9 Process and Mental Task Analysis: Methods and Examples

We illustrate specific methods of metasubjective task analysis (MTA). Two distinct complementary methods are outlined: the sequential, or step, MTA (an ascendent, abductive way) and the executive, or dimensional, MTA (a descendent or deductive way). To delineate these methods, we give a list of eight guidepoints. For further illustration, four very different (and age-distinct) examples of task process are analyzed in detail. We then show how these two ascending/abductive versus descendent/deductive methods are intertwined in practice and can be combined in theory. Examples are emergence of jealousy in infants and children's performance on a motor task that has moments of automatic processing and of mental-attentional processing.

The ascendent/abductive and descendent/deductive methods of an effective task analysis are dialectically complementary and in continuous interaction. Together they help to synthesize a problem solution (or to explain performance in postdictive analyses). These two methods can be used together as convenient. In a step *M-construction* (i.e., sequential MTA) the ascendent/abductive method may be more frequent, whereas in the *M-dimensional* (i.e., executive) MTA the descendent/deductive method is more common.

Sequential MTA (Step *M*-Construction) versus Executive MTA (*M*-Dimensional Analysis)

To see how these two methods of task analysis relate, we examine them in the context of one of our color-matching tasks (CMT, Arsalidou, Pascual-Leone, & Johnson, 2010; Arsalidou, Pascual-Leone, Johnson, Morris, & Taylor, 2013; Pascual-Leone & Johnson, 2011; see chapter 7). These are modified 1-back tasks, in which the stimuli are patterned figures with different colors (either a clown or a set of balloons; we focus here on the clown task). Colors of successive figures must be compared to determine whether the set of current-figure colors (i.e., *target colors*) is the same or different from that of the previous figure (i.e., *criterion colors*). Irrelevant features to be ignored are colors blue and green, location of colors in the figure, repetition of colors in the same figure, and colors in the clown's face. The two tasks differ in the form of the stimulus figure: CMT-balloon has as figure a bundle of balloons of various colors; CMT-clown has a clown with a varicolored costume. The balloon task presents a facilitating situation: colors are the balloons' most salient feature, because basic balloons are distinguishable only by their colors in everyday life. In contrast, the clown task is more difficult because it presents a misleading situation: the salient aspect of the stimulus is the charming clown itself with its expressive face (which must be ignored). As a result, relevant colors in the clown figure are more difficult to notice, hindered by the salience of the clown's body and costume, where relevant colors are embedded. CMT-clown was designed as an *M*-measure and has its classes of items differing only in the items' *M*-demand. To ensure that they had the executive and action schemes needed for the task, children were tested first with CMT-balloon and then with CMT-clown.

The two CMT versions (balloon and clown) are computerized tasks (Arsalidou et al., 2010, 2013). They have a brief pretraining in which relevant strategy and needed executive and action schemes are suggested and practiced. Figures are presented one at a time, and for each of them participants indicate, by pressing one of two buttons, whether the current set of relevant target colors is the same as those (criterion set) in the previous figure. There also are baseline items (containing only irrelevant colors, blue and green) that do not require a response. Items are presented in pseudo-random blocks of classes (a class of items is indexed by the number of relevant colors found). *M*-score in the CMT is the *M*-demand of the highest item class passed reliably.

The executive *M*-dimensional analysis of the clown task has the following generic form, where the suspension points stand for omitted schemes (and *M*[…] is also omitted):

RESET (RECUR (… MATCH&PRESS (SCAN&IDEN^{L1} ({…}$_{L1}$<…ccn>, tci)))) **(f1)**

In this formula we see four different main operative schemes (symbolized in capitals) with their operations separated by four sets of parentheses. Conventions of *M*-dimensional analysis have two functional orders jointly represented: (1) the *order of actual temporal occurrence* when the formula is enacted, which goes from right to left (every rightmost operation is applied or instantiated first), and (2) the *order of executive dominance or control* that goes from left to right. The leftmost operator is always the task-general one, which controls operatives on its right.

Formula **f1** is represented again in a completed manner in **f2**, which unfolds its four main temporal (right to left) operations into a step sequence:

(1) $M[\underline{\text{SCAN\&IDEN}}^{L1}\ (\{\#\text{IGN: f, irrC, locC, repC}\}_{L1} < \underline{\text{cc1}}, \underline{\text{cc2}}, \ldots, \underline{\text{ccn}} >, \underline{\text{tci}})]$
(2) $M[\underline{\text{MATCH\&PRESS}}\ (< \underline{\text{cc1}}, \underline{\text{cc2}}, \ldots, \underline{\text{ccn}} >, \underline{\text{tci}})]$
(3) $M[\underline{\text{RECUR}}^{L2}\ (\#\underline{\text{set.t:tci}}' \leftarrow \{\text{tci}\}_{L2})]$
(4) $M[\underline{\text{RESET}}^{L3}(\#\underline{\text{set.c}}' \leftarrow \{\text{set.t}\}_{L3})]$ **(f2)**

Step (1) shows the rightmost (temporally first) operation of **f1**, and steps (2), (3), and (4) are the other operations that complete the task's executive procedure. Added to the step formulas in this model are the key schemes of all sorts needed for the executive strategy to be carried out (or outlined) in a suitably concrete manner. Notice that the functional organization found in **f1** is respected in **f2**, albeit using an alternative representation (i.e., the same temporal occurrence and control dominance orders are assumed). Representation in generic formulas like **f1** and **f2** is metasubjective (modeling process sequences from within) and can be unfolded into finer and finer steps until a truly concrete *M*-construction (a step-MTA) has been produced when necessary. Indeed, the step sequence in **f2** is not a true *M*-construction, because each represented step is in fact a generic compacting of a number of truly concrete steps that are implied but not explicitly represented. We shall comment on this point below.

What we present in this task analysis is the sort of action schemes (operatives, figuratives, expectancies, parameters) that may instantiate the executive strategy. However, executive schemes themselves are not represented (nor are the truly concrete action schemes, unless unfolded into an *M*-construction). Executives are not included, because we assume that they are not boosted with the *M*-capacity used for symbolic action processing (i.e., the *Mk* scale of *M*-power). Instead, they are boosted with the *M*-capacity for sensorimotor processes (the *Me* scale of *M*-power; Arsalidou et al., 2010; Pascual-Leone & Johnson, 2005, 2011).

In the first step of **f2**, a participant must scan, one by one, and identify (SCAN&IDEN) the relevant target colors found in the current clown item. As the participant scans and identifies, he or she must ignore (#IGN) the face colors (f), irrelevant colors (irrC), location of colors (locC), and repeated colors (repC). These aspects and the embedding context that is the clown itself are features making the task misleading. We assume that this injunction to ignore is already chunked with the operative SCAN&IDEN. We symbolize such chunking by placing these #IGN schemes inside braces and subscripting the letter *L1* to the second brace, while placing a superscripted *L1* on SCAN&IDEN. This signifies that the latter is the operative-scheme portion of a chunk (a relational scheme) that controls the former. The *L*-boosting process, symbolized by *L1, L2,* and *L3* in formula **f2**, corresponds to multiple schemes that are so highly associated (structured together) that the chunk needs only one unit of *M*-energy to be hyperactivated, because the *L*-operator (*LC* or *LM* learning) is doing it already.

Step (1) in this model shows a moment when the participant, having just scanned the current set of target colors (set.t), now is keeping one of them (tci) in mind along with the total set of criterion colors (set.c, i.e., <cc1, cc2, …, ccn>) from the previous item. Note that a true *M*-construction analysis would have to present, one by one, all steps where each of the criterion colors was scanned, identified, and stored in the *M*-centration during following steps for subsequent use. Then other steps would have scanned the current target colors in front of the subject and retained one of them, tci, in *M*-centration for matching with criterion colors. Step (1) of our *M*-dimensional analysis shows the schemes kept in mind at such precise moment, with all previous steps of the possible *M*-construction being omitted, because they are less complex, although implied by our compacted step (1). In this step the participant must boost with *M*-capacity each of the criterion colors separately, because they are no longer present. Next he or she will have to match them, one by one, with each of the target colors (tci). This total set of criterion colors is symbolized in step (1) as <cc1, cc2, …, ccn>.

