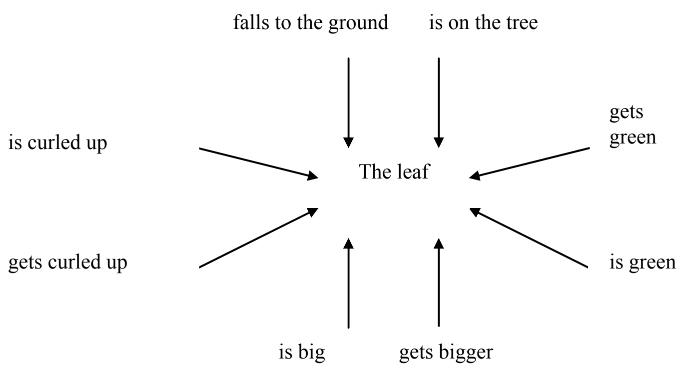

Figure 87. Possible variations of the features a leaf in time

- The leaf is green (no variation of the colour in time);
- The leaf gets green (variation of the colour in time);
- The leaf is curled up (no variation of the shape in time);
- The leaf gets curled up (variation of the shape in time);
- The leaf is on the tree (no variation of the position in time);

- The leaf falls to the ground (variation of the position in time);
- The leaf is big (no variation of the size in time);
- The leaf gets bigger (variation of the size in time);

7.3 Conjunctions

By using coordinating conjunctions, our mind designates a series of spatio/temporal relations between two “figures” set by the dorsal system. For example, the conjunction “and” in “the book and the pen” designates the attentional selection of each of the two figures and the selection of both of them together (these selections can also be imagined). The conjunction “and” can then be said to designate the interrelation.

The explicit logic circuit helps us to understand the meanings of some of these coordinating conjunctions. This circuit makes us aware of the logic relation: given that → then … hypothesis → verification. In particular, the anticipation process, when conscious, explainsthe meaning of the conjunction “or” rather well. If I flip a coin in the air, I will anticipate – through experience – two possibilities: heads or tails. Obviously one excludes the other.

The use of the conscious logic circuit can explain the correlative conjunction “not… but”. If I anticipate the hypothesis that a girl called Cinzia, who I’m going to meet for the first time, is beautiful, and then this hypothesis is contradicted by the perception that makes me realize that Cinzia is ugly instead, I will use the correlative conjunction “not… but” to keep together the two features: “not beautiful but ugly”.

As for subordinating conjunctions, most are correlative structures: for example the Italian “affinchè” (so that), “perchè” (because), “ciononostante” (nonetheless). Some others designate temporal relations between the actions expressed in sentences or between figures. The conjunctions “when” and “while”, for example, designate a referred/reference relation between the two times of the two sentences: “When I came in, he was not here”; “While I was going out, I met Andrea”

The Italian language uses the subordinating functor “che” (that/what) very often. It introduces, by itself, various subordinating propositions:

- Mi chiedo “che” hai contro di me (I wonder “what” you have against me) = indirect interrogative;
- Penso “che” Manuele non verrà più (I think “that” Manuel is not going to come anymore) = objective;
- Sembra “che” lei non sia felice (It seems “that” she is not happy) = subjective.

This functor, together with prepositions, adverbs, and locutions, is used in a great number of subordinating clauses: "per–ché" (given that) = causal clause; "affin-ché" (in order that/so that) = final clause; etc. It is not easy to explain the mental function of the Italian conjunction "che" (that/what) (subordinating functor). As with all subordinating conjunctions, it subordinates the dependent clause to the main clause. In the subordination, the subordinating element is the reference, whereas the subordinated one is the referred. In the same way, "of Luigi" designates a correlation where "Luigi" is referred to "of" (subordinating). In the sentence "Ti dico che è tardi" (I tell you that it's late), the clause "è tardi" (it's late) refers to the subordinating conjunction "che" (that) (not all the referred/reference relations generate a subordination. If the referred is a "feature" of the reference there is no subordination. The relation green/leaf is not subordinating because "green" is a feature of the leaf).

A plausible explanation of the Italian conjunction "che" (that/what), can be given by the following sentence: "Ho saputo che sei stato promosso" (I know that you passed). I think that, in this case, the term "che" (that) corresponds to "sei stato promosso" (you passed). This should be a prophrase (a pronoun that stands for a phrase) which, instead of being linked to something already said and already known by the speaker, is connected to something that follows, that is, to an anticipation of what is going to be said. In this case the prophrase is the direct object of the main clause and the reference of the following clause. This generates the subordination (Figure 88).

