The Working Mind

Meaning and Mental Attention in Human Development

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5 Schemes/Schemas and Their Causal Constructivist Learning

The constructs of organismic schemes and schemas are examined in detail as suitable psychological processing units for the neuropsychological organization. Expanding on Kant's original insights, we show how schemes mediate between hard Reality (the encountered resistances) and the organismic information processing that decodes experience and enables thinking. We describe the principles of schemes, their kinds, and their various modes of learning mechanism.

> Thus an intelligent functioning (that is, a successful functioning in the reaching of a goal) is, as I see it, an expectancy on the part of the organism, aroused by that part of the stimulus layout which is immediately presented, to the effect that such and such performances or behaviors (if carried out) would be successful in reaching such and such goal.
>
> —Tolman, 1945, p. 165

Jakob von Uexküll (1982; T. von Uexküll, 1982) considered signs and meaning to be part of animals' dynamics. They were essential for the constitution of a *subjective life-world*, that is, an interpreted immediate-environment or context/situation that he called *Umwelt*. He attributed a distinct Umwelt to every species and individual, with similarities expressing their functional biological proximity. He emphasized that "a sign never exists in its own right; it is always part of a circular process [i.e., a functional system or totality] in which a receiver (receptor) receives stimuli, codes them into signs, and responds to them as such" (T. von Uexküll, 1982, p. 9). We call *organismic schemes* the functional systems expressed by signs.

Schemes are elementary functional-structure units of meaning that Kant, Piaget, Tolman, and von Uexküll pioneered using different terms. Our organismic schemes, congruently with Tolman's "expectancies" (Tolman, 1959), von Uexküll's "functional/circular systems," and Piaget's "schemes of assimilation," can be seen as meaning-bearing dynamic functional units with which to interpret the life-world. Life-world is an animal's construal of its surrounding context, other animals, and itself; the immediate external reality experienced by the subject from within (Husserl, 1970). In this surrounding context animals encounter resistances to their own agency. This sense of resistance (with lowercase r) is psychological, because it expresses constraints (affordances or obstacles/encumbrances) that Reality imposes on the animals' senses or acts. We use the term Reality (with capital R) to mean the immediate environment, prior to being represented or perceived.

Call Resistances (with capital R) the potential constraints for a species, within any given unrepresented or unknown environment (this is Reality as experienced). Resistances affect animals as they sense or act, which induces them to adapt or accommodate. When experienced by the animals "from within," we call them resistances (with lowercase r; this is now an epistemo-psychological perspective) to indicate that the Resistances are now semantically interpreted. In figure 5.1 we illustrate this

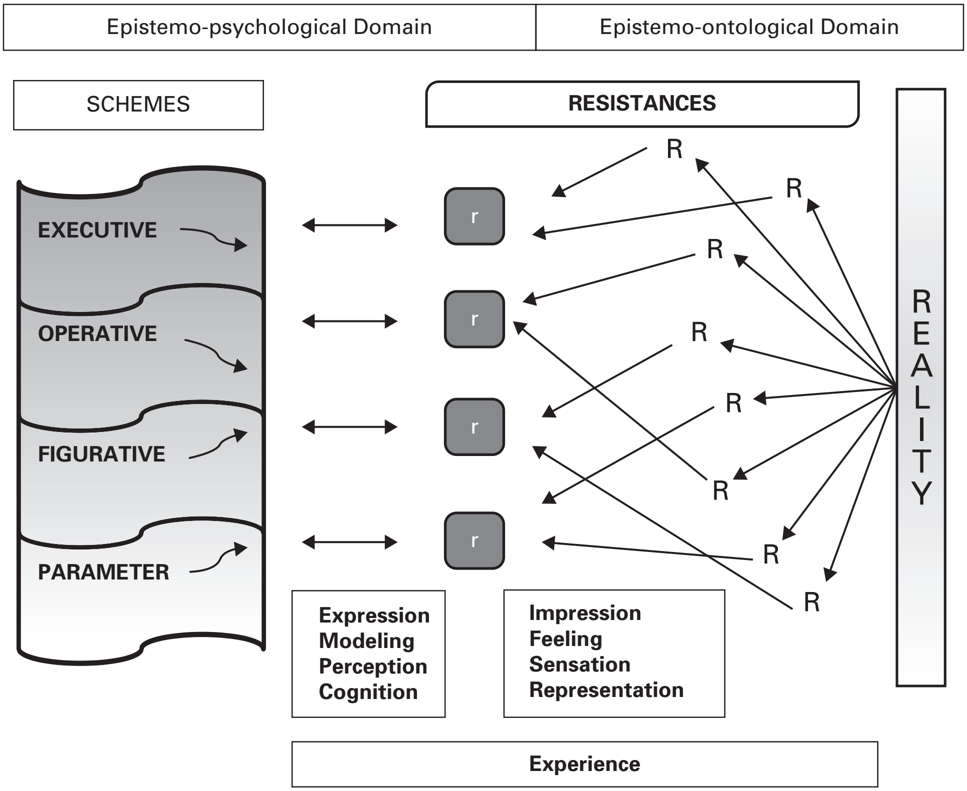


Figure 5.1
Model of organismic perception of reality/Reality.

Resistance → *resistance* transition. The two sides of figure 5.1 symbolize the two transitions that in classic psychology differentiate *sensations* (i.e., Reality stimulating the receptor organs; the right side of the figure) versus *perceptions* (sensations coded or modeled into percepts or cognition, the left-hand side). The center of the figure is where *resistances* emerge, incorporated to perceptual/cognitive processes in the making. This transition is at first (near the right side) a very *weak interpreted presentation* (only *C*-coding, impressions, feelings, sensations) of the input. Then, on the left side, they are transformed and incorporated into real *representations* (expressions, coding or modeling, perception, cognition). This second transition (strong representation) of the interpreted input is done by suitable schemes.

The schemes come in four kinds: executives, operatives, figuratives, and parameters. These four kinds resolve the dynamic interaction between the subjects' interpretive activity and Reality Resistances. This dynamism differentiates and incorporates into schemes four epistemo-ontological types of functionality: abstract and generic *pros* (procedures), action *pros*, action *obs* (internalized object representations), and relational and generic *ads* (adjunct information). There exist in the knowing subject many different concrete instances of these four basic functionalities. The various types are discussed in detail below.

Examples of resistances commonly occur in perception. When I look at the computer screen on my desk, raise it, explore it with my hands, and so forth, I unavoidably experience resistances that inform the schemes I construct. I attribute these resistances to Reality, that is, the encounters between my schemes (mobilized and differentiated when I act on the Real screen) and the screen's Resistances. These resistances (coded by active schemes) provide *cues* (matches between scheme conditions and Reality features). Reality constraints are resistances from an epistemo-psychological perspective and Resistances from an epistemo-ontological perspective. Perceptual illusions illustrate well the dynamic interactions between reality resistances and cognitive processes (see our discussion of the Kanizsa illusions in chapter 6).

Any resistance can be positively helpful (affordances) or negative/unhelpful (encumbrances or obstacles). Notice that the sign of resistances, positive or negative, appears relative to the goals or agency/praxis that the person pursues. Indeed, as such, Resistances of Reality do not have a sign; the sign appears in the resistances, that is, at the psychological not the epistemo-ontological moment/level. For instance, as Tolman (1961) emphasized, a major property or feature of chairs is their sit-on-ness (the aptitude of allowing us to sit on them easily). Solidity, shape, and size are major physical properties constituting the sit-on-ness of chairs, and when one is tired, the sit-on-ness with its three physical properties becomes a positive package of resistances. However, when the agency/praxis changes, for instance, when we wish to pass a big chair through a door, its solidity, shape, and size can become negative resistances—an obstacle or encumbrance. The sign of resistances is only within and relative to agency/praxis being pursued. These resistances eventually are internalized within schemes, which are our meaning-bearing units. Such "transmission of information" from Resistances to resistances to schemes is illustrated in figure 5.1.

A scheme is "an organized set of reactions that can be transferred from one situation to another by the assimilation of the second to the first" (Piaget & Morf, 1958, p. 86). Piaget also defined schemes as the common functional structure of all reactions (including signalic, symbolic, and agency/praxis functions) that a subject takes as interchangeable in pursuing a given affective or cognitive goal.[1] The concept of schemes or schemas, as internal mediators of knowledge processing, goes back to Kant. Interpreted in the language of current psychology, Kant (1929/1965; Pascual-Leone, 1998) saw the scheme/schema as a knowledge-processing bridge between our organism and its situational context (the Resistances of Reality), expressing actual constraints or resistances (both encumbrances/obstacles and affordances) of the current situation, as figure 5.1 symbolizes. However, schemas/schemes of Kant or Piaget are neither organismic (i.e., embodied in the brain and behavioral processes) nor always situated (i.e., contextualized to a situation). These authors do not show a relation of schemes/schemas with organismic constructivist processes in evolutionary epistemology (Pascual-Leone, 2006).

Human activity can be understood as a goal-directed interaction (intentional or not) with situations, with the key aim to control and understand objects, persons, or situations (Dormashev, 2010; R. Miller, 2011). It ultimately can be expressed as conscious or unconscious agency, whether praxis or not.[2] Goals always involve an affective component (appetitive/positive or aversive/negative), expressing the organism's history or innate internal constraints (Pascual-Leone & Johnson, 2004). We think of reality-out-there (Reality) as a universe of species-specific Resistances potentially affecting our goals: for instance, externally determined cognitive constraints or (often relational) sensorial-perceptual features of the experienced situations and outcomes. These resistances emerge during individual activity within a given context or situation. For instance, when I hit the table with my knuckle, I hear the sound (resistance1) and simultaneously feel the blow (resistance2) on my finger. These are resistances causally expressing two different "objects" that clash. As in this example, resistances often are found to have dependency relations with one another. Reality is populated with packages of interdependent potential Resistances that are relative to each species but also (when converted into resistances) related to the personal history of each individual.

Any physical object is (epistemo-ontologically) one such sort of package, which functionally may change with the subject's species and history. An example from Kagan (2002, p. 72) can serve as illustration: "a person who has just cut his finger on a knife and watches the blood ooze over his palm has no uncertainty about the existence of objects that can cause blood to flow, and is certain that he feels different than he did moments earlier." The finger and the knife are Real packages of resistances. They are distal objects—objects out there—construed by us to represent, and coordinate vis-à-vis life contingencies and action, the interdependent external Resistances (shape, size, color, utility, sharpness, and other characteristics). The cutting action (a key resistance of the knife) here serves to expose a conditional characteristic or resistance of the finger (i.e., when cut it will bleed). Although this construct of *Resistances/resistances* is our solution to the key problem of how thought can be effective in Reality (and how Reality can affect thought), some idea of Reality resistances opposing a person's agency is found (with different terminologies) in thinkers throughout history—albeit not stated as an epistemo-ontological explication of Reality.

Resistance packages can be interpreted, without falling into empiricist excess, as indexing Real (i.e., actually external) functional and probabilistic invariants (cf. Gibson, 1979; Nozick, 2001; Ullmo, 1967). They are recurrent relational aspects of Reality that animals can and must learn and cognize, to re-present these Resistances to themselves, as resistances by way of schemes. Motivation (which functionally intertwines affect/emotion, cognition, and Reality) leads higher animals to internalize these packages and their interdependencies, thus learning the *causal texture of the environment*[3] (Tolman & Brunswik, 1935). Notice that *internalize* means to learn by constructing schemes that epistemologically reflect (*epireflect*[4]), that is, express or attempt to control, important resistances and their affective value for us. They often do so iconically (see chapter 4) because the schemes epistemically reflect important aspects of the Reality at hand. From this perspective, it is appropriate to recognize that internalization (a conscious or unconscious epireflective abstraction) of reality's functional packages results from our own activity and occurs in three distinct but interrelated modes of invariance, three different sorts of packaged Resistances/resistances:

(1) First are packaged resistances of Reality that can serve as *targets* of the person's agency, which underpin the "*ob*jects" of experience, whether external or internal/mental experience. When these packages of resistances are represented psychologically, we call them figurative schemes (or internalized *model obs*). From a psychological semiotic perspective, these *model obs* correspond to simple or complex figurative (including parameter) schemes that have the function of signs (relational signal or symbols), together with their expectable meaning, their context or sense, and their referent.