In step (2) participants, pursuing analysis begun in step (1), must match each and every target color (tci) with the total set of criterion colors (checking whether the color in question is among the criterion colors). To do this they keep in mind (boosted with *M*-capacity) the operative scheme MATCH&PRESS, the current target color tci, and the *n* criterion-color schemes of step (1). Again, this *M*-dimensional step collapses a number of truly concrete *M*-construction steps that we imply here, in which each of the target colors is matched with the whole set of criterion colors, and then the appropriate button (match or nonmatch) is pressed to respond. Every target color has in turn to be so compared with the set of criterion colors until one mismatch appears. These *M*-construction steps are implied in our step (2).

Step (3) shows the RECUR operation. RECUR applies within the processing of each item; it changes *M*-centration within the set of target colors from one target color already matched (tci) to another target color (tci′) not yet matched (#set.t: tci′ ← tci). Notice that RECUR is chunked with tci (superscripted/subscripted L2). Finally step (4) shows the RESET operation. RESET applies whenever a new item is introduced, to ensure that the set of target colors (set.t) in the just finished item is retained with its function changed (←), to become the new criterion-colors set (set.c′). That is, the previous target set becomes the new criterion set at the end of the item (#set.c′ ← set.t). Notice that set.t is chunked with RESET (superscripted L3). Again, steps (3) and (4) are compacting within each finer M-construction steps that would be needed to model in real time every act required.

In formula **f2** the underlined schemes are those that in each step must have their activation boosted by using *M*-capacity. They must be boosted, because they are neither salient nor subordinate parts of an already hyperactivated scheme/schema (or chunk). Counting these underlined schemes for each step we find that in steps (1) and (2) the number of schemes to be boosted by *M* is equal to $2+n$, where n is the number of criterion colors in the trial item. For example, in step (1) participants must use *M*-capacity to boost the operative SCAN&IDEN, each of the colors cc1 to cc*n* of the criterion set, and the target-set color (tci), which they next try to match against the criterion set. Because steps (3) and (4) have lower *M*-demand (which is equal to 2), participants should be able to solve a given CMT-clown item, if they have the necessary schemes, when their *M*-power (*Mp*) is equal to $2+n$. Because classes of items differ in the number of relevant colors presented, the value of n varies with the item class from 1 to 6 so that corresponding *M*-demand varies from 3 (i.e., $2+1$) to 8 (i.e., $2+6$). Notice further that assumptions of the *M*-demand in items are predicated on the positing of chunking (*L*-structures) and perceptual or cognitive facilitation factors (e.g., due to *F*-operator's simplicity principles), plus other hidden operators/principles that can increase or decrease the task's effective complexity. This is why it is important to differentiate analytically between facilitating versus misleading situations. Once we have examined in the formula these facilitating or misleading factors (checking potential influence of every hidden operator and principle in the model adopted, which in our work is TCO) we may end up with a range of possible *M*-demand values for the task, each contingent on alternative plausible assumptions.

Thus executive *M*-dimensional analysis allows a first approximate estimation of the task's *M*-demand, less credible than that of the sequential *M*-construction. In the dimensional case, *M*-demand (as illustrated by **f1**) corresponds to the sum of various independent (not already *L*-structured) operatives involved, plus all essential data schemes on which these operations apply. This first approximative estimate may be revised when we deconstruct that formula, as done in **f2**, to obtain a finer sequential analysis of what is to be done and how. *M*-demand of this sequential *M*-construction will always be the *M*-demand of the step that has highest *M*-demand in the total sequence. Comparing **f1** with **f2**, it becomes clear that although the set of n criterion colors (ccn) and the current target color (tci) must be *M*-boosted, only one of the operatives needs *M*-boosting at any one time.

These two procedures of analysis are different, top-down versus bottom-up, although both methods address the same processes. The descendent strategy estimates task *M*-demand by counting the essential operative constraints needed for the total executive process, whereas in the ascending strategy (called *M*-construction) *M*-demand is estimated in terms of the most *M*-demanding step within the sequence. The two sorts of *M*-estimates are semantic-pragmatically equivalent, but the second is likely to be more precise.

Some Heuristics of MTA: An Incomplete Heuristics Checklist

We list several points that together may help to guide (**G**) new analysts. The order of points is somewhat arbitrary.

(**G1**) To do a task analysis, we must have already an intuitive model of the psychological organism (metasubject), which allows one to formulate causal operative models of the metasubject's functioning in the task. Second, we need an intuitive objective (figurative and operative) model of the situation, including the problem-to-be-solved (or performance to be produced) as well as facts, conditions, and unknowns that help in formulating the problem/performance. Third, an observer's (operative and figurative) objective model of the task to be performed is needed, with an explicit choice of the executive strategy to be followed.

To formulate this strategy, it is useful to begin by considering the task as an organized totality, from the initial (a-) to the final (-b) situation in which the task can be solved. One keeps deconstructing or differentiating these a-b transitions (often working backward from plausible or intended final solutions) and creating nested functional hierarchies of progressively finer a-b transitions that allow us to mentally actualize and eventually solve the strategy. These subjective a-b transitions are not conceptual but rather are intuitive mentation, modeled as actual mental or physical acts (i.e., infralogical processes modeled mereologically). Finally, the strategy to be chosen must be basic—as simple as it can be—and must take/accept as much error, or variation in performance, as the subject could afford given the chosen task. Thus, from the perspective of the analyst, the executive demand of the strategy adopted has to be minimized. Consequently, we do not try to enumerate all possible schemes of the final performance, but rather only the functional-infrastructure ones (schemes that belong to the minimal effective complexity) that must be activated (perhaps boosted by *M*) to cause organismically the intended performance.

(**G2**) The purpose of metasubjective task analysis is to produce a causal (via overdetermination), specific (operative and figurative) from-within model of the subject's intended task performance, given the chosen strategy (the simplest possible, with minimal executive demand, because subjects like to minimize complexity).

(**G3**) The intuitive causal model of the metasubject (psychological organism) is constituted in our TCO by a repertoire of schemes of all sorts, which are plausible for the type of subject, in terms of his or her expectable personal history. The subject is assumed to be motivated, highly active (schemes follow Piaget's assimilation principle—a propensity to apply under minimal elicitation if not suppressed by some other scheme), and driven by motives and expectancies. Organismic hidden operators and principles must be assumed explicitly, to explain how schemes can be boosted or inhibited in their activation, or dynamically synthesized to produce performance. The problem-solving performance is always overdetermined, that is, multidetermined by hidden brain factors that are variable in potency (weight) relative to both individual subjects and the situation (i.e., are context sensitive). These factors together combine to overdetermine an outcome that conforms to the *F*-mini-max rule: an outcome that minimizes effective complexity while maximizing adaptation to the situation within the goals and strategy pursued.

Learning takes place through reflective abstraction. Schemes emerge as constructive abstractions from task-relevant functional invariants in the situation—task-directed (intentional) actions and expectancies released by schemes previously developed by internalizing empirical invariants (e.g., abstracted via *LC*, *LM*). This recursive constructivist learning leads to functional hierarchies (schemes of schemes of schemes) defined at various levels of abstraction, which together, and often by steps, can internalize recurrent sequences of performance patterns. This sort of learning can occur within the task itself and be modeled in task analyses.

Performance is either automatic (attentionally effortless) or is constrained by mental-attentional demands and executive demands of the sequence in question (i.e., the needed a-b connections to be carried out). To be automatic, the metasubject must already have in its repertoire suitable schemes facilitated (directly cued) by the situation. Effortful performance, in contrast, requires sufficient mental-attentional capacity (particularly *E*, *M*, and *I* capacities) to cope with these demands. To minimize mental-attentional demand, subjects tend to break tasks into simpler steps. Consequently, task analysts should carry out a similar sequencing into simple (e.g., *M*-accessible) steps.

(**G4**) Every metasubjective analysis presupposes a strategy adopted by the subject, which the analyst should make explicit as soon as possible. Each new strategy requires a different MTA. Because subjects follow a principle of simplicity and take as much error as they can afford, we should assume the simplest possible initial strategy and apply the theory resources and principles (in the TCO hidden operators, such as *M, I, E, LC, LM, F,* and hidden principles) to see how a useful process model could evolve in solving the task or explaining subjects' errors. To demarcate a strategy, it is important to consider factors (schemes elicited, biases or dispositions such as those induced by

F-factor and others) that could distract or mislead problem solvers away from simple, correct solutions. Searching for and recognizing these misleading/distracting factors in the problem situation is a golden thread for establishing appropriate strategies, because correct strategies must avoid or control misleading and distracting factors (e.g., automatized shadow schemes, biases). Thus, good schemes chosen for the winning strategy are those that can bypass or control misleading factors when necessary.