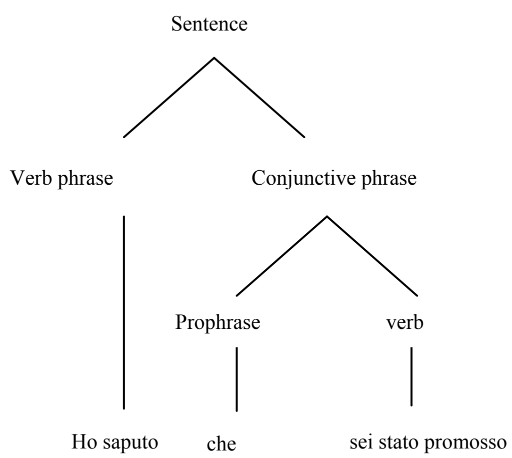

Figure 88. Correlative structure of the sentence "Ho saputo che sei stato promosso"

The Italian conjunction “perchè” (because) should have the correlative structure shown in Figure 89. This structure should be the same as that of all the conjunctions consisting of a “preposition + che”.

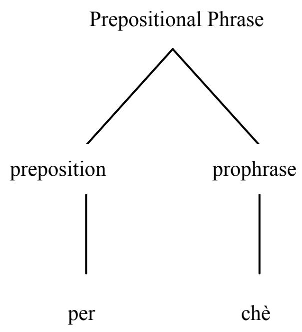

Figure 89. Correlative structure of the Italian conjunction “perchè”

7.4 Unconscious rules

Subordinating conjunctions make it possible to keep two thoughts together so that one is the expansion of the other. This kind of connection creates a new single thought. One example is when we mentally represent two thoughts, one corresponding to the “given that” and the other to the “hypothesis/retrieval” such as: “it rains (given that), John doesn’t go out (hypothesis/retrieval). If we construct this sentence with the conjunction “if”, this will be: “if it rains, John will not go out”. It should be understood in the following way: “if the fact that it rains occurs, then the fact that John doesn’t go out will also occur”. This thought can be understood as a hypothesis of what is going to happen in the future or as a rule. If I don’t know John very well and I don’t know what he does when it rains, my statement is just a hypothesis. If I know him well and I have noticed that, whenever it rains, he doesn’t go out, my statement is a rule on his habits. This interiorized rule will help to unconsciously process some mental states. If, for example, I see John under the rain, I surprise myself. This feeling comes from the perceived event that contradicts the unconscious rule. If the rule is contradicted, I can express this contradiction through a concessive clause: “even if it rains, John has gone out”.

We often introduce a cause to explain the contradiction of a rule. It can be a deterministic cause or a final one. "He has gone out with the rain because he has been called by his son", "He has gone out with the rain to walk the dog".

A sentence is formed by nuclear elements (usually necessary) and by other extranuclear elements (optional) (Salvi and Vanelli, 2004). For example in the sentence "John buys the fish on Friday" there are three nuclear elements: "John buys the fish", and an extranuclear element "on Friday". The extranuclear element can be removed without changing the meaning of the sentence. On the contrary, if we remove one of the three nuclear elements the sentence becomes agrammatical. Some of the extranuclear elements, in particular the temporal expansions, allow us to structure thoughts that can be used as unconscious rules. "John buys fish" cannot be a rule, but "John buys the fish on Friday" can be a rule. It depends on how many times we have seen John performing this action on Friday.

The interiorized rule allows us to make predictions and to generate thoughts with final, causal, concessive, explicative (etc.) expansions.

- This Friday John didn't buy fish so that his wife could cook something different;
- This Friday John didn't buy fish because he had enough of eating always the same thing;
- Yesterday it was Friday but John didn't buy fish;
- Although it was Friday, John didn't buy fish;
- It is Friday so here comes John with the fish he has just bought;
- It is Friday so John goes to buy fish;
- Yesterday, Friday, John was ill in fact he didn't go to buy fish;
- Today, Friday, John has bought not only fish but also meat.

References

AAVV. (1991a). “Anatomia del sistema somatosensitivo”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

AAVV. (1991b), “I sistemi sensoriali cerebrali: sensazioni e percezioni”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

Berlin, B., Kay, P. (1967). *Basic color terms: Their universality and evolution*. University of California Press. Berkeley.

Boccardi, E., Buzzone, M.G., Vignolo, L.A. (1984). “Alexia in recent and late Broca’s aplasia”. *Neuropsychologia, 22*: 745-751.

Caramazza, A., Miceli, G., Villa, G. (1986). “The role of the (output) phonological buffer in reading, writing and repetition”. *Cognitive neuropsychology, 3*: 37-76.

Catani, M., Howard, R. J., Pajevic, S., Jones, D. K. (2002). “Virtual in vivo interactive dissection of white matter fasciculi in the human brain”. *Neuroimage, 17*: 77–94.

Catani, M., Jones, D.K., Ffytche, D.H. (2005). “Perysilvian language networks of the human Brain”. *Annals of Neurology, 57*: 8–16.

Coté, L., e Crutcher, M. D. (1991). “I nuclei della base”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

Déjerine, J. (1891). “Sur un cas de cécité verbale avec agraphie suivi d’autopsie”. *Mém. Soc.Biol., 3*: 197-201.

Denes, G., Cipollotti, L., Zorzi, M. (1996). “Dislessie e disgrazie acquisite”. In *Manuale di Neuropsicologia*, a cura di G. Denes e L. Pizzamiglio. Zanichelli Bologna.