(2) Second are packages that stand for *patterns of action* or *mental operations*, which can change *obs* or relations among *obs* in expectable ways. Epistemologically we call these packages *pros* (from procedures). When internalized, we call them *operative schemes* (or *model pros*), which are substrata for constructing procedures and operative processes. From this perspective, *pros* correspond to the actual operative or transformational possibilities of action offered by *model obs* (figurative schemes) as they become activated. Or vice versa: figurative schemes or objects are definable, as Piaget emphasized, by the set of operatives that can apply on them and those that cannot.

(3) Finally, there are packages of Resistances, simple or complex, that give *ad*junct information about *obs*, *pros*, and situations in which they usefully can be applied. We call these packages *ads*. When internalized, we call them *model ads* or *parameters* (a sort of relational figurative scheme). They describe properties or relations pertaining to *obs*, or conditions (i.e., contextual parameters) that *pros* need to satisfy to be applicable to particular *obs*. From this perspective, *model ads* (parameters) often correspond to signalic or symbolic (iconic or indexical) cues. *Ad*jectives, *ad*verbs, the meaning of relative clauses, and *ad*vertisements all have this category of *adjunct-information* as their reality foundation.

In the quote of Kagan above, the finger, the knife, the blood, and the palm are each represented in the person's brain as *ob*-indexing processes or models (figurative processes). The category description "objects that can cause blood to flow" is an *ad*-indexing process that causally relates *obs* such as knives to parts of the body (e.g., fingers) and to blood. The brain representation of the knife's action, which caused the blood to flow, stands for a *model pro* (and operative). By reflectively abstracting these *obs*, *pros*, and *ads* from experience, intelligent animals can internalize descriptive dynamic representations, and causal relations, relevant for life within their environment. These three sorts of resistances are psycho-logical processes, in Hegel's or Piaget's sense of (dialectical) logic, that is, schematized effective processes that mentally mediate amongst Reality, life experience, and action.

Pros, when internalized as action moves or procedures, serve as blueprints for people's actions or transformations, expressed as constituents of *operative schemes* or *operatives* (generators of scheme *effects*, see below). In contrast, *obs* and *ads* are internalized as descriptions of states and relations; combined, they make up units that we and other developmental constructivists call *figurative schemes* or *figuratives* (i.e., declarative or representational knowledge, implicit or explicit). Psychologically (i.e., when represented) a main difference between *obs* and *ads* seems to be motivational: *obs*, but not *ads*, can usually serve as targets for the person's praxis. Notice further that reflective abstraction and internalization of *obs*, *ads*, and *pros* cannot be made in a piecemeal manner. They emerge all together, coordinated in the context of activities within situations, as distinct functional aspects of the internalized total activity. They are *dialectical trios* abstracted together in coordinated packages, which produce organismic schemes. They are carried in the brain by distinct unitized neuronal circuits distributed over the brain. These circuits are cofunctional (vis-à-vis certain activities) and often coactivated in some tasks. Functionally, the unitized circuits are organismic schemes, definable within functional totalities of psychological brain processes.

Organismic Schemes

Schemes are situated (i.e., situation specific) and self-propelling. They are causal factors that together overdetermine manifest performance when they are cofunctional and often coactivated (Piaget's assimilation principle tacitly embodies this assumption). Every scheme **(Sch)** has a dual reality. **(Sch1)** It appears as a *package of qualitative functional characteristics* that informs (i.e., injects form into) experience and action when it applies. **(Sch2)** It has a variable *quantitative parameter* (i.e., *activation weight* for its neural network area), which conditions probability that the scheme can become highly activated and apply in a given context (perhaps as a synchronized neural circuit) to cause performance. Schemes are like recursive procedures (can produce schemes of schemes of schemes) and can be learned. It is common to have coordinated flexible hierarchies of schemes (i.e., heterarchies) with a context-sensitive ranking of dominance for the schemes. Complex schemes are often called functional *structures* or *schemas* (such as the coordinated "scripts" that govern our behavior in restaurants or within already-familiar complex problem-solving situations). Complex schemes express coordinated neuronal circuits or networks (Arbib, Érdi, & Szentágothai, 1998; Fuster, 1995; Kagan, 2002; Mars, Sallet, Rushworth, & Yeung, 2011).

Long-term memory results from the repertoire of schemes/schemas sorted in kinds: *executive* schemes (prefrontal), *operative* schemes (frontal), *figurative* schemes (i.e., perceptual or representational or linguistic; occipital, parietal, or temporal), and coordinated packages of more or less automatized *operative/motor* schemes (frontal hemispheres, basal ganglia, and cerebellum). There are also *affective or emotion* schemes (connected with the limbic system and the medial cortex), *analytical* problem-solving schemes produced with mental effort (initially in the left hemisphere, inferior and dorsolateral prefrontal), *holistic or automatized* schemes (right hemisphere), *complex analytical thinking (mentation)* schemes (frontopolar networks), and so forth.

From a functional-structure perspective, a scheme can be understood as expressing a unitized, well-learned coordination of three subsystems or components: *functional, releasing, and effecting* components. The *functional component* (*fc*) embodies the gist of the scheme's functional organization (scheme goals and task-relevant model configuration of its *pros* or *obs*). It embodies implicit or explicit expectancies about future outcomes of the scheme's application(s), as well as the gist of its whole functional activity. Further, the *fc* possibly has within it a *terminal state* or *stop rule* (Pascual-Leone, 1970) that tells the scheme in question when it has achieved its expected results. Notice that expectancies carried by the *fc* of schemes are essential to enable the inner appraisal (top-down and perhaps bottom-up) of a scheme's relevance for a given task or situation. The executive processes can use this information. When an affective need or goal induces executive schemes to bring about this affective-goal satisfaction, the fc of schemes, with their expectancies, can provide inner cues semiotically, telling the currently dominant executive that the scheme in question is or is not task-relevant here and now. This is why when one is thirsty, any potential source of water becomes more salient; and mailboxes become more noticeable when one needs to mail a letter. If they are congruent with intended cognitive or executive goals, *fc*'s of schemes are boosted with mental attention by executive schemes, increasing the perceptual sensitivity for task-relevant schemes cued by the situation. Thus, effectiveness of situational cues is potentiated by the figurative and operative expectancies in a subject's schemes.

Second is the *releasing component* (*rc*), that is, a set of conditions (perhaps indexed by schemes—models of *ads*, *obs*, or *pros*) that activate or release the scheme. Scheme conditions that satisfy current features or resistances within the immediate (external or mental) situation become cues. Thus, cues are never only external: they express matches between releasing components of schemes and the external resistances/Resistances or features of the actual reality/Reality.

Finally the *effecting component* (*ec*) is a set of effects (often expressed by models of *pros*, *obs*, or *ads*) that follow from the scheme's application to reality experience. For instance, I encounter my spouse in the kitchen holding a knife. In this context, the *rc* of the knife scheme is its visual characteristics and the way it is held; the *fc* is my anticipation in this context that she may be preparing dinner; the *ec* is my operative knowledge of how to use a knife to chop or slice food.

A scheme can be conceived as a dialectical dynamic system <: *fc* : *rc* : *ec* :> constituted by the three components, each dialectically coordinated (:) with the other two, and all constituting an integrated dynamic triplet that cannot be divided without breaking the scheme as a unit of processing. It cannot, because schemes emerge developmentally as functional and probabilistic (dialectical/dynamic) trios—the viable functional invariants from interactions among these three components extracted from regularities of actual experience or thought.

Although most schemes express *pros*, *obs*, and *ads* as models, the actual relative importance of these distinct semantic-pragmatic constituents changes with the sort of scheme. Some schemes can be said to function mostly as models for *pros* or *obs*, others mostly as models of *ads*. We cannot show it here, but our formulation of a scheme's functional structure is congruent with the processual units that Vygotsky pioneered with his organismic conception of semiotics (Dormashev, 2010; R. Miller, 2011; Pascual-Leone, 1996a, 1996b; Van der Veer & Valsiner, 1994; Zinchenko, 1985). Our scheme construct also is congruent with the implicit units (often called, e.g., chunks, structures, moves, responses, options, schemas) formulated within current reinforcement-learning theories of neuroscience (Mars et al., 2011).

To be well defined, these organismic carriers of signs and operative activity must, in our view, satisfy some other basic postulates of schemes **(Sch)**:

(Sch3) Schemes are recurrent (probabilistically invariant) functional constituents of *agency or praxis*. Therefore, they must be defined relative to the totality of agency (activity, actions, or mental performance) that prompted their emergence. For instance, relative to the task of shopping for food, necessary complex scheme constituents are <getting dressed to go out>, <walking to the store>, and so on. From a neurological perspective schemes are functional-activity component systems of brain processing that carry active information (are subjective operators of the brain "software") relevant for some sort of agency/praxis, which can organize functionally various content domains (e.g., visual, auditory, motor, affective, psychosocial, cognitive-relational). As information carriers, schemes are qualitative, functional-relational (*intentional* or *intensive*) entities with specific activity dispositions or propensities. Schemes have no here-and-now *extension* until they are applied (i.e., no set of concrete instances, objects, or operations exist related to them prior to the schemes' activation and application). Every scheme is self-propelling (Piaget's assimilation) under releasing conditions (cues), and an applied scheme imposes attributes, restrictions, or constraints to the external or internal performance, unless other contradictory schemes prevent its application. Competition among schemes often precedes performance.

(Sch4) Functionally, schemes are *indivisible units*. Distinct aspects of experience that are not cofunctional must be kept within separate coordinated schemes if they are to be used separately. Thus, schemes must be internally consistent to be formed and congruent to be coordinated. This constraint implies that whenever two objects, or two aspects of the environment, or two action moves, are functionally different in terms of agency/praxis, they have to be expressed organismically as two distinct schemes—even when they are similar in other respects. Otherwise, the organism cannot perceive or treat them as distinct and cannot use them differently (this is postulate SC1 of Pascual-Leone, Goodman, Ammon, & Subelman, 1978).

(Sch5) A scheme is a sort of *recursive function*: “the conditions and/or effects of any scheme could in turn be constituted by schemes” (Pascual-Leone et al., 1978, p. 254). Schemes can be defined at different epistemic or knowledge levels within functional hierarchies, with schemes functionally nested (usually into heterarchies). The conditions or effects of higher-level schemes are constituted by partial “copies” of other lower-level schemes that remain functionally autonomous.

(Sch6) Organismic schemes substantively correspond to cofunctional and often coactivated neuronal circuits that carry shared semantic-pragmatic meaning. As with the “symbolic forms” of Cassirer (1923/1957) or the schemes of Piaget, “*the form of a scheme’s structure is the structure of its functioning*” (Pascual-Leone, 1984, p. 183). From this perspective, schemes or schemas may be seen as semantic-pragmatic systems of processing for the performances they help to produce; performances being overdetermined by sets of compatible schemes that can apply together and achieve intended results. Notice that each scheme embodies a distinct, necessary, and invariant functional constituent of the strategy of action (agency, praxis, or practice) from which it is abstracted. However, the functional structure of any scheme tends to be minimalist, in the sense that, in the process of a scheme’s psycho-logical formulation (i.e., reflective abstraction by the organism), this functional structure remains as general or generic as possible. In constructing a scheme, and vis-à-vis the intended performance, the organism always takes as much error (variability, features, or aspects omitted from the prescription and left undefined) as it can afford, relative to the intended ideal agency or praxis. In other words, for as long as the abstracted scheme is viable, no further differentiation or refinement of the scheme may take place. This progressive degree of abstraction facilitates generalization of schemes to similar or related situations (i.e., transfer of learning).

(Sch7) To emerge or be formed, schemes must be abstracted from performance/experience or constructively learned by the subject. A high enough *ecological frequency* of situations (and affective goals) to promote formation/learning of these schemes must therefore exist in the life experience.

(Sch8) Schemes are key organismic-causal determinants of agency/praxis and experience, but they do not suffice to explain truly novel or creative performance. Agency, praxis, and causal abstraction use processes of the brain “hardware” together with the schemes’ “software.” These “hardware” brain resources (e.g., hidden operators like mental attention, space or time factors, internal Gestalt-field factor), along with organismic principles such as Schemes' Overdetermination of Performance (*SOP,* see chapters 1 and 2), Piaget's equilibration, and so forth, apply on schemes to generate truly novel *dynamic syntheses* that create probabilistically transitory organismic states that can induce and orient a subject's performance and may lead to emergence of new schemes. These transitory states can synthesize performance (via "creative" coordinations) in ways not previously expressed in already learned schemes and can do so without assuming a *homunculus* (i.e., a "little man" inside the organism that produces its performance). These novel and ephemeral dynamic functional structures could, with repetition, be learned, generating new schemes or schemas.