(**G5**) It is fundamental to decide whether the task and the schemes used in it are sensorimotor or symbolic. Sensorimotor (e.g., signalic) schemes are concrete and mediate no meaning beyond themselves; in addition, they are directly activated by affects—affectively immediate. In contrast, symbolic schemes mediate meaning beyond themselves (e.g., the hat on mother's head means for Piaget's 12-month-old daughter that her mother is about to leave the house), and they are directly activated not by affects but by executive schemes and cognitive-perceptual cues. Symbolic but not signalic schemes are executive-mediated and, as symbols, they are not affectively immediate. Clear differentiation between symbolic versus signalic (sensorimotor) schemes is fundamental in task analysis. As discussed in chapters 3, 4, and 7, two different scales of measurement for *M*-capacity, *Me* (signalic) versus *Mk* (symbolic), must be distinguished. These two scales cannot be mixed. In facilitating situations, subjects can use sensorimotor-scale processing. However, in complex misleading situations they must use symbolic-scale processing.

(**G6**) Although the distinction between sensorimotor and symbolic schemes must be maintained, actual *M*-demand of a scheme within each category is unrelated to the amount of information it carries. All well-learned schemes have in some sense similar *M*-demand (which counts as one *M*-unit), because when well constituted, schemes become structurally unitized or chunked by logical-relational (*L*-) learning. Once constituted as distinct schemes, each needs only one unit of *M*-boosting, and the organism allocates the mental energy needed. To accept a scheme as a suitable unit in task analysis, we must estimate the plausibility of such scheme being already well learned within the subject's repertoire. This depends on the expectable personal learning history of the subjects in question.

(**G7**) As mentioned, a series of questions should be explored to clarify task-analytical issues: What is the task, and what does the subject have to do to solve it? What is the structure of the situation(s) serving to define the task? What is the unknown? What is the strategy to be analyzed? Which are the relevant schemes in the subject's repertoire elicited by the situation? Which affective/personal schemes (such as motive or shadow schemes) could facilitate or hinder the intended performance? Which are the compelling task-irrelevant (shadow) schemes elicited by the situation? What relevant schemes can be chunked to reduce the mental load of the problem? How do these schemes relate to one another in the context of the task? How can hidden operators or principles (from the chosen organismic theory) affect and change activation or application of schemes to the task? Do they suffice with their dynamic interaction to cause the intended performance? Which other schemes or hidden operators may be needed?

(**G8**) A plausible analytical sequence for approaching metasubjective analysis (concurrently pursuing its four key moments, i.e., objective, subjective-1, subjective-2, metasubjective) consists in adopting six complementary analytical perspectives. First is *informal ascendent/abductive analysis* (predominant in sequential *M*-constructions) to evoke, from the intended task results, the essential schemes that subjects may have in their repertoire or construct during the task process. Second, *informal descendent-deductive analysis* (predominant in executive *M*-dimensional analyses) helps to clarify how various constructs (e.g., schemes, hidden operators, principles) of the adopted organismic general model can induce the subject to infer or evoke schemes (or biases) necessary to solve the task. In this regard it is mandatory to ask oneself how each construct of the chosen organismic model may be mobilized by the task solution process. Third is a more *formal descendent-deductive analysis* (with explicit symbolic notation and suitable completeness). Fourth is a more *formal ascendent-abductive analysis*, with all its explicit steps toward the task solution. This sequential *M*-construction should be consistent (and complementary) with the executive *M*-dimensional analysis obtained in the prior analysis, therefore helping it to be corrected for the final MTA model. Fifth, coordination and integration of the first four perspectives produces the final causal (operative and figurative) process model. When various distinct competing strategies have been elicited by the task (often a correct effortful strategy vs. an automatized misleading one), the functional relations holding between or among these strategies must be investigated theoretically (schemes and hidden operators involved) and empirically (feature/cues in the situation eliciting one or another scheme) to determine functional interrelations. The analysis of complex and misleading tasks may be culminated with a strategy-relational MTA (see formula **f4** in chapter 8 for an example of this strategy-relational analysis).

Notice that these various perspectives should be explored and coordinated, although the order of exploration can vary. With practice, this often can be done concurrently and implicitly, without requiring explicit formulation of each perspective. However, explicit formulation may be needed to resolve contradictions or confusions.

Illustrative Examples of MTA in Chosen Ages and Domains

Example 1: Attachment in the Sensorimotor Period

Consider first an example of task analysis in the sensorimotor period: developmental emergence of the attachment motive. A current definition of *attachment* would say that it is a personal, emotional bonding to a primary caregiver or protector-companion. It is indexed when the child uses the primary caregiver as secure base from which to explore unfamiliar situations and as a haven of safety and a source of comfort. Attachment begins in infants at 8 to 9 months, and it peaks at 12 to 18 months. It "seems to emerge in every society around the age of one to one-and-a-half years" (Oerter, 2000, p. 65). Nobody has explained why it peaks at 12 to 18 months. What seems clear from animal research is that it is founded on an innate complex disposition of *affective-social beings* (i.e., *affect*-driven beings, affective-plus-cognitive schemes). We express with a *B*- (personal/social beings) operator the intertwining of affects and cognitions, the coordinated affective plus cognitive functional totality of schemes/schemas that enable psychosocial and personal interactions. According to our task analysis (Pascual-Leone & Johnson, 2004), the following essential schemes constitute this attachment disposition:

- **mother*OB***: Mother is the first *internalized social object*—a complex synthesized personal inner-object. This is an instance of internalized (*LCLM*-learned) complex scheme, which we call an *OB* to signify a distal (in this case, personal) object.
- **mother***per:* Mother's *OB-percept*. The internalized representation of the mother's coordinated percepts, which index her actual presence in situations.
- ***Self1*** (Damasio's, 2012, core self): The baby's *first basic awareness of Self vis-à-vis an immediate* Other (mother, father, caretaker).
- **#context**: Concrete and specific cognitive/perceptual/affective representation of the actual here-and-now *situation*.
- **BE-WITH**: Personal/social operative scheme expressing *need to BE WITH*—protected, loved by the intimate protector-companion.

$$\underline{\textit{BE-WITH}}_{L2?}\ (\#\underline{\text{context}},\ \underline{\textit{Self1}}^{L2?},\ \underline{\textit{MotherOB}}^{L1,AB}\ \{\text{mother}\textit{per}\}_{L1,AB}) \rightarrow \textit{Attachment-representation} \qquad \textbf{(f3)}$$

Again, operatives are written in capitals (i.e., *BE-WITH*). Schemes that involve expectancies and are temporally structured in themselves (fluents in our terminology), we write in italics. Three of the schemes in **f3** are written in italics for this reason: *BE-WITH*, *Self1*, and *MotherOB*. These personal schemes emerge within social interactions, and they present as a feature their having fluent (temporally structured and often causal) interrelations. The superscript *AB* stands for the affective (A) and personal (B) operators, which boost and chunk the mother schemes. The core-self scheme *Self1* may be (?) boosting, and be chunked with, the personal scheme *BE-WITH*, as indicated with the superscripted and subscripted *L2*? Overdetermination (➔) by these schemes explains emergence of attachment at about 12 months whenever affect (AB) is low, causing the *Self1* to have weak bonding with mother and *BE-WITH* (in which case four schemes have to be boosted by *M*; they are underlined in formula **f3**). However, when affect (AB) is high, causing a strong bonding of *Self1* with *BE-WITH,* only three sensorimotor schemes would have to be boosted by *M* (which should reduce the age of attachment acquisition to 8 or 9 months, see table 3.1). Notice that all the schemes in this task are sensorimotor (e.g., signalic), because they are concrete and mediate no meaning beyond themselves; also, they are directly boosted by affect and do not need executive-driven mediation. The scale of *M*-capacity used is the *Me* scale discussed in chapter 3.

Example 2: Anticipation of Mother Leaving

Another spontaneous, sensorimotor behavior is Piaget's example of Jacqueline's crying when mother puts on a hat—a cognitive expectancy about separation anxiety anticipating mother's leaving. The child had learned to connect the hat on Mom's head with the absent-mother who does not appear when called. Piaget (1963) writes, "[F]rom 0;11(15) Jacqueline cries as soon as her mother puts her hat on. This is not due to fear or anxiety as before, but due to the certainty of the departure" (p. 250). Jacqueline seems to know that a hat (or coat) on her mother signals that mom will disappear and not return when called.