Denes, G., Semenza, C., Magno, Caldonetto, E. (1996). “Disturbi fonologici nell’afasia”. In *Manuale di Neuropsicologia*, a cura di G. Denes e L. Pizzamiglio. Zanichelli. Bologna.

Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., Rizzolati, G. (1992). “Understanding motor events: A neurophysiological study”. *Experimental Brain Research, 91*: 176-180.

Faglioni, P. (1996). “Il lobo frontale”, pp. 70-750, in: *Manuale di neuropsicologia*, a cura di Gianfranco Denes e Luigi Pizzamiglio. Zanichelli. Bologna.

Ghez, C. (1991). “Il controllo del movimento”. In *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

Goldberg, E. (2001). *The Executive Brain. Frontal Lobes and the civilized Mind*. Oxford University Press.

Gouras, P. (1994), “La visione dei colori”. In: *Principi di neuroscienze*, a cura di E. Kandel, J. H. Schwartz, T. M. Jessell. Ambrosiana. Milano.

Heilman, K. M., Barret A., Adair J. C. (1998). “Possible mechanisms of anosognosia: A defect in self-awareness”. *Philosophical Transactions of the Royal Society of London, Biological Sciences*, *353*: 1903 – 1909.

Kandel, E., Jessel, T. M. (1991). “Il tatto”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

Kelly, J. P. (1991). “Le basi nervose della percezione e del movimento”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

Kosslyn, S. M. (1983). *Ghosts in the mind’s machine. Creating and Using Images in the Brain*. W. W. Norton and Co. New York.

Lichtheim, L. (1885). “On Aphsia”. *Brain, 7*: 433-484.

Lissauer, H. (1890). “Ein Fall von Seelenblindheit nebst einen Beitrag ur Theorie derselben”. *Archiv fur Psychiatrie, 21*: 222-270.

Livingstone, M., Hubel, D. (1988). “Segregation of form, colour, movements and depth: Anatomy, physiology and perception”. *Science, 240*: 740 – 749.

Marchetti, G. (2007). “Time is energy. A hypothesis on the attentional origin of the conscious experience of time”. www.mind-consciousness-language.com

Martin, J. H., (1991). “Codificazione ed elaborazione delle informazioni sensoriali”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Elsevier Science Publication Co. Ambrosiana. Milano.

Mason, C., Kandel, E. R. (1991). “Le vie visive centrali”. In: *Principi di neuroscienze*, a cura di E. R. Kandel, J.H. Schwartz, T.M. Jessel. Ambrosiana. Milano.

Mc Carthy, R. A., Warrington, E. K. (1984). “A two-route model for speech production. Evidence from aphasia”. *Brain, 107*: 463-485.

Mishkin, M., Ungerleider, L. G., Macko, K. A. (1983). “Object vision and spatial vision: Two cortical pathways”. *Trends in Neuroscience, 6*: 414 – 417.

Pavlov I., (1982). “Il riflesso condizionato”. In: *Antologia degli scritti*. Il Mulino. Bologna.

Posner, M.I., Petersen, S.E. (1990). “The attentional system of the uman brain”, *Annual Review of Neuroscience, 13*: 25-42.

Rizzolatti, G., Gentilucci, M. (1988). “Motor and visual-motor functions of the premotor cortex”. In: *Neurobiology of Neocortex,* a cura di P. Rakic e W. Singer. Wiley & Sons. New York.

Rizzolatti, G., Sinigaglia, C. (2006). *So quel che fai. Il cervello che agisce ed i neuroni specchio.* Raffaello Cortina Editore. Milano.

Roeltgen, D. P., Heilman K. M. (1984). "Lexical Agraphia. Further support for the two strategy hypothesis of linguistic agraphia". *Brain, 107:* 811 –827.

Rugg, M. D. (1995). "ERPS studies of memory". In: *Electrophysiology of mind: Event-related brain potentials and cognition*, edited by M. D. Rugg and M.G. H. Coles. Oxford University Press. New York.

Salzano, R., (2003). "Taming stress". *Scientific American, 289*: 88–98.

Salvi, G.,Vanelli, L. (2004). *Nuova grammatica italiana*. Il Mulino. Bologna.

Skynner, B. F. (1938). *The behavior of organisms: An experimental analysis.* Appleton-Century-Crofts. New York.

Tolman, E. C. (1948). "Cognitive Maps in Rats and Men". *Psychological Review*, 55: 189-208.

Wheeler, A. M., Stuss, D.T., Tulving, E. (1995). "Frontal lobe damage produces episodic memory impairment". *Journal of the International Neuropsychological Society, 1*: 525-536.

Yucel, M., Wood, S., Fornito, A., Riffkin, J., Velakoulis, D., Pantelis, C. (2003). "Anterior cingulate dysfunction: Implications for psychiatric disorders?". *Journal of Psychiatry and Neuroscience, 28*: 350–354.