There are interesting epistemological convergences of our process-qualitative, developmental approach with current dynamic field/system theories and with computational-rationality probabilistic-process models (Friston, 2010; Gershman, Horvitz, & Tenenbaum, 2015; Schöner, 2014; Spencer, Perone, & Buss, 2011). They are all dynamic-process theories of various sorts that produce performances by activating locally ("in situ") multiple processes; in our case, schemes/schemas and operators, which with their interactions make affectively motivated (internal or external) performances emerge. Schemes/schemas (together with TCO's organismic hidden operators and principles) could perhaps serve as a qualitative-process, general causal account that may add an intuitive macro perspective to dynamic or quantitative probabilistic-process models of human performance.

(Sch9) The *assimilatory strength*, or total weight, W_T, of a scheme (Pascual-Leone & Goodman, 1979, p. 321) "is a combination of all the weights received by it from the various organismic boosters." The boosters usually are cue salience, hidden operators, or innate propensity to apply. A tentative mathematical sketch for this sort of weight combination was offered by Pascual-Leone and Goodman (1979), which we present (modified) to add epistemological clarity to the issue:

$$W_{\mathrm{T.i}} = (W_{E.i} + W_{A.i} + W_{C.i} + W_{L.i} + W_{F.i} + \ldots - W_{I.i})\ W_{cues.i}$$

In other words, the total activity weight of a scheme h_i is a function of the sum of all the factors (e.g., hidden operators) that boost this scheme, minus the weight of deactivation factors such as attentional inhibition (I_i). The result of this algebraic combination applies on ("multiplies") the weight of the cues that activate this scheme ($W_{cues.i}$). Notice that *cues* in the TCO are matches between releasing conditions in the *rc* of the scheme and features, characteristics, Resistances of the input (immediate Reality).

(Sch10) The main mechanism for causal abstraction is the formation and application of schemes, which are the most important dynamic causal constructs of the organism.

Action Schemes

In TCO's terminology, *action schemes* can directly produce performance. In contrast, executive schemes need action schemes to do so. Action scheme is a category that includes cognitive (operative, figurative, and parameter) as well as affective and personal schemes. Application of action schemes directly causes actual experience or performance (activity in the sense of Vygotskian psychologists).

The two main superordinate kinds of action scheme are affective and cognitive. *Affective schemes* (Greenberg & Pascual-Leone, 1995, 2001; Antonio Pascual-Leone, Greenberg, & Pascual-Leone, 2009; Pascual-Leone, 1990b, 1991b; Pascual-Leone & Johnson, 2004; see also chapter 6) add biological and life evaluation feelings, *vital values,* to the experience or situation at hand (feelings such as good/bad, like/dislike, and seek/avoid). They set up the life or vital-value appraisals (*values* for short) for experiences and evaluate situations (external cognitive states) and inner states, in terms of vital feelings they elicit.

Affective schemes introduce tendencies, which we call *affective expectancies* and *affective* (abbreviated as *A*) *goals,* which boost (*A-boosting*) activation of cognitive schemes congruent with the dominant affective tendency in question (e.g., if in fear, escape; if in love, approach). The *fc* of a purely affective (*A*) scheme stipulates the qualities or propensities of a given affective tendency. Its *rc* contains the cognitive states (signals or symbols; models of *obs*, *pros*, or *ads*) and the intuitive mental/experiential configurations that release the affect(s) in question. Its *ec* contains the effects occurring when the affective scheme applies: affect-related physiological manifestations (e.g., paling with fear, warming with love), related cognitive memories, and an affective activation weight (*A*-boosting—sometimes called *conation* or *psychic energy*) that applies on cognitive schemes suitable for the affect's affective goal—to bring about affect-valued outcomes or experiences. Purely affective schemes easily combine with cognitive schemes to constitute affective-cognitive hybrids, often called *personal* or *emotion schemes* (including emotions, character/moral schemas, psychosocial and sociocultural schemes, and others).

Unless they are personal (i.e., hybrid) schemes, *cognitive schemes* are distinct from affective schemes, because they do not contribute feeling-appraisals of vital value to the organism. Instead, figurative cognitive schemes provide epistemic *truth appraisals*: correct/incorrect, right/wrong, agreement/disagreement between perception or thought and actual experience. Truth can be appraised in agreement or disagreement with reality/Reality in four different ways: direct appraisals of correspondence with reality/Reality, appraisal of the schemes'/schemas' internal consistency, appraisal of pragmatic utility, or via consensual validation. These are tests of the schemes as signs, testing their relation to their referents and to one another.

To recapitulate this important point: within the initial biological complex system that von Uexküll first outlined (the system formed by an organism vis-à-vis its own interpreted life-world or immediate environment), affective/personal schemes yield feelings or vital-value appraisals, whereas predominantly cognitive schemes that are figurative produce truth-value appraisals. The latter evaluate whether the interpretation/representation embodied by a scheme corresponds to resistances offered by this aspect of Reality that for the scheme is referent (referential *intentionality*).

As mentioned, cognitive schemes split in two complementary sorts: figurative and operative. *Figurative schemes* are processes that assign predicates of all sorts, simple or complex (including relations, here construed as multiterm predicates), and more complex compound predicates (at times temporally structured in sequences and epistemic levels), which may generate models in the brain. Such models are distal objects (*obs*) or complex procedural descriptions (description of *pros:* strategies for doing "jobs" of one or another sort) or else complex adjunct information (*ads*). When figurative schemes apply, they together generate a mental state (phenomenal representation), which is an intuitive synthesis, or configural experience, bearing meaning and perhaps accompanied by figurative or operative expectancies. *Figurative expectancies* are associative anticipations of "what" is related to something else, contingent on some action. For instance, given an object examined from one perspective (my home, my pet, my street), I can anticipate what I can see or experience when I act and take other viewpoints: for example, when I go and look at the back of such object or mentally seek parts of the object that are hidden but accessible after using appropriate operative-scheme steps.

Operative schemes (*operatives* for short) are mental or external transformations or actions. Their application induces emergence of *operative expectancies* (Tolman, 1959, aptly called them "means-end-readinesses"), that is, anticipations of results when applying one or another operative scheme. A transformation changes a figurative state into another, distinct and possibly different, figurative state. For instance, I hit a glass, and it will fall from the table, breaking into pieces. This anticipation is an operative expectancy; the action itself is a transformation. Encompassing across situations, and more abstract, is the special sort of operative stipulating plans for action that are called executive schemes. This term, now very popular, was first introduced in psychology by Koffka (1963/1935) before its importance could be understood.

Executive Schemes

Much current literature has an overly broad definition of executives and executive functions. Executive functions/controls often are seen to subsume all planning and control of cognitive/personal processes, together with the brain resources (e.g., mental-attention activation or inhibition) needed for functioning. Generally, the literature recognizes two kinds of executive control: before 4 years of age and after 4.5 years. This is congruent with our sensorimotor mental attention versus symbolic mental attention (Espy, 2016; see chapter 3). In our organismic formulation we restrict the term *executive* to refer to a person's currently dominant set of compatible executive schemes. We restrict *executive functions* (often illustrated by the functions of shifting or updating[5]) to refer to certain executive-driven schemas caused by learned complex packages of executive schemes (*LC*- or *LM*-structures, see below). Our theory recognizes other organismic factors in executive-driven performances, such as mental attention (activation and inhibition or attentional interruption). These are distinct brain resources that executives use and control (Im-Bolter, Johnson, Ling, & Pascual-Leone, 2015), thus acquiring power to activate or inhibit action schemes of any sort. Other organismic factors, like affective/personal schemes, are the initial mobilizers of executives, sometimes controlling them (Pascual-Leone, Pascual-Leone, & Arsalidou, 2015).

Functional heterarchies and the nesting of schemes are illustrated in the dynamic interactions among executive schemes and ordinary action schemes. *Executive schemes* are higher-level operative units that embody plans or blueprints for action and strategy. Within situations, *executives* (i.e., currently activated, compatible, and dominant executive schemes—often known as *the executive*) define tasks and can regulate application of general-purpose brain resources. These resources are hidden organismic capacities—complex and innate subcortical and cortical controls (e.g., activation and inhibition functions of mental attention, various sorts of learning, field factor). They are applicable to action schemes to change their functioning, in a context-sensitive manner. Executives are induced or mobilized by (often implicit) affective goals or motives. Affective goals are brought up by currently dominant affective and personal schemes, and their conversion into cognitive goals, often via executives, is what we call *motivation*. This sense of motivation (i.e., conversion of affective goals into cognitive ones) has specific processing sites in the cortex, such as the insula and anterior cingulate cortex; at least in sufficiently complex cognition (Arsalidou, Pawliw-Levac, Sadeghi, & Pascual-Leone, 2018; Pascual-Leone et al., 2015).

By controlling organismic resources, executives can monitor application of suitable action schemes to the task at hand. To have the relevant action schemes strongly activated when needed, executives can mobilize mental-attentional (*M*) capacity and/or attentional inhibition (*I*). With practice, however, a chunking or associative-learning process may take place, which we call *logical*-structural *content* (or *LC*) *learning*, which transforms the flexible hierarchical package of schemes into a single, more or less flexible, complex schema or chunk (which, in our theory, we call *LC-structure,* an automatized and coordinated complex processing package). Once formed, executives and mental energy (*M*-capacity) can treat and boost the *LC-schema* as if it were a single unit. The semantic ground (or meaning) of well-established signs often corresponds in the organism to *LC*- or *LCLM*-schemas/structures (see below).

There are two sorts of executive schemes, which often are confounded: *plans* and *controls* (Pascual-Leone et al., 1978). As plans, executive schemes are in charge of selecting a task strategy and organizing processing for and within the task (i.e., schemes that must be simultaneously activated at each task moment, and the sequencing of task steps). As controls, executive schemes (in the service of current affective/cognitive goals) can mobilize and control application of brain resources such as mental attention, to ensure that essential task-relevant schemes become not just activated but dominant, to carry out the intended task performance. This would be effortful executive-driven (or executive-mediated) processing.

Executive-driven processing requires executives to "recognize" schemes relevant for the situation at hand and notice schemes that are misleading and should be interrupted (attentionally inhibited). How do executive schemes know which action schemes to recruit or inhibit? This important question should be answered at two distinct levels: At the level of action schemes (stipulating what they can do for the task) and at the level of the type of task (estimating degree of relevance/irrelevance of one or another scheme, in terms of its task effects). At the level of action schemes, the functional component (*fc*) of schemes is extremely important, because it carries expectancies about what a scheme can do or bring about, and the gist of its action. The functional components of schemes can provide information to, and are activated by, executives. This enables the current task executive to qualitatively appraise potential relevance of action schemes.

A quantitative (probabilistic) appraisal of degree of relevance can also be provided at the level of type of task. Such probabilistic appraisal would constitute a *criterion of relevance* (Pascual-Leone, 1984). This criterion may emerge via some sort of heuristic rule like the following (this is a hypothesis): schemes that in the past were frequently highly activated (or boosted by M; i.e., inside the field of mental centration or working memory) at moments when a suitable performance in this type of task was produced are regarded by the executive as relevant for producing this performance (proportionally to the frequency of occurrence).[6] Other schemes that had low activation (or were absent from mental centration) during past performances in this type of task are taken to be irrelevant by this criterion. Such criterion of relevance is similar to those adopted in neuroscientific computational models of reinforcement learning. This similarity is illustrated by the scientific model of Cockburn and Frank (2011, p. 319): "the pre-SMA [the pre-Supplementary Motor Area of the medial cortex] eventually learns to refine its selection of candidate actions based on the probability of having selected these actions in the past for a given context."

In misleading situations, executive-driven processing is more likely to succeed when executives are mental and symbolic, that is, functionally detached from action schemes applicable in the task (see chapter 4). However, when executive schemes are only sensorimotor and signalic (usually automatic), ability to cope with misleading situations depends on associative connections to task-relevant (local) operative schemes, which is only possible when the task is not novel, and the goal-relevant associative learning already has taken place. Furthermore, signalic executives may not be able to control ongoing task processing due to functional attachments (associative chunking) to other irrelevant action schemes—a common source of errors and performance inadequacies.