According to our dialectical constructivist interpretation, this behavior expresses the learning (and dialectical competition) of two *WANT-MOM* schemes that constitute two competing alternatives (a dialectical pair) of the *Mother-OB* scheme. Namely, (1) a *Good-MotherOB* scheme, which will make the mom appear on call (Present-Mom) when the mom is not wearing a hat and (2) a *Bad-MotherOB* scheme, manifest when mother wears a hat, who does not appear (Absent-Mom) when called. Constructive abstraction of these two schemes requires the possibility of keeping in the sensorimotor *M*-centration the essential constituent schemes that make up the particular functional facet of the complex scheme *Good-MotherOB* (formula **f4**), and of the contradictory complex scheme of *Bad-MotherOB* (formula **f5**), that our task is addressing.

$$\underline{\textit{WANT.MOM1}}\ (\#\underline{\textit{Mom-no-hat}},\ \underline{\text{CALL}}\ (\underline{\textit{Mom[Present.Mom}}]))\ \boldsymbol{\rightarrow}\ \text{CALLING.}\textit{Mom}[\rightarrow\textit{Present.Mom}] \tag{f4}$$

$$\underline{\textit{WANT.MOM2}}\ (\#\underline{\textit{Hat-on-Mom}},\ \underline{\text{CALL}}\ (\underline{\textit{Mom[Absent.Mom}}]))\ \boldsymbol{\rightarrow}\ \text{CALLING.}\textit{Mom}[\rightarrow\textit{Absent.Mom}] \tag{f5}$$

The two schemes in question have the same mental (*Me*) demand, so they will be formed concurrently, and in dialectical interaction, one is the reciprocal (reverse) of the other. As the number of underlined schemes shows, *Me*-demand of both formulas is four sensorimotor schemes, which makes their constructive learning (in the *Me*-scale) accessible to 12-month-olds. The schemes are indeed sensorimotor for reasons given in the previous example.

The two formulas are complementary and similar. The experience that initiates the functional facets of the two *MotherOB* complex schemes is a desire or longing to be with mother, which we express with schemes *WANT.MOM1* and *WANT.MOM2*. These and other schemes in the formulas are written in italics because they represent fluent schemes (i.e., temporally structured schemes that have emerged through daily interaction with mother across different situations and moments). As these formulas show, in **f4** the child expects that mother will appear (*Present.Mom*) when called, and at this moment the mother *should not* have a hat on (*Mom-no-hat*). In contrast, in **f5**, calling the mom will bring no response (*Absent.Mom*) when mother has the hat on. Thus, Jacqueline cried seeing her mom wearing the hat.

Example 3: Object Permanence

The object permanence task (Barth & Call, 2006; Pascual-Leone & Johnson, 1991; Piaget, 1954) is paradigmatic of Piaget's constructivist epistemological idea (new at the time) that children's learning occurs by internalizing functional invariants abstracted from experience. For him distal (cognitive, not just perceptual) objects are represented by complex schemes (functional-relational systems of structures probabilistically invariant—more or less constant—across space and time, which relate to other schemes). This explains object permanence, as well as (later on) various sorts of conservation properties. We present here and in chapter 3 versions of this family of tasks to illustrate our method (Benson, 1989; Benson & Pascual-Leone, 1997; Pascual-Leone & Johnson, 1991). We cannot review the abundant literature. A recent study of this sort of tasks, using apes and children, is provided by Barth and Call (2006). Complementing, we hope, their empirical work, we briefly outline here a theoretical model of metasubjective processes for this family of tasks, thus explaining differences in age of acquisition by children, which vary with task characteristics.

In this family of tasks there is always a desired object (e.g., a toy) that disappears behind a screen (it may be one screen, **a**, or several of them, **a**, **b**, **c**, … all aligned in proximity). The paradigm can be complexified in different ways: for example, by having more than one displacement of the toy behind screens, or making the toy displacements visible (child can see the toy) versus invisible (toy is place inside a container, hand or cup; and the container, with the toy hidden inside, brought behind the screens), or by varying the distance (adjunct or nonadjunct) between screens where the toy is being hidden, or by varying the waiting time (long/short delay, nondelay) until the child/ape is allowed to reach for a screen as he or she looks for the object. In all cases, the subject (child or ape) who desires the object is given an opportunity to reach to a screen, and remove it, seeking the desired object (which in apes is food).

Single Visible Displacement The simplest version of this paradigm is a single visible displacement and a single screen. After some suitable motivating introduction, the tester presents the child with one screen and places the toy, visibly displaced with the hand, behind it. The tester then encourages the child to find the toy. The child can remember that the toy disappeared behind the screen (this is acquired at about 4 months; Renée Baillargeon, 1987). Thus infants would have schemes *screen[toy behind]* and #*toy[FOUNDbehind screen]*. Consequently, the child may bring the hand to the screen (*screen [toy behind]*) to remove it (GET.TOY:.*REMOVE.screen*) and obtain the toy. With these schemes (sensorimotor because their activation is affectively immediate, not deferred or executive driven, and there are no misleading factors) our task-solving formula is:

$$\begin{aligned}&\underline{\text{GET.TOY}}^{L2,A}\ (\textit{screen[toy behind]}_{L1},\{\textit{REMOVE.screen}\}_{L2}\\&\quad(\{\#\textit{toy[FOUNDbehind screen]}\}_{L1},\ \underline{\text{toy}}^{L1,A}))\rightarrow \text{toy}\end{aligned}\tag{f6}$$

Notice that this formula has only two schemes underlined (i.e., requiring *M*-boosting), because *screen[toy behind]* is already *L*-boosted, along with the parameter (#) scheme, by the scheme toy^{L1}. All these schemes are also *immediately* boosted by affects (*A*-operator), and so no executive scheme is needed to mediate them: the *Me*-scale of *M*-capacity has to be used, which predicts (see table 3.1) success at about 4 or 5 months—a bit after the age when the child can use his or her gaze to show knowledge of where the toy is hidden (Renée Baillargeon, 1987).

More difficult is when the child must choose which of two or more screens (**a**, **b**, **c** …) the toy was hidden behind. After the toy is placed behind a screen, to solve the problem the child needs a process formula such as the following:

$$\begin{aligned}&\underline{\text{GET.TOY}}^{L2,A}\ (\{\textit{screen[toy behind]}\}_{L1},\ \{\text{SELECT \& }\textit{REMOVE.screen}\ \}_{L2}\\&\quad(\#\textit{toy[FOUNDbehind }\boldsymbol{a}]_{L1},\ \underline{\text{toy}}^{L1,A},\ \underline{\mathbf{a}})\rightarrow \text{toy}\end{aligned}\tag{f7}$$

In this formula, *#toy[FOUNDbehind **a**]* is the expectancy scheme that stems from the experience of the toy disappearing behind **a**. This scheme serves as parameter to the operative SELECT that chooses which screen (**a**, **b**, **c**) to REMOVE to find the toy. This is clearly an affectively immediate task driven by perception and without executive mediation—a sensorimotor task. The *Me*-scale (see table 3.1) shows that three distinct schemes can be simultaneously *M*-boosted when the infant is about 8 months old, not earlier.

The well-known A-not-B error discovered by Piaget has a formula similar to **(f7)** when the child in fact commits the **a**-response error (directly driven by affect, as analyzed in formula **f6**). This error consists in the following: when the infant is presented with two or three screens **a**, **b**, **c**, and the desired object (e.g., toy) is hidden by the tester behind **a**, the child, seeing the tester's action, selects **a** (an active SELECT operation may not be needed because the response is facilitated by a perceptual and learned habit to do the **a**-response), then the child REMOVES **a** to get the toy. The tester repeats the same procedure two or three times, and the child gives the same response (which induces in the child an **a**-response habit). Next, without warning, the tester hides the toy behind screen **b** or **c**, thus creating a dialectical contradiction between the **a**-habit and the recent-scheme memory of where the toy is hidden. Reliably, infants younger than 12 months or so commit the error of persisting in responding to **a** (because of the learned expectancy that toy is behind **a**), even though the child just saw the toy being hidden behind **b** or **c**. This is the A-not-B response. A more complex version of the same task appears using multiple visible displacements, in which errors can be called A-not-B/C/D responses.