A clear distinction and diagnosis should be made between these two sorts of executives (i.e., mostly sensorimotor/signalic vs. fully mental/symbolic executives), because their respective strategies and demands on brain resources are very different. One difference tends to be in *complexity*: a greater number of distinct (executive and action) schemes is involved in mental-symbolic executives, which demands mental effort, and where relevant, schemes must be activated jointly or in the prescribed sequences. However, an important, more subtle difference is found in *their relation to affective goals* that motivate or induce the task. As discussed in chapter 3, sensorimotor/signalic executive tasks are always motivationally immediate (usually affectively or cue driven), because task activity (agency, praxis) is automatically cued by the actual immediate situation, which activates most or all needed task schemes (via *C, A, B,* and *LC* boosting). In contrast, symbolic-processing (high mental) tasks involve affective goals that must use mediation by symbolic executives.

In these executive-mediated tasks, the necessary operative processes are not directly related to current affective goals (e.g., working on a math assignment because my mother wants me to is executive mediated, if I do not much like working on math). Instead, the needed operative processes are activated and kept alive in a mediated manner by mental attention and other brain resources. For instance, when I take my car to visit my friend to get a book from him, the current goals/schemes activated for driving, getting to his place, parking, and so on, are unrelated to the symbolic executive (i.e., the main operative process of getting the book). These goal-schemes are kept alive in my thinking by both automatized/signalic executives (by prior LCLM learning) and mental attention (i.e., effortful activation or inhibition). Another example more relevant for development and education is when a primary-school teacher designs a task and asks children to do it. A child's dominant affective goals may not be doing the task but pleasing the cordial, friendly teacher and the child's parents, who encouraged his or her attendance and value his or her work. In this case, the tasks themselves are not affectively immediate but mediated by executive schemes boosted by these personal affective goals (e.g., pleasing teacher and parents, doing what the child feels he or she must do—an "ethical/moral" injunction). Even when the child finds the task tiring or boring, executive mediation may motivate the child to do the task.

Because distinction between signalic versus symbolic executive processes is so important, we illustrate signalic executive processes again using a sensorimotor (affectively immediate) task, which is complex and motivating enough to induce in babies an executive-mediated activity. Take the case of a 9-month-old who spontaneously reaches for a rattle to shake it because she likes its sound. Her sensorimotor behavior emerges as an overdetermined sequence of dialectical/dynamic syntheses in performance: coordination and application of several figurative schemes, operative expectancies, and transformation operatives. Table 5.1 symbolizes the stream of processing elicited by this task when it is solved via signalic/sensorimotor performance. There are two aspects to the description in table 5.1. The first is the likely activated repertoire of schemes that a child may need to generate a stream of processing that can solve this task. The second aspect is our descriptive model for this stream of processing.

The first three schemes listed in the activated repertoire are figuratives (i.e., predicates) for three aspects of the same distal-object (*ob*) rattle: the visual rattle, the touched-and-handheld rattle, and the sound-producing rattle. When, with child development, the figurative schemes of three "perceptual rattles" are coordinated, these figuratives contribute to constitute the symbolic distal-object "rattle." We name these schemes with meaningful abbreviations and, after the equal sign (=), we give more detailed description of each. We have numbered the schemes (i.e., … :1; … :3; … :5; … :2) to simplify description of the complex schemes they constitute, representing these constituents by their number (e.g., *GRASPING*:2.1.3). In a purely signalic processing, as we are now modeling, the three perceptual aspects of distal rattle may not be integrated, and each may represent a distinct perceptual object. Notice further that, as usual, we represent figurative schemes by writing their names in lowercase (we omit the prefix * used elsewhere to symbolize figurative schemes).

Recall that any scheme has three dynamically coordinated components that define it. Let us illustrate these three components in the simple schemes just mentioned. In the scheme vis.rattle:1, the functional component may correspond to the description [*fc*:= visual pattern signaling the distal rattle that can produce rattle sound when shaken, and can be touched]. This stands for a purely experiential, nonverbal associative description in the child. The releasing component corresponds to [*rc*:= sensorial-perceptual features that match conditions characteristic for a distal rattle]. Its effecting

Table 5.1

Secondary circular reaction: reaching for and shaking a rattle

Activated Repertoire of Schemes

vis.rattle:1 = “visual rattle:1”

touch.rattle:3 = “touched-and-handheld rattle:3”

sound.rattle:5 = “sound-producing rattle:5”

GRASPING:2 = “reaching and grasping:2”

SHAKING:4 = “shaking:4”

***GRASPING*:2.1.3** = “GRASPING:2; visual rattle:1; touched-and-handheld rattle:3”

***SHAKING*:4.3.5** = “SHAKING:4; touched-and-handheld rattle:3; sound-producing rattle:5”

APPLY.THEN: 2.1.3-4.3.5 = “**APPLY** *GRASPING*:2.1.3 **AND THEN** *SHAKING*:4.3.5”

Stream of Processing (Model of Processing Steps in Performance)

{vis.rattle:1} → {*SHAKING*:4.3.5, vis.rattle:1} ➔

{APPLY.THEN: 2.1.3-4.3.5, *SHAKING*:4.3.5, *GRASPING*:2.1.3, GRASPING:2, vis.rattle:1} ➔

{*SHAKING*:4.3.5, SHAKING:4, touch.rattle:3} ➔ {sound.rattle:5, ...}

component could be [*ec*:= the actually experienced pattern of a visual rattle, which, when shaken, yields its specific sound, and so on]. The overall distal rattle is constituted as a probabilistic invariant by experiential coordination of the three distinct schemes: vis-rattle, touch.rattle, and sound.rattle.

The next schemes in the list of the repertoire (table 5.1) are two operatives: GRASPING:2 and SHAKING:4. We indicate operative schemes with CAPITALS. Next, we have written two operative expectancies, identified by writing their names in italics: *GRASPING*:2.1.3 and *SHAKING*:4.3.5. Again, digits identify heterarchical constituents or subordinate schemes. For instance, in the first case the three subordinates are the operative transformation GRASPING:2 that applies on vis.rattle:1 to bring about touch.rattle:3. The last scheme in this repertoire is APPLY.THEN:2.1.3-4.3.5. This complex operative is temporally structured (i.e., 4.3.5 applies after application of 2.1.3) and embodies an operative expectancy (i.e., *APPLY.THEN*), which is not explicitly represented because it is part of the same scheme. As an example, consider briefly how the full scheme <:*fc*: *rc*: *ec*:> of the operative expectancy *GRASPING*:2.1.3 could be represented: <:[*fc*:= WHEN GRASPING is applied, THEN vis.rattle turns into touch.rattle] : [*rc*:= vis.rattle] : [*ec*:= touch.rattle]:>.

Let us now examine the second section of table 5.1, the stream of processing model. In this representation, schemes included within the same braces {…} are activated within the same attentional centration (focus of attention or attentional act). Centrations separated by arrows occur sequentially in the given order. Within each centration, the schemes are arranged in a functional hierarchy: operative schemes at the left apply on and control schemes on their right. An English paraphrase of the flowing sequence of actions described in this stream of processing model follows: the child sees the visual rattle [{first centration}]. Then [→] seeing-this-rattle activates the operative expectancy of shaking the handheld rattle, to produce the rattle's sound [{second centration}]. Next [➔] to implement this expectancy, a grasping-the-rattle expectancy is activated as an intermediate step to the actual grasping act, and grasping of the rattle occurs [{third centration}]. To add clarity, we describe again, very concretely, this third centration of the sequence: the operative APPLY.THEN controls and mobilizes expectancies *GRASPING* and *SHAKING*, which in turn mobilize the operative GRASPING:2, which applies on vis. rattle:1 to produce an expected touch.rattle:3 feeling (not represented but appearing in the next centration). The mentioned sequence occurs within a single centration, within a short time or simultaneously. Finally, the shaking expectancy can be applied, and this application mobilizes the operative SHAKING:4 upon the rattle being touched [{fourth centration}]; which causes [➔] the rattle's sound [{fifth centration}].

Such sequence may result from signalic processing. Each scheme to the left in the sequence should induce activation of schemes on its right because of associative (*C*, *LC*—see below) learning; the process begins with the cues from vis.rattle:1. However, this or similar sequences may also occur (without much associative learning) under symbolic processing with the help of mental attention (*M*-activation, attentional inhibition). In this latter case, a symbolic executive scheme (not represented in table 5.1) would exist, activated to anticipate and "prescribe" the set of schemes, which mobilizing mental attention, could produce dynamically the sequence of the third centration in the "stream of processing" model of table 5.1. Use of mental attention, and presence of control executives, explain the functional difference between symbolic versus signalic processing, as Cassirer (1929/1957, 1944/1966) may have recognized. In signalic processing the sequence of applied schemes is known only a posteriori, being induced by here-and-now affective goals and by circumstantial local cueing of one scheme or another. In contrast, sequences produced by pre-existent, now activated, symbolic executives are controlled or prescribed. This makes such sequences more robust to local circumstantial variations, enabling individuals to anticipate sequences more easily.

Diagnosis of Schemes in Concrete Situations

For many researchers, an objection to the scheme-unit construct is difficulty in finding criteria to identify schemes unambiguously. Schemes are constructivist concepts, and so they often appear in nested flexible hierarchies, because many abstracted cognitive processes are complex. We now sketch a useful approach for the diagnosis of schemes that may underlie a performance. The method uses constructs and definitions already given. We investigate each term in the scheme sequence, using five analytical-test steps.

Diagnostic step 1: Relative to the characteristics of the explicitly formulated target task and chosen strategy we recognize and itemize the *totality* of schemes that may cause the *task's final performance*, given a chosen strategy. This deconstruction of the performance into schemes (plans, controls, and courses of action) is a preparatory step—an inference of plausible causal processes that may determine (overdetermine) the intended performance. We often begin by demarcating the intended final task performance (and final cognitive goal or goals), analyzing backward from this expected performance to infer distinct "jobs" that, combined together, can cause it. Finding these component "jobs" requires that we enter a problem-solving process prior to task analysis.

We can illustrate this prior problem solving with a simple example: when a tourist in a new city wants to attend a certain concert in the city's concert hall, she has to configure the final task performance of arriving to the hall to purchase a ticket and enter. One job needed for getting there is to find the location on a map. A second job is to decide the means of transportation. If it is near a metro/subway station, this way will be cheaper; if not, a taxi may be the choice. Assume that the choice is the metro. Where is the nearest station? One must find out and get there, and so on. Notice that this and many final task performances become progressively configured and clarified as we encounter possible encumbrances or obstacles (Reality resistances) and find suitable ways of resolving them while obtaining means-end affordances needed. Schemes are concise representations of these psychologically internalized obstacle solutions and obtained affordances, as we explain below. This sort of final-task-performance problem-solving helps to clarify what sort of schemes would be needed for a given task prior to a detailed task analysis.

In the task modeled in table 5.1 the intended final cognitive performance is "getting the rattle sound," cued initially by the sight of the rattle and prior experience with rattles (*LC* learning). To reach the intended performance, a sequential operative-expectancy scheme available in the subject's repertoire (i.e., "the rattle can be grasped and then shaken") must be present to induce an affective goal that activates, in our example, the scheme APPLY.THEN associated with this motive (*LC* learning). The grasping of the rattle causes new stimulation, configured by application of the figurative scheme touch.rattle. It is upon this particular touching-the-rattle facet, a partial *ob* of the distal object (i.e., the total *ob* rattle), that the operative SHAKING is cued to apply. The "stream of processing" model in table 5.1 shows the result of this backward analysis—a sort of analysis that Peirce would have called a chain of *hypotheses* or *abduction*.[7]

In this table the operative schemes within each attentional centration (i.e., demarcated by braces) tend to be ordered: operatives on the left side applying to schemes on their right. This is an iconic way of representing pragmatic relations holding among schemes in an attentional act. Notice further that different distinct processes that influence the task dynamics must be represented as separate schemes, cued by the situation or retrieved from memory. Without separating distinct processes within distinct schemes their distinctiveness would be lost.

Diagnostic step 2: When the totality analysis and potentially relevant schemes have been demarcated, we must address the issue of whether affective goals can, by activating this functional set of schemes, directly cause the overt or covert intended performance. Affective goals (*A*- or *B*-schemes applying their pragmatic tendencies) work either directly in an immediate manner (as could be the case in affective, motivationally immediate tasks) or via mediation by executives, in executive-driven or mediated tasks. Diagnostic step 2 must determine which of these two sorts of motivation applies to the task being analyzed. Motivationally immediate tasks typically are facilitating, and here signalic processing may suffice. Then slow associative learning may lead to automatization with practice, even without mental attention being mobilized. In executive-mediated tasks, however, symbolic processing is necessary, because such tasks often are misleading. They demand use of mental attention (attentional inhibition and *M*-activation), which brings about much faster learning. (As we discuss later in this chapter, this is *LM* learning and its automatization via *LCLM* learning.)

The use of this effortful (presymbolic or symbolic) processing is constrained by the individual's mental-attentional (*M*-) capacity limit, a capacity that develops from infancy to adolescence in a graded manner (see chapters 3 and 7). For instance, if the process symbolized in table 5.1 were to be done by a child using mental attention, complex schemes not easily acquired via associative learning should have to be synthesized and boosted with *M*-capacity. These potentially M-boosted schemes have been underlined in the stream-of-processing section of table 5.1. If we take the third attentional centration {…} of this stream, the schemes underlined are APPLY.THEN and the two operative expectancies *GRASPING* and *SHAKING*. A 9-month-old infant should have already automatized the operative GRASPING and the object-facet vis.rattle, which therefore should not need boosting from mental attention. There are only three schemes to be boosted jointly with mental attention (here symbolized by underlining the schemes). This amount of *M*-capacity is generally available to 8-month-olds (Pascual-Leone & Johnson, 2005; see chapter 3). Thus, 9-month-olds could solve the task presymbolically (creatively inventing the task solution without much prior practice).

Diagnostic step 3: To refine and clarify the schemes entertained in steps 1 and 2 a task analyst should examine again, more abstractly, the schemes found in step 1. For each of these schemes the analyst should identify them as carriers of the pragmatic functions (*obs, pros,* and *ads*) demanded by the task (i.e., the target cognitive goals, the strategy). This is done to see whether these functions are expressed in the schemes chosen in step 1: figuratives, figurative expectancies, operative transformations, operative expectancies, or executive schemes (such analysis may validate results of step 1, clarify the need for other schemes, or show redundancy in some chosen schemes).

Diagnostic step 4: This step attempts, like the previous step, to investigate further; and when necessary revise, schemes chosen in step 1. To do so one can re-examine qualitative information-processing in the intended performance. This can be done from two complementary perspectives. (1) Investigate the component-structure of the analyzed task schemes, by concretely formulating the schemes' functional component *fc* (gist and outcome expectancy of the scheme), concretely formulating their releasing component *rc* (concrete conditions that activate the scheme), and formulating concretely their effecting component *ec* (effects resulting from the scheme application). (2) If there is a doubt about the function of chosen task schemes, investigate how these schemes (particularly figurative schemes, and figurative or operative expectancies) should be classified *semiotically*. This involves analyzing schemes in terms of four semiotic functions (see chapter 4): symbolic (with detached sign and referent), signalic (with attached sign and referent), iconic (with configural similarity between sign and referent), or indexical (with no similarity but an arbitrary relation between sign and referent).

Diagnostic step 5: Complex schemes are often semantic-pragmatically nested, organized in flexible hierarchies that may change adaptively with the situation. We can investigate the chosen schemes further by determining the different *levels* of processing (different epistemic "grains" of analysis) in the concrete task where they appear as functional invariants. For instance, in table 5.1, within attentional centration three, we find three distinct necessary levels. At the most abstract we find APPLY.THEN, which during signalic processing functions as a sensorimotor executive (or complex signal). At the middle level we find the two operative expectancies, *SHAKING* and *GRASPING,* which stipulate how to implement the most abstract operative. At the lowest concrete level we have GRASPING and vis.rattle, the two concrete operative and figurative schemes that actually implement the task.

Theory of Schemes Applied: Organismic Explanation of Hierarchical Reinforcement Learning

There are two ways in psychology to formulate change: *development* proper and *learning*. Development proper brings change within the organism; for instance, change of schemes and of hidden operators or brain resources. It results from maturation patterns carried by genes (including, for mental-attention resources, its growth in infancy up to adolescence and then decay during old age). Learning (neuroplasticity) is a change within the organism resulting from life experience and training.

A dominant view in North American psychology and education emphasizes learning and often conflates development and learning to reduce the former to the latter. However, these two processes are distinct and complementary, interacting to effect growth in performance. As De Houwer, Barnes-Holmes, and Moors (2013) have emphasized, different formulations exist about learning that should be explicated (note that Tolman raised a similar point eighty years ago). We retain here the important distinction between learning as a *functionalist descriptive construct* that formulates *from an observer's perspective* "regularities" of behavioral and neurological change (i.e., what we have called functional invariants, recurrent invariances); versus the *organismic-learning* construct, aiming to explain changes in the psychological organism that *cause emergence* of these regularities. This distinction is useful, as shown by two established classifications of learning, namely: (1) *associative learning versus cognitive learning* (Holyoak & Cheng, 2011; Shanks, 2010) and (2) within associative learning, the distinction between *Pavlovian (i.e., classical) conditioning versus instrumental (i.e., operant) conditioning*.

Except Skinnerians, most researchers today see the associative-learning concept as expressing the two distinct (often coordinated) aspects we just mentioned: descriptive-functional changes in performance (i.e., behavioral/neural probabilistic regularities) versus change in the underlying organismic-causal processes, which along with external factors cause visible performance and brain changes. De Houwer et al. (2013) emphasized that the two aspects are needed and must be distinguished: regular (probabilistically invariant) changes in performance can index learning, irrespective of whether organismic-causal theories of associative or cognitive learning are correct. Currently the consensus (Gallistel & Matzel, 2013; Holyoak & Cheng, 2011; Mars et al., 2011; Shanks, 2010) is that associative and cognitive learning are complementary brain processes, jointly required for a complete account.

The second necessary classification of learning constructs is between Pavlovian (i.e., classical, respondent) conditioning versus instrumental (i.e., operant) conditioning. From the perspective of performance and adopting a functionalist descriptive viewpoint, these two sorts of learning are fully distinct. *Pavlovian conditioning* involves contingency relations between two figurative schemes (first and second stimuli), S1 and S2.*O* (e.g., the sound of the bell and the sight and taste of food—the latter experienced as reward because it carries a desired outcome *O*, i.e., feeding, in Pavlov's dogs). *Instrumental conditioning*, in contrast, involves contingency relations between an operative scheme R and a figurative scheme S1.*O* (for instance, the dog's motor act of standing on its rear legs *and* the food it gets as a reward). There is also in instrumental conditioning a later-acquired "discriminant stimulus" (to use Skinner's term): the cue S2, whose meaning is to signal that in this situation the association R-(S1.*O*) is likely to succeed. Notice that the example just given of appetitive (positive-outcome) learning is just one case. Aversive (negative-outcome) learning is another alternative case, not mentioned here for the sake of simplicity.

Note that, as Tolman (1959) emphasized, this kind of outcome learning tends to be *discriminative* in the sense that as the learner learns positive outcomes (with their contingency conditions and context), he or she also acquires, in a probabilistically contrasted fashion, learning of negative outcomes (and vice-versa) when contingency conditions fail to materialize and there is no expected outcome. Tolman called these (positive- or negative-outcome) learned connections S2-R-(S1.*O*) *expectancies,* or learned "means-end-relations" ("sign-Gestalts" or "means-end-readinesses"; Tolman, 1959).[8] Although rarely mentioned, Tolman's purposive/cognitive learning theory pioneered current reinforcement-learning theories (Klein, 1987). From this perspective, the two main descriptive forms of associative learning can be seen as two distinct forms of expectancy: the Pavlovian *figurative expectancy* [S1-(S2.*O*)] and the instrumental *operative expectancy* [S2-R-(S1.*O*)]. To enable effective performance, associative learning requires that figurative and operative schemes, together with suitable motivation (affective goals, affective schemes), be available to the learner.

As De Houwer et al. (2013) suggested, recognition of this "two-process" functional-descriptive theory of reinforcement learning (i.e., Pavlovian vs. instrumental conditioning and its corresponding organismic-causal theory) must be maintained. Indeed, such "two-process" formulation is universally admitted from a functional-descriptive perspective (Mars et al., 2011; Rescorla & Solomon, 1967; Talmi, Seymour, Dayan, & Dolan, 2008). However, from an organismic-causal perspective, the "two-process" distinction could be reduced to an organismic multiplicity of distinct causal processes common to both types of descriptive learning. Thus, Pavlovian and instrumental learning are different situation-paradigms, which have in part common organismic-causal determinants. This is supported by the finding that Pavlovian processes and instrumental processes affect one another in their manifestation (Liljeholm & O'Doherty, 2011; Rescorla & Solomon, 1967; Talmi et al., 2008).

The best-known illustration of this interaction occurs in the research paradigm called *Pavlovian-instrumental transfer* (PIT). This paradigm is achieved by training participants (animals or humans) on two distinct schemes or relationships: (1) a perceptual stimulus S1 associated with a rewarding outcome O_1; and (2) an instrumental action

R associated with a rewarding outcome O_2. These two rewarding outcomes can be distinct and have different affective goals, ag_1 versus ag_2 (symbolized in the $_1$ and $_2$ of O_1 versus O_2). After training the two schemes, participants exhibit increased instrumental responding during presentations of S1, relative to the responding found when S1 is not present and a neutral alternative stimulus S′ is present. These increases occur even when O_1 has a different affective goal than O_2. The PIT effect disappears when animals are satiated, which shows basic motivational determinants in PIT—an effect that hierarchical reinforcement theory cannot explain (Liljeholm & O'Doherty, 2011). Notice the importance of the PIT phenomenon. It shows empirically that instrumental and Pavlovian conditioning share the same organismic processes. TCO can explain why.

Metasubjective (TCO) Model for the PIT Effect

Unlike the S-R or S-S associations of reinforcement learning, constructivist schemes are self-propelling units applying to codetermine performance under minimal conditions of activation: A assimilates B, when B is construed as part of or related to A. This is an asymmetric "psycho-logical" relation between A and B, if they do not assimilate one another (Piaget's *reciprocal assimilation* or coordination), producing a schema or *L-structure* (a chunk). This mutual assimilation principle has a consequence: when a situation activates multiple schemes (as often happens), all activated compatible schemes tend to apply together to overdetermine performance (*SOP*). If they are not compatible, there is a competitive conflict and the stronger (most activated) *cluster of compatible schemes* will apply, suppressing noncompatible clusters. Affective schemes (either appetitive—affectively positive—or aversive—affectively negative) are also part of the SOP competition. This TCO principle explains the PIT (Pavlovian instrumental transfer) and other reinforcement-learning phenomena (e.g., latent learning, outcome selective transfer, conditioned inhibition).

To explain PIT effects, the needed schemes come from prior training: **(tr1)** The first training with S1 (scheme *S1) produces the scheme *[$S1 \rightarrow O_1.\ ag_1$]. In our notation star * indicates that this is a figurative scheme, and italics indicate an expectancy. Finally, square brackets with a sequence-forcing marker [→] indicate the expected consequence brought by scheme *S1; that is, outcome O_1 (serving affective goal ag_1) follows S1. In our formulas the symbol "→" indicates the act of *forcing* into actuality or bringing about O_1. **(tr2)** The second training produces R_1 with its operative (*OP*) expectancy *OP*[$R_1 \rightarrow O_2.\ ag_2$]. This second training also produces a discriminant stimulus for this *OP* expectancy, that is, the stimulus S2 (scheme *S2) that incorporates aspects of the context where the scheme in question can work (*S2cxt). The performance PIT results from the self-propelling (*SOP*) concurrent application of all these schemes. This is symbolized in formula **f1**:

$$R_2\ [\#OP[S2cxt\!: R_1 \rightarrow O_2.\ ag_2],\ \#{*}[S1 \rightarrow O_1.\ ag_1],\ {*}S2cxt,\ {*}S1] \Rightarrow PIT \tag{f1}$$

That is, when *S1 and perhaps *S2cxt are present in the situation (and the animal is suitably hungry), scheme Response R_2 applies, because it has been mobilized by the two parameters (or necessary conditions #), which express the two learned schemes: relevant figurative expectancy (*[*S1*→ …) and relevant operative expectancy (*OP*[*S2cxt:* $R_1 \rightarrow 1$ …). The response application R_2 produces (➔) the performance PIT. Notice that ➔ stands for the *SOP principle* (which causes R_2). Thus, all available compatible schemes (in this example, *S2cxt, *S1, ag_2, ag_1, and the two expectancies) will summate (in a dynamic synthesis) their strength, combining compatible characteristics to cause the result of R_2. There is no misleading scheme in this situation, and training is provided until participants have learned all schemes. Thus, this is simple learning based on signalic (i.e., sensorimotor) processing, which after slow habit learning yields fast and effortless performance. No symbolic mental attention is needed; rats or babies of about 8 months with a mental attention of $Me = 3$ (see chapter 3) could learn and perform this paradigm. Content-structural learning, however, may occur at very different levels of processing complexity. Consider our theory's classification of this complexity.