Multiple Visible Displacements with Multiple Screens To solve the multiple visible-displacement task, when the child has seen the toy go behind **a** (one or more times) and gotten the toy by removing **a**, the child must overcome the **a**-response habit. He or she can do so if enough task-relevant and compatible schemes opposing the **a**-response have been hyperactivated by mental attention to force suppression of the **a**-response habit (via overdetermination against this habit). Four different schemes are needed: (1) the memory of the screen (**c**) where the hand with the visible toy last disappeared (*toy-at-hand-TO-**c***); (2) the learned intuitive rule that the object will be found where it disappeared last (*toy-FOUNDbehind-LAST-screen*); (3) the remembered-fact that toy was no longer in the hand when it reappeared after being hidden behind **c** (No-toy-at-hand-after-c); (4) The main operative scheme described above (GET.TOY:.*SELECT & REMOVE.screen*). Thus, the solution formula could be this operative model:

$$\underline{\text{GET.TOY}}^{L2}\ (\#\underline{\textit{toy-FOUNDbehind-LAST-screen}},\ \{\text{SELECT}\ \&\ \textit{REMOVE.screen}\}_{L2}\ (\#\{\underline{\textit{toy-at-hand-TO-}\mathbf{c}}\}^{L1,Sit} \leftarrow \{\text{No-toy-at-hand-after-}\mathbf{c}\}_{L1,\ Sit}),\ \underline{\mathbf{c}}) \Rightarrow \mathbf{c}\text{-RESPONSE} \qquad \textbf{(f8)}$$

Let us analyze this formula showing a dialectical interaction between the ascendent (bottom-up, abductive) method and the descendent (top-down, deductive) method. The child wants to GET.TOY but when the tester has completed the hand-with-toy displacements, the toy is no longer in the tester's hand (scheme No-toy-at-hand-after-c). This fact-scheme and the child's desire to get the toy, make children recall (←) that hand and toy were last behind **c** (*toy-at-hand-TO-***c**). This scheme is temporally structured (a fluent), because it describes the movement of hand-toy going behind **c** (we emphasize this fluent idea by writing the scheme in italics, and its operative sub-scheme of going *TO*, behind the screen, in capitals). The child intuitively thinks the toy is likely to be behind screen **c**, because the actual situation (*Sit*) suggests so. The memory (←) that *toy-at-hand-TO-c* together with scheme No-toy-at-hand-after-**c** should raise the inference that toy is to be FOUND behind **c**. This thinking causes the child to aim for **c** (**c**-RESPONSE), to *SELECT* and *REMOVE* this screen and find the toy. It should be obvious that this is an affectively immediate task using sensorimotor schemes. The *Me*-demand is four schemes, a capacity that emerges at about 12 months.

Multiple Invisible Displacements with Multiple Screens The task is virtually the same, but now the toy is not visible, because it is always hidden by the tester's hand (or in Barth & Call's, 2006, research with apes, the toy is hidden inside a cup being displaced). In Piaget's method, the tester exclaims, "*The toy! the toy!*" as the toy, hidden in the tester's hand, leaves a given screen to enter behind another screen, and so on till the last screen.

$$\begin{aligned}
&\underline{\text{GET.TOY}}^{L2}\ (\#\underline{\lambda\textit{toy!}[\textit{toy behind screen}}]\ (\{\text{SELECT}\ \&\ \textit{REMOVE.screen}\}_{L2}\\
&\quad(\#\underline{\textit{toy-FOUNDbehind-LAST-screen}},\\
&\quad(\#\{\underline{\textit{toy-at-hand-TO-}\mathbf{c}}\}^{L1}\leftarrow\{\text{No-toy-at-hand-after-}\mathbf{c}\}_{L1,Sit}),\ \underline{\mathbf{c}})))\ \Rightarrow\ \textit{c-RESPONSE}\qquad\textbf{(f9)}
\end{aligned}$$

For this reason, as shown in **f9**, children of 12 or 18 months understand the utterance (*λ*—lambda is our symbol for linguistic schemes) *λ:The toy! The toy!* as meaning that the toy is being carried behind the screen when the utterance is voiced (scheme #*λtoy!*[*toy behind screen*]). This scheme results from the inference that if utterance *λtoy!* were voiced prior to the hand entering behind a screen, then the toy would be inside the hand entering the screen. This parameter (#) is boosted by *M,* because it involves a novel inference essential for task solution. When the child sees that the toy is not inside the hand emerging from **c** (scheme No-toy-at-hand-after-**c**), he or she experiences a contradiction with the prior inference that the hand with the toy went TO **c** (an inference based on the schemes #*λtoy!*[*toy behind screen*] and *toy-at-hand-TO-***c**). However, to be able to SELECT the suitable screen, the child needs to be guided by the empirical concept-rule abstracted after 12 months of age: the toy is always found where it disappears last (*toy-FOUNDbehind-LAST-screen*). This scheme, an expectancy-parameter (#), is available after 12 months, because its essential constituent schemes are at most three or four units: *FOUNDbehind*, *LAST*, *screen, and *toy; but notice that schemes *FOUNDbehind* and *toy may be chunked (*L1* subscript/superscript) because of the child's prior playing experience. As the underlines of formula **f9** suggest, the sensorimotor *Me*-demand of the total task is five, accessible at about 18 months of age. The important categorical scheme *toy-FOUNDbehind-LAST-screen* should be available in the child's repertoire at this point.

Example 4: Simon Task

The Simon task, discussed in chapter 7 (see Figure 7.13), illustrates a symbolic processing task. In the standard Simon task, the child sits before a monitor and has two response buttons (left vs. right). Stimuli appear one at a time, on the left or right side of the screen. The task is to press the right button when a given stimulus (e.g., the frog) appears and press the left button when another stimulus (e.g., the butterfly) appears. The Simon effect is the strong tendency (present in 4-year-olds) to press the right-side button when a stimulus appears on the screen's right, and press left when stimulus appears on left, irrespective of the stimulus. This tendency (induced by the subject's *F*-operator) slows responses to any *incongruent* trial—one in which the stimulus appears on the opposite side to where the response must be made. The task analysis formula for the standard Simon, in the case of an incongruent trial, is:

$$\underline{\text{PRESS}}^{L1}(\#\mathit{RESPbutton\text{-}left}_{L2},\ \{\text{IDEN(LOCATE\# right}\}_{L1},\ \underline{\text{butterfly}[\mathit{RESP{:}left}]}^{L2})) \rightarrow \text{RESPONSE [correct button press]} \qquad \textbf{(f10)}$$

The task-process sequence begins at the right side of the formula before the arrow (as always in *M*-dimensional analysis): the stimulus butterfly appears located at the right side of the screen. The subject perceives this location using automatic/perceptual attention (LOCATE# right) and then cognitively identifies it (IDEN) as one to be responded to with the left button (butterfly[*RESP:left*]). This recognition may already be chunked (*L2*) with the parameter (#) *RESPbutton-left*, which stipulates the button, right or left, to press. A dynamic overdetermination (➔) by these schemes brings the child to the moment of PRESS, producing the correct RESPONSE. Notice that cognitive identification (IDEN) is needed because the task is misleading, because of the *F*-factor. With congruent trials, in contrast, fast processes of automatic/perceptual attention and S-R compatibility can suffice to produce the performance. Mental attention is needed to overcome these automatic processes in the incongruent trials.

The cognitive/conceptual identification and the necessary verbal instructions show this task to be symbolic. The mental (*Mk*-scale) task demand is $e+2$ (i.e., two symbolic schemes plus sensorimotor *Me*-capacity, used to activate executive schemes not directly represented in formula **f10**). The task should be accessible to 5- or 6-year-olds. The

Simon effect persists into adulthood, yet adults are not affected by the _M_-demand of the task, because it is well within their capacity. However, they still experience misleadingness induced by S-R compatibility.

Example 5: Fraction Word Problems

The problems that follow and their task analyses stem from the doctoral research work (in progress) of our York University graduate student, Cheryl Lee. Consider the following word problem: “Carla’s pencil case contains 12 things, including 3 pens. The pens are what fraction of all the things in Carla’s pencil case?” We assume that participants recognize that the question requires computing the _part of a whole_. Formula **(f11)** symbolizes the schemes that must be activated during task solution.

$$\underline{\text{PARTWHOLE}}^{L1}\ (\{\textit{DIV.equal.shares}\}_{L1}\ (\#\underline{\text{num--denom}},\ {*}\underline{\text{pens}[\textit{PART}]},\ {*}\underline{\text{things}[\textit{WHOLE}]}))\ \boldsymbol{\Rightarrow}\ \text{SOLUTION} \qquad \mathbf{(f11)}$$

PARTWHOLE refers to the conceptual and procedural understanding of this type of problem. As we have mentioned, superscript _L1_ stands for a logical (_L_ learning) structure or schema—an overlearned connection between schemes. Here it conveys that participants know the part-whole concept as linked to a scheme for division into equal shares. The subscript _L1_ outside the braces indicates that operative _DIV.equal.shares_ is _L_-boosted by PARTWHOLE, because of prior learning.