Developmental Levels of Affective-and-Cognitive Processing Complexity: *A, C, LC, LM, LCLM*

Affective (*A*) Schemes

We distinguish the *A*-operator from *A*-schemes as follows: *A*-operator is a general affective booster, a quantitative potency or power. *A*-schemes, in contrast, are specific sorts of affects, qualitatively distinct, which *A*-operator can boost as they are activated by the external or internal context. *A*-schemes implicitly or explicitly produce affective goals (*ag*) in tasks, which influence choice of strategies, planting seeds for *motives*. They also actively boost (*A*-boosting) relevant cognitive schemes active (or inactive) in the situation. *A*-boosting of cognitive schemes comes earlier and is possibly weaker than the *M*-boosting (mental attention) that cognitive schemes may receive under the direction of executive schemes. Cognitive schemes mediate information about world, experience, self, own or Other's capabilities, and so forth. They emerge in interaction with *A*-schemes whose affective goals boost or interfere with these cognitive schemes (including executive schemes). Thus *A*-processing (affective goals and their contextual cues) is a determinant of the *cue-function* (salience, induced activation) of experiential-content schemes (*C*-processing) and schemes at other higher levels (executives and knowledge/parameter schemas). Above the primal *A*-level are cognitive schemes, often organized in flexible levels of control (heterarchies) that work together by overdetermination. Cognitive schemes emerge developmentally as probabilistic functional regularities of situated experience or behavior.

Constructivist Learning and Schemes

We now discuss key levels of complexity from a causal-organismic perspective, classified by determinants that may cause their emergence (starting from local and concrete schemes). This presentation elaborates on Pascual-Leone and Goodman (1979), who attempted to formulate principles of associative-and-cognitive learning that result from dynamic interactions among features, habit learning, and inferential processes. These levels of complexity are causal-organismic but congruent with explanations found in current learning theories (Mars et al., 2011; Shanks, 2010). The learning principles are empirically grounded functional distinctions within our theory, which could help to explicate findings and heterarchies found in current reinforcement-learning theory, as illustrated above.

However, before discussing different basic forms of learning, we should clarify how we understand the very complex notion of *content*, which to us appears as an encoded initial expression (interpretation) of what has been called matter. Matter is Reality prior to any interpretation. Our sense of content corresponds to what neuroscience may call the input and its initial processing, first occurring in primary brain areas. It also relates, we think, to the most concrete substratum (the relational resistances) of diverse content domains in psychology and in our culture; the basic differential concrete substratum for (qualitative or quantitative) sensorial-perceptual and action processing of any sort. These are the initial differential constraints (resistances of all kinds) imposed by Reality to reflective abstraction and elaboration in any content domain (visual, auditory, motor, spatial, verbal/linguistic, social, or causal—dependency relations that predict change). These domains (undetermined in number) emerge when our reflective abstraction (thinking and learning) applies to various sorts of content for various kinds of praxis. For instance, Demetriou and Spanoudis (2018) demarcated some six to eight distinct domains (called *specialized capacity systems*) especially important for the study of intelligence, although they are not the only ones. We agree with the importance of these differentiated capacity domains but omit their discussion in this book. For us, they result from application of hidden operators and principles, reflective abstraction, and so forth on schemes generated by different sorts of agency/praxis. Our book is exclusively concerned with causal (and neuropsychological) processes of the working mind's context-sensitive strategies for agency/praxis.

Content Learning: *C*-Schemes As suggested, content (*C*-) for us is what neuroscience may call the received input and its immediate processing in the primary brain areas and limbic system. *C*-schemes are initial mediators of the content; they are the basic concrete substratum of experience and processing. *C* learning is the first cognitive learning level. It corresponds to what Piaget, Wallon, Werner, or J. J. Gibson may have called *local* (bottom-up) scheme *differentiation*. It also relates to what Piaget called accommodation of schemes to "physical experience," which causes *empirical abstraction*. These schemes represent or embody local functional invariants, that is, probabilistically recurrent and situated context-specific features or moves, concrete figurative or operative patterns. *C*-schemes, the products of *C* learning, express innate organismic (neurological) determinations for sensorial, simple perceptual, and simple motor processes and express local experiential resistances, driven by sensorimotor neurological readiness. According to Piaget and others, when experience violates expectations built into a scheme's prescribed invariant (i.e., violates regularities or lawfulness that this scheme represents) the scheme adapts or accommodates. This is what in chapters 1 and 3 we have called secondary or Piaget's accommodation; in it, schemes modify themselves when failing to assimilate experience, to bring the represented invariants in closer agreement with Reality resistances.

There is, however, another complementary sort of accommodation: primary or Gibson's accommodation (which he called *differentiation learning*). This is the neurological internalization of invariants via bottom-up neural adaptation or coordination (to encountered resistances) of relevant circuits. This primary accommodation may become incorporated into more complex circuits/networks and may enter the psychological organism (appearing as *C*- or *LC*-schemes that eventually could reach consciousness). During this accommodation process, the *fc, rc,* and/or *ec* of schemes change their characteristics to increase adequacy and viability of the schemes vis-à-vis local resistances of the attended-to reality/Reality. Functional aspects, conditions, or effects changed during *C* learning may themselves be psychological schemes, but they often constitute physiological (sensorial, motor, or associative) central processes never represented in the psychological organism, as explained in chapter 1 (this would be a primary accommodation).

For us, any psychological organism or metasubject includes regulations (hidden operators and principles) plus the repertoire of cognitive, affective, personal, or action schemes. Whenever accommodation change consists in coordinating two or more preexistent schemes (an instance of Piaget's secondary accommodation), *C* learning appears as an *asymmetric relation*. A main scheme h_i comes to *assimilate* (incorporate, making associative bonds with) another scheme h_j, which thus becomes subordinate to

h_i (h_i changing into $h_{i[j]}$). This change is likely to occur when this contingency repeats, and the change renders more efficient the application of h_i. This case corresponds, using a different notation, to both S1-S2.O_i learning (Pavlovian conditioning) and S1-R-S2.O_i learning (instrumental conditioning). In the second case, when C learning is not yet psychological, just a purely physiological process, that is, not yet present in the brain's psychological organization, the modified scheme h_i (i.e., $h_{i[j]}$) may come to embody conditions or effects that are *truly novel* for the metasubject. This is the intuition behind Gibson's concept of *differentiation* (practice without feedback, like in repeated wine tasting, can create possible discriminations and judgements that were previously inaccessible). It also helps to understand the centrality of trial-and-error learning, as well as practical learning (learning with practice and often without feedback), products of a purely experiential (not mentally reflective) know-how.

Our purpose in this chapter is not to review current work on learning or have proven rules for each level of learning. We wish to differentiate clearly *neuroscientific* (epistemo-ontological) *levels of learning*, formulating plausible differential rules (hypotheses), and show how change from associative learning to constructivist (cognitive-inferential) learning is a graded transition. The graded transition is caused by changes in the differential balance of organismic determinants (e.g., hidden mental-attentional operators), which all sorts/levels of learning share (Pascual-Leone, 2012a; see chapters 1 to 3). Learning is a constructivist *internalization*—a durable acquisition by the brain of repetitive, replicable patterns (external or mental) of performance constituents, whether qualitative or quantitative. These repeatable patterns constitute probabilistic functional invariants that can facilitate learners' "purposeful" activities. The various compatible levels of learning that we now discuss are complementary ways of pursuing internalization.

There are three conditions jointly needed for C learning to take place. **(C1)** First is a *high assimilatory strength* (i.e., a high degree of activation and propensity to apply; Piaget's concept of assimilation) of the main scheme h_i. This high activation and propensity to apply may be due to activated affective goals (A-schemes) or to sensorial salience, motor readiness, and so on. **(C2)** Second is a *lawful relation of coactivation* between the main scheme h_i and the subordinate scheme h_j (or, if h_j is not yet formed, its purely physiological processes that h_i may incorporate). Coactivation occurs between two or more schemes when their activation is physiologically interconnected, tending to occur simultaneously or in immediate succession, as a probabilistic invariant. **(C3)** Third is a *lawful relation of functional service that relates* h_i *with* h_j (or with purely physiological processes), meaning that within a given context the same affective/cognitive goals are served by both schemes. When application of h_j invariantly facilitates (or at least does not hinder) application of h_i, the first has a relation of functional service with the second. When such relation is mutual, we talk of a *cofunctional relation*.

Logical (*L*) Learning The *L* stands for *Logical* in the psycho-*logical* sense of embodying functional, relational structures (i.e., schemes, schemas) that emerge as generic, probabilistic invariants from one or other kind of external or mental experience. These emerging *L*-structures express some experiential (external or mental) functional characteristics abstracted as thinking proceeds. Notice that this concept of functional structure (i.e., scheme, schema) is very different from the quasi-architectural, passive concept of structure often found in cognitive psychology. This neo-Piagetian concept of functional structure, our *L*-structure, is expressing or abstracting an active way of functioning. As R. Miller (2011, p. 410) put it: "the term 'functional-structure' could be replaced by 'structure/way/form of functioning.'" It embodies coordinations or integrations of *C*-schemes or *L*-structures into more encompassing structures, often seen as more-or-less-complex packages of interrelated associative-learning schemas. Notice that *L learning* is like a recursive function: it can apply to coordinate its own products. The resulting *L*-structures/schemas are complex, perhaps superordinate, schemes that epistemically reflect integrated patterns of coordination found in agency/praxis across compatible schemes. Recurrent simultaneous or successive patterns of coactivation existing among schemes in the repertoire (i.e., long-term memory) are abstracted into *L*-structures when they recur sufficiently to generate probabilistic invariants in performance. Piaget explained this case of learning as *reciprocal assimilation* or *coordination* among schemes involved.

The *rc* of an *L*-structure has as conditions "copies" of releasing components in its different subordinate scheme constituents, and perhaps also patterns of coactivation among them. The *ec* of an *L*-structure is the various compatible and coordinated effects found among its scheme constituents when they apply. The *fc* should have as a functional totality its overall script (e.g., the summarized gist of a musical piece or a play, as intuitively felt by a working musician or writer). With the help of *L*-structures, the metasubject may achieve an internal *functional model* of schemes applicable to performance in frequent types of contexts and situations, progressively reaching a situated functional totality. *L*-structuring processes explain developmental emergence of cognitive-psychology constructs such as semantic networks, representations of distal objects (our *ob*-structures), procedural systems or subroutines (our *pro* complex schemes or structures), knowledge structures (our *ad*- and *ob*-structures of all levels of reflective abstraction), control processes (task and organismic-resource executives), complex scripts or operative/procedural models of performance, and so forth.