The next three schemes are the parameter #num–denom and figuratives *pens[_PART_] and *things[_WHOLE_]. The parameter indicates that PARTWHOLE{_DIV .equal.shares_} is applied by forming the numerator and denominator of a fraction. The parameter indicates that *pens[_PART_] is numerator over the denominator *things[_WHOLE_]. The predicted _M_-demand of this strategy is four symbolic units (as the number of underlined schemes in **f11** indicates). Such _M_-demand is accessible to children of 9 years or older.

More challenging is multiplication of two proper fractions, as exemplified by the following problem: “Kathy has 4/5 of a bag of peanuts [fraction 1: a_1/ b_1]. Ryan has 2/3 as many peanuts as Kathy has [fraction 2: a_2/ b_2]. What fraction of a bag of peanuts does Ryan have?” The full formula for solution of this problem is:

$$\underline{\text{PARTWHOLE}}^{L2}\ \{\textit{DIV.equal.shares}\}_{L2}\ (\underline{\#\text{num--denom}},\ \underline{\text{SCALAR}}^{L1}\ (\{\text{MULT}_2\}_{L1}\ (\#\underline{\text{mult-tab, }{*}\text{b}_1},\ {*}\underline{\text{b}_2) \rightarrow {*}\text{denom}},\ \{\text{MULT}_1\}_{L1}\ (\#\underline{\text{mult-tab, }{*}\text{a}_1\text{, }{*}\text{a}_2) \rightarrow {*}\text{num}}))\ \boldsymbol{\Rightarrow}\ \text{SOLUTION} \qquad \mathbf{(f12)}$$

Formula **f12** is an example of _M_-dimensional analysis (an executive MTA). Here the thin arrow (→) indicates the result of the locally preceding operation. The strategy modeled can be unfolded in several steps that proceed from right to left in the formula.

We show this in formulas **f13** to **f15** below. When the following steps are put together, we have an instance of a sequential *M*-construction analysis (a step MTA).

$$\underline{\text{PARTWHOLE}},\ \underline{\text{SCALAR}}^{L1}\ (\{\text{MULT}_1\}_{L1}\ (\#\underline{\text{mult-tab}},\ {*}\underline{\text{a}}_1,{*}\ \underline{\text{a}}_2)) \rightarrow {*}\text{num} \qquad \textbf{(f13)}$$

Step 1 (**f13**) requires participants to hold in mind five symbolic units: (1) the general operative scheme for a part-whole problem; (2) because the problem requires rescaling one quantity by the value of another, the operative stipulates a scalar type of multiplication; (3) the scheme of the multiplication table; (4) the numerator of first fraction; and (5) the numerator of second fraction. In formula **f13**, starting from right to left, the figurative schemes *a_2 and *a_1 refer to numerators of the two fractions. The scheme #mult-tab is the parameter indicating that the multiplication table (or relevant number facts) must be held in mind. $\{\text{MULT}_1\}_{L1}$ is an operative of multiplication. It carries number 1 subscripted because it is the first multiplication to be calculated. The subscripted *L1* outside the braces indicates that this scheme is not being boosted by the *M*-operator but by SCALAR^{L1} to which it is chunked; this corresponds to the conceptualization of the problem as requiring scalar multiplication in the service of the part-whole solution. PARTWHOLE is the overall concept (general operative) of the problem. The solid arrow (➔) indicates the product of this dynamic synthesis of schemes (which apply together via overdetermination) yielding the actual numerical result (*num) of the operation. Predicted *M*-demand of this step is five symbolic schemes.

$$\underline{\text{PARTWHOLE,}}\ {*}\underline{\text{num}},\ \underline{\text{SCALAR}}\ ^{\text{L1}}\ (\{\text{MULT}_2\}_{\text{L1}}\ (\#\underline{\text{mult-tab}},{*}\underline{\text{b}}_1,\ {*}\underline{\text{b}}_2)) \rightarrow {*}\text{denom} \qquad \textbf{(f14)}$$

Step 2 (**f14**) represents multiplication of the denominators (b_1 and b_2), while also holding in mind the result of the previous step (*num). The solid arrow points to the operation's actual numerical result (i.e.,*denom). Predicted *M*-demand of this step is six symbolic schemes.

$$\underline{\text{PARTWHOLE}}^{\text{L2}}\ (\{\textit{DIV.equal shares}\}_{\text{L2}}\ (\#\underline{\text{num–denom}},\ {*}\underline{\text{denom}},\ {*}\underline{\text{num}}))$$
$$\rightarrow {*}\text{num/denom} \qquad \textbf{(f15)}$$

Step 3 (**f15**) mirrors the task analysis for the simpler problem discussed above (**f12**). The parameter #num–denom indicates that PARTWHOLE$^{\text{L2}}$ $\{\textit{DIV.equal shares}\}_{\text{L2}}$ is to be applied to the previously obtained numerator (*num) and denominator (*denom). The fraction *num/denom is the obtained result. Predicted *M*-demand of this step is $e+4$.

Each step has a different *M*-demand, and the total *M*-demand of the task is given by the step with highest demand. In this example, the *M*-demand of the task is six mental schemes, derived from Step 2. Thus, this task should be accessible to 13-year-olds and older. The *M*-demand could be decreased, however, if we assume the problem solver has had relevant experiences that further chunked these schemes. For example, if the participant has memorized and automatized the multiplication table (i.e., relevant number facts), then scheme #mult-tab may not have to be *M*-boosted, and so *M*-demand would decrease by one unit. In our task analyses we usually assume that problems will be fairly novel to participants, and afterward calculate the decrease in *M*-demand that may result from further relevant experience. Additional steps to solve a problem do not necessarily add to *M*-demand. However, the need to plan and coordinate multiple steps does increase executive demand of a problem (and may require better prior experience). Agostino, Johnson, and Pascual-Leone (2010) found that children performed worse on multistep multiplication word problems than they did on one-step problems matched for *M*-demand.

Let us now compare the *M*-dimensional analysis as illustrated in formula **f12** with the *M*-construction analysis as given in combined formulas **f13**, **f14**, and **f15**. As mentioned before, *M*-dimensional analysis exhibits more clearly the overall executive-processing structure of the task and shows its key figuratives, operatives, and parameters. However, the *M*-construction analysis shows better how the executive process is implemented in real time and makes more explicit assumptions locally made to justify the *M*-demand of the task. Given that the two methods, albeit complementary, are different—the one mostly top-down (descendent) and the other bottom-up (ascendent)—why should they yield the same *M*-demand estimates (as they usually do)? The answer to this important question was explicated earlier in the chapter. Because in both cases the same strategy and effective complexity is being modeled, we must expect, if the analyses make no error, that their respective *M*-demand estimates will be the same. Thus, results of one method can serve to check and complement the other method.

Methodological Synthesis of Sequential MTA (Step *M*-Constructions) and Executive MTA (*M*-Dimensional Analysis)

Step MTA is particularly useful in sequential tasks, such as tasks involving human performance and motor activities. Its complementary alternative, dimensional/executive MTA, is more useful in problem-solving or inferential mental tasks. However, these two sorts of analysis can be synthesized into a common methodology. We illustrate again such synthesis with two very different examples: one dealing with babies' emotions, on the emergence of the feeling of jealousy, the other dealing with speeded motor performance in school children, a child's mental strategy for coping with a hard-to-do motor performance.

Example 1: Emergence of Jealousy

Consider first the emergence of jealousy in a 20-month-old. This is a true concrete happening communicated to us by the father of the child. This child (we will call him J) had had (three months before) the event of a brother (T) born into this family of four (counting Mom and Dad). Prior to the present incident, J had always expressed positive regard toward his brother, accepting to share with him Mom and Dad. “J has been known,” his father says, “to give T gifts, his favorite toys, foods, even his sucky blanket. He puts these things on T’s belly. Sometimes he kisses the baby.” But the day we talk about was different. Although at 17 or 18 months, his mother says, J occasionally expressed distress about his brother, in the event we are presenting J’s actual motive and intention seemed much clearer. Mom was holding and breastfeeding T, and J approached trying to attract Mom’s attention. Mom kindly moved J away from her. The father says, “This time he was pulling at his mom’s arm. Prying her hand off the baby she was feeding. He also was using his free hand to try and hit T in this process.” J attempted with some emotional distress to push his brother away. Dad went to J and moved him away. Father recognized that J had now expressed jealousy of his brother, which he had never done before. Why now?

Let us reconstruct in a sequence the experiences J went through. In step (1) J notices/feels Mom’s love and attention for his brother T, and Mom is not attending to J. In step (2) J has now enough M-capacity to simultaneously attend (in his working mind) to both Mom’s love for T and J’s love for Mom, which elicits a negative feeling that T is taking away Mom’s love from J. In step (3) the previous negative feeling has elicited in J’s emotional mind an operative feeling of hostility toward T, which induces J to physically show this hostility in an overt RESPONSE. The three steps are symbolized in formula (**f16**):

(1) $\text{J-NOTICES}[\underline{\text{LOVE}}_{\text{M}}\ (\underline{\text{Mom}}\text{: }\underline{\text{T}})] \rightarrow \textit{J}[\textit{feels Mom's love of T}]$
(2) $\text{J-THINKS}[\underline{\text{LOVE}}_{\text{J}}\ (\underline{\text{J}}\text{: }\underline{\text{Mom}}^{L1}[\underline{\text{LOVE}}_{\text{M}}\ (\{\text{Mom}\}_{L1}\text{: }\underline{\text{T}})])] \rightarrow$
$\textit{J}[\textit{feels T is taking away Mom's LOVE from him}]$
(3) $\text{J-FEELS}[\underline{\text{HOSTILE}}\ (\#\underline{\textit{J}^{L1}[\textit{feels T is taking away Mom's LOVE from him}}],\{\text{J}\}_{L1}\text{:}\underline{\text{T}})] \rightarrow$
$\textit{J-RESPONSE}[\textit{shows hostility}]$ **(f16)**

As usual, words in italics stand for fluents; square brackets […] placed to the right of an object/noun (or operative/verb) indicate that the scheme in question embodies cognitive/affective characteristics (or states) described inside these brackets. The symbol *L1* affixed as superscript/subscript to schemes indicates the schemes in question are *L*-structured into a chunk, and so only one of them needs to be *M*-boosted to activate the two schemes.

These formulas could be read as just complicated ways of presenting a narrative of what happened. Such interpretation would miss an important point: the narrative is here deconstructed into schemes, self-propelling constructs, and their co-activation necessitates their being boosted by *M* (because, although affectively driven, they are not perceptually salient, and contradictory negative affects—products of internalized parental “interdiction”—tends to suppress them). This is a process model, not just a narrative, and it has causal-explanatory power. It shows that limitations of *M*-capacity prevented J from being jealous before the age of 18 months. The steps of formula **f16** exhibit, respectively, an *M*-demand of $Me=3$, $Me=5$, and $Me=3$ (counting the underlined schemes in formula **f16**). These schemes express sensorimotor and not symbolic processing, because there are no misleading factors at the cognitive level, and both the affects (our *A* and *B* hidden-operators) and salient cues (*C*- and *LC*-operators) of the situation facilitate this embodied/experiential emotional processing. The demand of the total formula/model is $Me=5$—the *M*-capacity of 18-month-old or older infants (see chapter 3; Pascual-Leone & Johnson, 1991).

The three personal (i.e., affective and cognitive) schemes of J, that is, J-NOTICES[…], J-THINKS[…], or J-FEELS[…] stand for J’s emotional states, whose meaning is expressed inside the square brackets […]. The new emotional experience occurs in step 2 as an emotional not-verbalized THOUGHT of J, which in English may be expressed as, “J loves Mom who loves T!” This is a primal emotional conflict—a dialectical contradiction within the emotional *love-system* of the child: the frustrated love elicits its reciprocal emotion, *anger-aggression-hate* (Pascual-Leone, 1991b). This conflict immediately leads to step 3: J feels hostility toward T, which produces the overt aggressive RESPONSE (➔) we represent by scheme “*J*[*shows hostility*].”

This task analysis shows sequentially (*M*-step analysis) what in a dimensional/executive MTA would appeared more compactly but also more abstractly and perhaps less clearly. A dimensional/executive analysis of the same formula appears in **f16′**:

$$\begin{aligned}&\underline{\text{J-FEELthinksActs[HOSTILE}}\ (\#\underline{\text{J}_{L2}[\textit{feels T is taking away Mom's LOVE from him}}],\ \text{J}_{L2}\ :\underline{\text{T}}),\\ &\quad \underline{\text{LOVE}_{\text{J}}\ (\text{J}^{L2}}:\ \underline{\text{Mom}^{L1}[\text{LOVE}_{\text{M}}\ (\{\text{Mom}\}_{L1}:\ \text{T})}])]\ \rightarrow\ \textit{J-RESPONSE}[\textit{shows hostility}] \qquad \mathbf{(f16')}\end{aligned}$$

A comparison of **f16** with **f16′** shows that the three steps of **f16** have been collapsed, from right to left in the formula **f16′**, into a single “manifold step,” which produces as a result the final outcome. In this formula, like in all *M*-dimensional analyses, executive control of processes goes from left to right of the formula line, but temporal occurrence of events goes from right to left of the line. With these rules, **f16** appears as an unfolded version of **16′**.

A second remark worth making for this example is that it shows how personal emotions emerge within the personal mind. This sort of personal task analysis suggests how refined analyses may be conducted in clinical (and sociocultural or psychotherapy) individual-difference studies. They are congruent with (albeit more explicit than) task analyses done within the emotionally focused therapy approach (Antonio Pascual-Leone, Greenberg, & Pascual-Leone, 2009, 2014).

Example 2: Motor Rho Task

The motor rho task is a speeded-performance task in which mental problem-solving occurs as the subject synthesizes intended motor performance. Participants need to coordinate dimensions/constraints of the action sequence to maximize speed and quality of performance; this is the effective complexity of this task. The present summary is extracted from Pascual-Leone (1987). Its data (summarized in more detail in chapter 10) were replicated in Pascual-Leone's lab. The MTA of the rho task involves three successive analytical "moments": (1) the repertoire of essential schemes needed; (2) a sequential *M*-construction analysis, which presents the dimensional/operative processes involved and their effective order; and (3) an executive *M*-dimensional analysis summarizing (1) and (2) and exhibiting its executive structure.

Originally used in human performance research, the rho task was brought to our attention by Dr. John Todor (1977, 1979) in a personal communication. It is best explained with a diagram of its apparatus, which appears in figure 9.1. The apparatus consists of a crank mounted on the top of a wooden box, with a small handle to be held with thumb and index of the stipulated hand. The crank must be rotated by the hand horizontally 360 degrees, until hitting a small bumper. At the other end of the box, two warning lights, a "ready" and a "go" light, control in every trial the initiation of hand-movement action. Onset of lights is separated by a random interval. Next to the lights there is a metallic paddle that participants must hit and knock down with the hand that moved the crank, very quickly, as they complete the crank rotation. At the end of every trial the hand will have completed a trajectory resembling the Greek letter rho. The dependent variable is speed of movement in this trajectory, measured in latencies (participants were urged to proceed as fast as possible). Participants were trained in every segment of the movement performed; their final scores were average latencies when speed practice had stabilized (i.e., at the end of thirty trials) under instructions of maximum speed.