There are four necessary conditions for *L* learning. **(L1)** First is a *high assimilatory strength* of every one of the constituent schemes involved in the structure to be learned. **(L2)** Second is a *nearly equal assimilatory strength* among the constituent schemes involved. **(L3)** There must be a *lawful relation of coactivation* among the constituent schemes. **(L4)** Finally, an optional relation that seems to facilitate *L* learning (and may be necessary for *LM* learning, see below) is *a lawful mutual relation of functional service* among or between schemes involved. Thus, *L* learning is facilitated when schemes involved are cofunctional, and this relation is mutual among the schemes involved, that is, it is functionally *symmetric* (in contrast with *C* learning). Consider, as example, health food, such as ripe avocados, to replace butter on your bread. The beginner is shown how to open the avocado and how to use a knife to get some ripe flesh to spread on bread. If the person likes it, after few trials his or her feeding schemes will get changed: the scheme "eating bread with butter" is replaced by "eating bread with avocado flesh," and the expectancy of taste is replaced by the creamy taste and flavor of avocado. Soon this scheme h_i "eating bread with avocado flesh" strongly coordinates with the sensorimotor scheme h_j "sight of avocado and its flesh." Coordination of these two schemes is an instance of *L* learning, "reciprocal/mutual assimilation." Thereafter, when the person feels like having a snack, and the operative h_i (eat bread with avocado) becomes activated, he or she experientially anticipates taste and flavor of avocado flesh; conversely, when the person sees avocado or its flesh there is a temptation to eat it, which people with addiction may find difficult to avoid.

There are at least three compatible ways of generating *L* learning. **(L-learn1)** Overlearning/automatization of *C*-schemes leads to habituation and automatized patterning, cause of *L*-structures, as Tolman (1959) and other classic learning theoreticians (Harlow, 1959; Hebb, 1949/1961) pointed out, using different terminologies. We call this form of learning *LC learning*, because in it an *L*-operator (or logical/structural-learning process) applies on *C*-schemes. **(L-learn2)** When a set of cofunctional and often coactivated schemes is repeatedly boosted in activation with mental attention (i.e., our *M*-capacity resource or *M*-operator) the postulates **L1** to **L3** or **L4** are fulfilled, and they generate *L*-structures much faster. We call this form of learning *LM learning*, because it results from *L* applying onto *M*-processes. **(L-learn3)** Finally, a set of cofunctional and coactivated schemes may be strongly boosted in activation by affective (*A*-) schemes, that is, affective goals/motives. Such *A*-boosting could lead to overlearning, giving origin to an *L*-structure via *LA learning*. This case is more common in emotionally exceptional circumstances (e.g., personal crises, car accidents) or in people with difficult lives, great affective sensitivity, or emotional problems. We shall not discuss *LA* learning further but elaborate on the other forms of *L* learning.

Logical content (*LC*) learning (L-learn 1): This is *LC* learning or *L*-structuring via overlearning. If someone encounters many times the situations that coactivate a cluster of cofunctional schemes, which bear on affective goals, conditions will be set for *C* learning (as prescribed by **C1**, **C2**, and **C3**). Such learning occurs much without conscious control, particularly when this contextually grounded invariant is too complex to be consciously analyzed (e.g., Bach's musical style for a music lover; or the many cues helping a wood cutter to find his way through a forest, without trails, on the way to a certain cottage; or the know-how coming from much book writing or business practice). Repeated exposure to the same practice will tend to make coordination of *C*- and *LC*-schemes progressively stronger, causing emergence of probabilistically invariant patterns, which leads to *LC* learning.[9]

There are four important characteristics of *LC* learning. **(LC1)** Learning is quite slow and incremental. **(LC2)** The learning process is often implicit or tacit, that is, may take place latently and without mental effort. The resulting *LC*-structures correspond to what is often called *chunks,* but these are *effortless chunks*. **(LC3)** Because of the packaged (or associative-compound) nature of the *LC*-structure, when a package as a whole is relevant for a task, its activation will tend to become fast and effortless (because habit-driven), and its subjective (phenomenal) experience will be holistic, relational, and Gestalt-like. **(LC4)** Interference occurs whenever constituent substructures of an *LC*-package must be separately activated, because other schemes from this package are inconvenient for the task at hand. Indeed, constituent schemes/schemas of one *LC*-package may be functionally interlocked with unwanted contextual or context-driven schemes (cognitive or affective), connected to this *LC*-package during some learning process. As a result, *LC*-structures cannot be transferred easily across contexts or situations, because interference occurs easily. These structures make up much of the experiential knowledge or empirical experience of many individuals.

Tolman (1959) was first to point out that *LC* structural learning (called associative learning) occurs more easily under conditions of free-time repetition and low-to-average affective arousal. That is: to maximize *LC* learning it is better to satisfy in advance the subject's needs. Tolman worked with rats, and cognitive maps of rats are more likely to be developed when they are placed in a maze when well fed and anxiety free (analogically this is also true in humans). This makes sense, because under emotional disarray or stress not all schemes involved may be equally activated (violating postulates **L1** and **L2** given above), making *LC* learning more difficult.

***L*-structuring via *M*-boosting, or *LM* learning (L-learn 2):** Mental-attentional energy or effortful activation (i.e., *M*-capacity allocation, or working-memory's attentional centration) can produce rapid *L* learning when applied onto a set of cofunctional and coactivated schemes. This is because *M*-energy can boost the level of activation of schemes to reach a maximum level, which immediately brings all activated cofunctional schemes to a high and equal level of coactivation.[10] Such state of affairs fulfills postulates **L1**, **L2**, **L3**, and **L4** given above, producing rapid *L*-structuring. The time duration of *M-allocation* (or attentional *centrations*) required to cause such effect is a parameter in need of experimental investigation using *LM* learning paradigms. In our postulates of *LM* learning, we hypothetically estimate such time duration "qualitatively" in terms of the number of protracted *M*-centrations required to cause *L*-structuring of two schemes (more of them may take longer). We define a *protracted M-centration* as being a self-paced effortful mental-processing step.

We describe ten processing rules for *LM* learning. **(LM1)** If two cofunctional schemes are boosted by *M* during two (or three) successive and protracted *M*-centrations, they will form a superordinate *L*-structure that embodies or reflects them in their functional coordination. The learning concept of a very effective rehearsal (when rehearsal is not construed necessarily as verbal) is congruent with this principle. This *LM*-structure can then functionally replace the two original schemes in mental processing within the required *M*-centration(s), lowering the *M*-demand. That is, the needed expenditure of effort or *M*-energy will be reduced from two units to one. This postulate expresses the principle of *effortful chunking*. **(LM2)** The **LM1** process cannot be applied at once to more than two schemes, but it can be reapplied recursively until all schemes involved have been incorporated into the *LM*-structure, provided that at each two-schemes step there is a consolidation-process time that is cumulative. **(LM3)** *LM*-structures formed by the process **LM1** could be ephemeral unless they enter a consolidation process. Consolidation requires some amount of effortful re-attention to the formed *LM*-structure. In the context of process-task analysis, we have found that this consolidation process must be equal to one or more effortful and protracted *M*-centrations to have stable *LM*-structures. **(LM4)** The *LM* process may also occur with a single scheme or structure. In that case, the *LM* process may strengthen the structure formed (or create "replicas" of the scheme/structure in question, which increases its assimilatory strength and prevents forgetting).

(LM5) The ease of *LM* learning, or even its possibility, depends on the *M*-capacity available to the subject, relative to *M*-demand of the *LM*-structure in question (indexed by number of distinct separate schemes to be effortfully coordinated). When *M*-demand is small, relative to the subject's *M*-capacity, *LM* learning may be all-or-none or very fast. Thus, vis-à-vis *LM* learning there is a *trade-off* between the subject's *M*-capacity and the task or item's *M*-demand, which determines meta-subjective item/task difficulty. Subjects will tend to pass items when *M*-capacity is equal to or larger than *M*-demand, and tend to fail otherwise (Pascual-Leone & Baillargeon, 1994).

(LM6) This form of learning brings awareness of mental effort (James, 1892/1961; Kahneman, 1973) and tends to use conscious learning strategies with executive schemes monitoring it. Once learned, the resulting *LM*-schema will still need mental effort (i.e., *M*-boosting and/or *I*-interruption) to be fully activated and apply. However, because the *LM*-schema already has in it the appropriate interrelated constituent schemes, strategic application of this *LM*-schema will tend to be errorless and relatively fast, because selection by executives of the task-relevant scheme constituents is no longer needed.

(LM7) Figurative *LM*-structures (and their operative counterpart, complex operatives) are functionally autonomous, that is, discrete and usable across contexts with little interference from other schemes. Sequences of *M*-operations monitored by executive schemes are necessary to constitute and to apply flexible hierarchies of *LM*-structures and complex operatives. For instance, symbolic/mental executives require *LM* learning to emerge. This contrasts with signalic/sensorimotor executives that can be produced by *LC* learning, with the help of human mediation. **(LM8)** Interference with contextual schemes is minimized within *LM*-structures (and within complex *LM*-operatives). Indeed, because only *M*-boosted schemes are coordinated within *LM*-schemes/structures, and other nonboosted contextual schemes are automatically interrupted or inhibited, the latter are excluded from these *LM*-schemes. Thus, this sort of learning creates flexible and mobile schemes relatively robust to interference. High-cognition rational processes, responsible for the good problem solving and judgment in adults (what Piaget called "formal" mental operational structures) emerge in this manner, via *LM* learning. Piaget called *logico-mathematical experience* this sort of learning but failed to formulate the causal processes. With practice *LM* processes become overlearned and in part automatized.

Automatization of *LM*-structures or *LCLM* learning: Because they are automatized (overlearned), these *LM*-structures no longer need mental attention to be activated and applied. They do not involve mental effort (*M, I*). This level of learning allows emergence of mental operative models and refined cognitive maps, within high cognition. It requires two further processing rules. **(LM9)** Our three main types of learning (i.e., *C, LC,* and *LM* learning) are not only mutually compatible (each can apply on the products of the others), but they are often developmentally intertwined. They function as constructive operators of diverse types, which apply on each other recursively to generate hybrids such as *LC, LA, LCA, LMCA, LMLC, LCLM,* and so on. (Each resource-operator here applies to those on its right.) *LCLM* marks a fourth level of learning. As mentioned, it consists in automatization (*LC*) of *LM*-schemas/structures, supported by diverse scheme-learning types (*C, LC, LCA, A,* etc.). Because they are automatized, *LCLM*-schemas no longer have to be boosted by *M*-power to apply; they are now effortless. This automatization may include the executive processes (*E*-schemes) that planned and regulated the *M*-operations now turned into *LM*-structures. Such process can form complex automatized high-cognitive *LCLM* functional totalities. This is a fourth level of processing because it enables peak performance of the working mind. This produces an *encompassing reason* that can take a cognitive "distancing" (Sigel, 1993; Werner & Kaplan, 1984) or *cognitive decoupling* (Evans & Stanovich, 2013) of high *LM*- or *LCLM*-schemes from more concrete, lower-level schemes that semiotically/symbolically relate (but are not essential) to the *LCLM* functional totality in question. This is needed to enable a distinct re-representation of equivalent meanings at different orders of relation (different levels of processing).

The constructive levels of processing expressed by our heterarchy of learning and scheme types (*C, LC, LM, LCLM,* etc., with their dynamic combinations) explain with organismic causal mechanisms currently recognized, important modes or ways of thinking (Evans & Stanovich, 2013; Kahneman, 2011). The types (or "systems") of processing, Type 1 and Type 2, are often characterized as *automatic* (*LC* or *LCLM* learned) versus *controlled* (i.e., *attentionally effortful* and executive driven). Evans and Stanovich (2013) do not formulate these two types as polar dichotomies, but rather as a sort of functional-structural continuum—two modes of processing that can be combined gradually as demanded by current cognitive goals. This useful cognitive characterization is a descriptive model, in need of a matching organismic-causal model to explain its causal determinations. The constructivist-learning theory just summarized, and explicated further in the next two chapters, generates organismic causal models of task processing consistent with the descriptions of Evans and Stanovich and of Kahneman.

(LM10) Because *LM* learning requires use of a mental attention, which increases with chronological age in children (Pascual-Leone, 1970; see chapters 1, 3, and 7), we should find as many distinct sorts of *LM* learning as there are levels of *M*-capacity. Notice further that the individual's obtained *M*-level is a combination of his or her age group *M*-capacity limit (i.e., the age-group's *reserve or structural M*—Pascual-Leone, 1970) and the individual's own ordinary or common *M*-capacity level of functioning (the individual's *functional M*). The various sorts of *LM* learning (and their resulting schemes/schemas) differ in the *M*-demand of tasks that can be solved with them (this *M*-demand is estimated via metasubjective task analysis). The developmental *M*-capacity/*M*-demand trade-off principle (mentioned in **LM5** and **LM10**) suggests that mental complexity (*M*-level) of the *LM* learning accessible to a subject changes with his or her developmental stage because of developmental growth in the *M*-reserve (e.g., Arsalidou et al., 2010; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Johnson, 2005). These developmental levels of *LM* learning correspond to substages of cognitive development, consistent with those of Piaget or Case, among others (see chapters 3 and 7). Such modeling of *M*-levels offers a quantification method for other current cognitive-complexity theories (e.g., the Type 1 vs. Type 2 modes of thinking), which lack developmental quantification and methods of process/task analysis.

LM-structures cannot emerge in an individual unless he or she has, in addition to the requisite *M*-capacity level, executive schemes needed to organize the complex processing required. Suitable task-relevant executive schemes are necessary to monitor sequential *LM* learning. These sequential executives are particularly needed because of scarcity: the limited power of subjects' *M*-capacity, relative to the complexity of high cognition. When *M*-capacity and good-enough executives are available, sequential *LM*-processes can be formed rapidly (which tend to incorporate few associative bonds with unwanted schemes). The result is relatively independent abstract structures (*LM*-, *LCLM*-) that remain detached from context and unwanted details; thus keeping a decoupling or "distancing" from other related schemes. This option, made possible by executive control, is very important in misleading situations (see chapters 6 to 8). Finally, because *LM* learning is recursive and can be applied repeatedly to create schemas of schemas of schemes, hierarchical reinforcement learning (Mars et al., 2011) can be reinterpreted as a by-product of schemes' constructivist learning in the organism.

Types of Reflective Abstraction That Schemes and *C, LC, LM* Learning Generate

Abstraction is the process of extracting from experience generic aspects (functional invariants) possibly useful for future acts of agency and praxis. So defined, abstraction is at the heart of learning. Abstractions that are not arbitrary are informed by, or express (epistemically reflect—epireflect), contents and relational characteristics of actual experience, indexing resistances encountered by the knower. Piaget called this epireflective abstraction *reflective abstraction* (see chapters 1 and 2).

There are three complementary senses or modes of reflective abstraction, which correspond to three dimensions of variation (and dialectical moments). The three modes are mutually compatible, complementary, and often interacting. Together, they characterize the working mind's processing complexity. These three modes of reflective abstraction are listed in table 5.2. This table also gives hypotheses about key regions in the cortex that, along with their subcortical interconnections, are important for the mode of abstraction in question. We discuss them successively.

Table 5.2
Modes of reflective abstraction and hypothesized key cortical regions

Modes of Reflective Abstraction			Brain Projection
Reductive (or Symbolic) Abstraction	Conceptual: Logological (or *LM*-structures)	↔	Left Hemisphere
	Mereological	↔	Left and Right Hemisphere
	Experiential: Infralogical (or *LC*-structures)	↔	Right Hemisphere
Constructive Abstraction	Intellectual	↔	Quaternary Area
	Intellective	↔	Quaternary and Tertiary Areas
	Intelligent Perceptual	↔	Tertiary and Secondary Areas
	Sensory Perceptual	↔	Secondary and Primary Areas
Causal Abstraction	Executive	↔	Prefrontal Lobes
	Operative	↔	Frontal Lobes
	Figurative	↔	Parietal, Temporal, and Occipital Lobes

Reductive Abstraction: High/Symbolic versus Low/Signalic

Empiricist thinkers often see abstraction as a construction of informational units (i.e., schemes and *L*-structures) that ignore or reduce task-irrelevant aspects of the experience and retain only relevant aspects. The more aspects of experience excluded from abstraction, the higher the level of reductive abstraction. Piaget called *logical abstraction* the high-reduction levels of abstraction, in which a selected-few relational invariants extracted from experience are retained (and many are omitted). This is the mode of high abstraction often identified with high conceptual processing. This *high-reductive abstraction* could also be called symbolic, because the symbolic function (not just signals) is needed to accomplish such abstraction form (which demands *M*-processing and *LM* learning). This sort of high-reductive abstraction comes in three distinct forms. One is pure *logological* abstraction, named to highlight that language emerges as a symbolic vehicle for communication by using this sort of high-reduction abstraction. Another form of high-abstraction is not directed to language but to explicate functionally invariant, generic aspects of objects, procedures, and adjunct information abstracted from experience; via visuospatial, temporal, causal, and more or less generic representations (experiential cognitive maps and intuitive models). This is what has been called *mereological processes* (from the Greek *meros* "part"—part-whole relations within objects and physical entities; Mieville & Vernant, 1996). By using logological structures adapted to stand for and represent experiential objects, procedures, and so forth, the mereological processes internalize (in more or less generic ways—e.g., object-centered models, cognitive maps) useful functional experiential invariants of objects and situations.

Finally, Piaget called *infralogical abstraction* (or empirical experience) the low-level, *low-reductive abstraction* that may be called *experiential processing* (if we exclude high-abstraction mereological schemas, which are also experiential but complex). Here, many particulars from concrete experience are internalized into scheme(s) or *L*-structure(s). This sort of experiential abstraction could be done by *LC* learning. Principles of learning discussed above make clear that reductive abstraction varies in a graded manner, with its logological or mereological poles demanding both *M*-processing and *LM* learning, and its infralogical pole demanding less of both *M*-processing and *LM* learning.

Table 5.2 suggests that deliberate, perhaps symbolic, conceptual/logological or complex mereological processes (involving mental attention*, LM*-structures, and complex schemes needed in misleading situations) tend to be stored preferentially in the brain's left hemisphere, in right-handed people. In contrast, automatic and often signalic, experiential/infralogical/mereological processes (involving automatic-perceptual attention*, LC*-structures, and usually automatized operative schemes—efficient in facilitating situations) tend to be located in the right hemisphere of right-handed people (Arsalidou et al., 2018; Pascual-Leone, 1989).

Constructive Abstraction

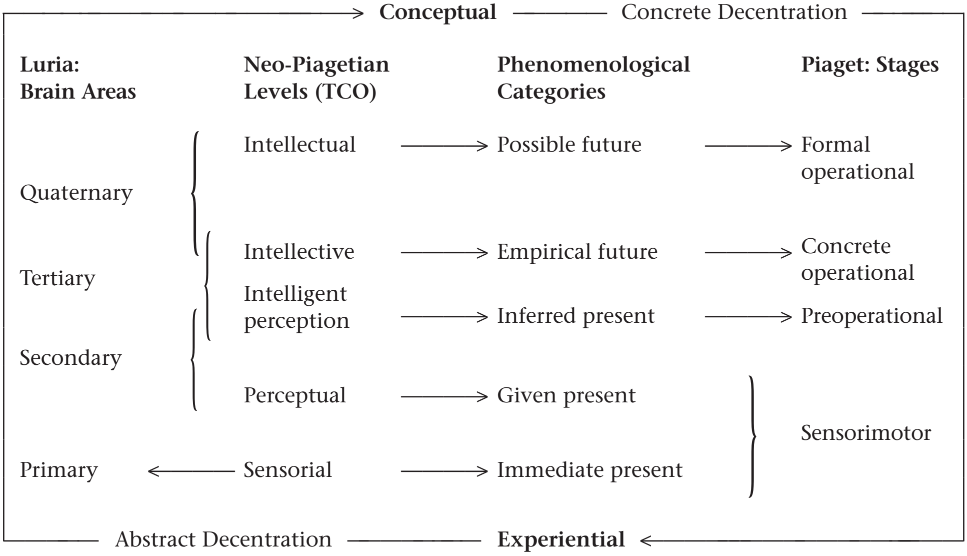
Constructive abstraction internalizes functional regularities that may have a wide scope of relevant experiences: complex probabilistic functional "invariants" (various levels of resistances, or ways for coping with them) abstracted across types of situations (across space and time, perhaps across conceptualizations). Whereas degree of reduction is a key mark of reductive abstraction, scope of referential domain is the keynote of constructive abstraction. The *scope of the referential domain* of a scheme is the set of different sorts or types of referent from which the scheme/structure in question has been derived as a functional invariant.

Congruently with distinctions in the literature under different names, we distinguish four modes or levels of constructive abstraction **(CA)**: **(CA1)** *sensorial-perceptual processes* deal with easy information, schemes activated in the here and now (i.e., the *immediate present*) or the very-close present-related events (practically, the "saliently given" present). This is basically the processing level that Piaget called *sensorimotor stage*, found in children and also in adults. **(CA2)** *Intelligent perception* deals with information closely related or linked to present events but stored in long-term memory (the *inferred present*).

This is basically the level of Piaget's *pre-operational stage*. **(CA3)** *Intellection* (intellective processes) deals with information bearing on both the present and the future. These are schemes or structures activated either by the present situation or by mediational processes (the *empirically possible,* remembered or expected present of executive and action schemes; Edelman, 1989) stored in the repertoire. Piaget's *concrete-operational stage* expresses this level of processing. **(CA4)** Finally, *reason or intellectual processes* deal with all sorts of events (present, future, and *formally possible*—noncontradictory). These are schemes of high-cognitive levels that may encompass or synthesize experiential-and-conceptual results from schemes with diverse modes and modalities of processing.

Table 5.3 summarizes these levels of constructive abstraction and shows which their key cortical regions may be, relative to the classic category modes or levels of processing: *primary* (initial areas of cortical reception/afference and of efference), *secondary* (locally coordinated, domain-specific, receptor or effector areas), *tertiary* (regional multimodal areas of cortical processing synthesizing information across domains, integrating some of their specific sorts of processing), or *quaternary* (also called *high tertiary,* the highest and most comprehensive multimodal areas, no longer specific).[11] It should be clear that, broadly speaking, as brain areas progress from primary to quaternary, the *M*-demand (*M*-levels) of the corresponding *LM*- and *LCLM*-schemes and structures

Table 5.3
Levels of constructive abstraction



→ **Conceptual** — Concrete Decentration

Luria: Brain Areas	**Neo-Piagetian Levels (TCO)**	**Phenomenological Categories**	**Piaget: Stages**
Quaternary	Intellectual	Possible future	Formal operational
Tertiary	Intellective	Empirical future	Concrete operational
Secondary	Intelligent perception	Inferred present	Preoperational
	Perceptual	Given present	Sensorimotor
Primary	Sensorial	Immediate present	

Abstract Decentration — **Experiential** ←

tends to increase, up to the maximum *M*-capacity that the age group in question can afford. Thus, initiation of Piagetian stages may be related (in its stage-characteristic processes) to these brain areas, without of course excluding lower areas. Note that in table 5.3 levels of processing are assumed to be nested from low to high, in the sense that higher (more conceptual) processes are controlling, but largely founded on, the lower (more experiential) levels. Higher levels are functionally built and dependent on lower ones. Another implication of this model is that, relative to the age group of normal children, the higher a brain processing level (from primary to quaternary in table 5.3), the more errors in thinking/cognition, within misleading situations, could be related to the *M*-capacity limitation and executive deficiencies. When processing levels increase, task demands with regard to *M*-level, *LM* learning, and executive know-how should also increase, unless processes have already been automatized via *LCLM* learning.

Notice further that levels of processing suggested in table 5.3 result from dynamic/dialectical interactions among the three forms of abstraction indicated in table 5.2: reductive abstraction, causal abstraction, and constructive abstraction. These three forms of abstraction, in their intertwining, co-construct the working mind (Vygotsky's gradient from low cognition to high cognition).

Causal Abstraction

This is abstraction of functional invariants related to *change* (i.e., what leads to what; figurative or operative expectancies), as well as prediction of consequences when the needed antecedents are given. If reduction and scope are, respectively, the characteristic markers of reductive and constructive abstraction, the marker of causal abstraction is *control and prediction of change*. This modal dimension can be grasped (at least in complex situations) only when temporal sequences of action and change are coordinated with the situation and its changing spatial arrangements. Three sorts of schemes play basic, distinct functions in this mode of processing: figuratives (configural representations, state and process descriptors like our parameters), operatives (blueprints for and dynamic representations of action), and executive processes (encompassing processes of coordination). Causal learning can recursively apply at any level of constructed complexity as it dialectically coordinates with reductive- and constructive-abstraction processes to synthesize functional invariants that can control, predict, and/or postdict the change. Cognitive psychologists have recognized existence of causal abstractions but have usually failed to see this mode of processing as epistemically distinct from the other two modes, even though reduction and scope have very different processual characteristics than control of change. Indeed, control of change involves critically constructive/reductive abstraction of temporal sequencing—related to what we describe as the *T* (time) hidden operator in the next chapter.