Four consecutive latency measures were used that index clearly distinct phases in the task. Pascual-Leone predicted these differences, and Todor (1977, 1979) first demonstrated them experimentally. These were: *reaction time* (RT: time elapsed from onset of "go" light to initiation of the crank movement); *circular time* (CT: from offset of RT to about 30 degrees prior to hitting the bumper); *pause time* (PT: from offset of CT to the moment when the hand releases the handle); and *linear time* (LT: from offset of CT to time of hitting the paddle). From a developmental-constructivist perspective, RT and CT are ordinary perceptual-motor performance factors: speed of motor processing and ability to "draw" very quickly a circle with the hand on the horizontal plane, which produce fast times. In contrast, PT and LT reflect problem-solving

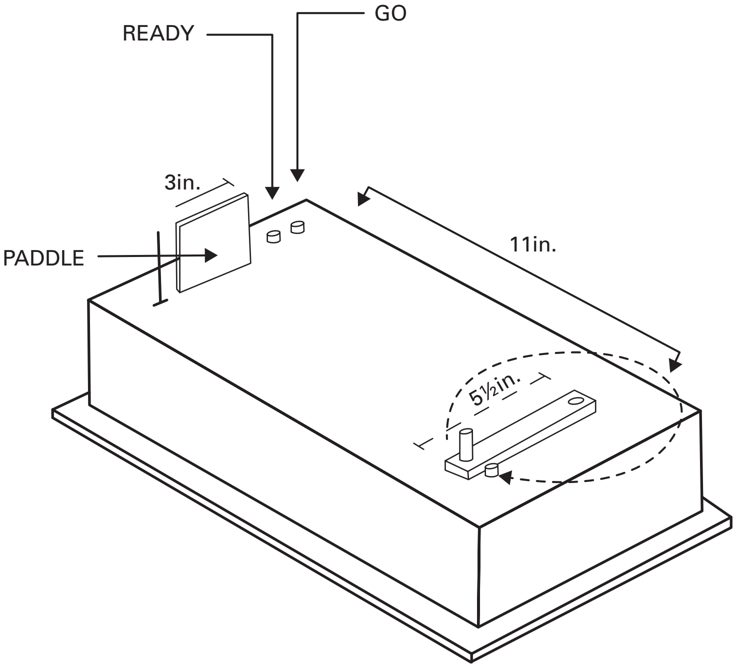

Figure 9.1

Rho task apparatus (right-hand unit). (From Pascual-Leone, J. [1987]. Organismic processes for neo-Piagetian theories: A dialectical causal account of cognitive development. *International Journal of Psychology, 22*, 559. Copyright 1987 by Elsevier.)

(concrete-operational) processing, because during them participants adjust schemes (timing of various actions) to follow the executive plan and adjust every moment to maximize speed of performance. PT and LT scores index dynamic mental-motor syntheses of mentation (mind work). A task analysis of the three “moments” or models of rho task shows its full dynamics with critical decisions taken at maximal speed. We discuss them in the natural order.

Rho Model 1 Table 9.1 shows the key repertoire of schemes required to perform the task. Identifying the schemes is first step for any task analysis. Three distinct sorts are needed: executive schemes, action schemes (both operative and figurative), and parameters (i.e., conditions, often temporally structured schemes, regulating the processing). The table evokes these schemes using intuitive terms. When the repertoire of task-required schemes is completed and refined, the other two moments in the total task are easier to complete.

Table 9.1

Three types of schemes involved in the mental processing of the rho task (PT and LT segment)

EXECUTIVE SCHEMES: PLANS FOR
“go fast,” “scan for target,” “open hand now,” “locate target now,” “go and hit target”

ACTION SCHEMES: ACTIONS FOR
GO FAST!
LOCATE TARGET PRIOR TO BUMPER!
OPEN HAND PRIOR TO BUMPER!
GO+HIT target

PARAMETERS
open hand NOW!
locate target NOW!

Adapted from Pascual-Leone, J. (1987). Organismic processes for neo-Piagetian theories: A dialectical causal account of cognitive development. *International Journal of Psychology, 22*, p. 560. Copyright 1987 by Elsevier.

Rho Model 2 Formula **f17** presents a sequential-and-executive MTA in four steps.

(1) $\underline{\text{TASKRho}}^{L1}\ (\#\underline{\text{OPENhand}}, \#\underline{\text{LOCATEtarget}}, \{\text{PUSH+TURN}\}_{L1}, (\#\underline{\text{FAST}}, \{\text{hand-on-handle}\}_{Sit})) \rightarrow \text{LOCATEtarget}$
(2) $\underline{\text{TASKRho}}^{L1}(\#\underline{\text{LOCATEtarget.PRIORbumper}}, \{\text{LOCATE}\}_{L1}(\#\underline{\text{NOW}_1}!, \#\underline{\text{FAST}}, \underline{\text{target}})) \rightarrow \$\text{LOCtarget[paddle]}$
(3) $\underline{\text{TASKRho}}^{L1}(\$\underline{\text{LOCtarget[paddle]}}, \underline{\text{OPENhand}}^{L2}\ (\#\underline{\text{PRIORbumper: \#OPENhand}}, \#\underline{\text{NOW}_2}!, \{\#\text{FAST}\}_{L1}, \{\text{hand}\}_{L2})) \rightarrow \$\text{hand[OPENED]}$
(4) $\underline{\text{TASKRho}}^{L1}(\{\text{GO+HIT}\}_{L1}(\#\{\text{FAST}\}_{L1}, \$\underline{\text{hand[OPENED]}}:\$\underline{\text{LOCtarget[paddle]}})) \rightarrow$
$\rightarrow \$\text{RESPONSE}$ **(f17)**

The task’s sequence is represented. In step 1 a general operative of the task (TASKRho) is already chunked (coordinated via intratask learning) with the task’s hand and handle circular movement that leads the hand toward the bumper, that is, PUSH+TURN (this chunking is symbolized by super/subscripted *L1*). In other steps TASKRho is chunked also with LOCATE (the target in space) and with GO+HIT. OPENhand has a misleading scheme (not represented in the formulas) inducing it not to open the hand until hitting the small bumper (as is done in most life activities, induced by *F* and *LC* factors); this misleading scheme is contradictory with going very FAST. Unless local cues have been fully automatized, which is not expected, TASKRho must carry two parameters (#LOCATEtarget and #OPENhand) telling it when, to optimize speed, the target/paddle must be localized and then the hand opened. PUSH+TURN has another parameter with the injunction of doing it as FAST as possible (notice that, in steps 3 and 4, FAST no longer needs to be *M*-boosted because, via intratask learning, it has been chunked with TASKRho).

In step 2 the general operative, carrying a parameter to locate the target PRIOR to hitting the bumper, implements the now-required LOCATE response. This specific operative has two parameters, #FAST and #NOW_1!. At the appropriate time the scheme to LOCATEtarget is called by the corresponding parameter NOW_1!. The figurative scheme *target, on which LOCATE applies, must be boosted with *M*. This step produces the response (➔) of location of target in true space, which will guide in step 4 movement of the hand. Notice that $LOCtarget[paddle] is prefixed with the symbol $ to mean that this scheme refers to a here-and-now real event (it is applying on a real object in space, it is actually true).

In step 3, the child proceeds to OPEN hand prior to bumper when parameter #NOW_2! demands it. As a result of this action (➔), the hand becomes free from the handle ($hand[OPENED]). In step 4, the hand moves toward the paddle to HIT it, producing the intended FAST and true ($) final RESPONSE.

The steps with highest *M*-demand (number of schemes underlined) are 2 and 3. This *M*-demand is five symbolic schemes (i.e., $Md = e + 5$). This is the mental-attentional demand when a speeded optimal-performance strategy is used. However, children with less *M*-capacity may solve this task using less speed in their performance. Indeed, there are three possible passing strategies in the Rho task.

Passing strategy 1 is a slow strategy that uses the four key operative schemes but no parameters. With this strategy, children can perform the task without exhibiting errors, such as "forgetting to open the hand before attempting to move toward the target" or "moving toward the paddle without having located this target in space." These two errors, together or separate, can be found in 5- or 6-year-olds: the first appears as an attempt to move the hand toward the target while still holding the handle; the second as rapid hand movements that miss the target and go toward the ceiling. Using strategy 1 (with no parameters) children with a maximum *M*-capacity of $e + 3$ (i.e., 7- and 8-year-olds) would be slow but succeed in the task.

Passing strategy 2 uses the three key action schemes and one parameter (one of the various parameters # indicated in formula **f17**), with an *M*-demand of $e + 4$, first accessible to 9- and 10-year-olds. Thus, these two ages should exhibit significantly faster PT+LT latencies than 7- and 8-year-olds, and the 7-year-olds should not differ from 8-year-olds because they have the same maximal *M*-capacity. These predictions are supported by Todor's (1977, 1979) data and unpublished results from our lab from about 1985 (Pascual-Leone, 1987), some of which we summarize in chapter 10.

Passing strategy 3 is modeled in formula **f17;** it has four operative schemes and two key parameters: Now1! (Locate) and Now2! (Open). The *M*-demand of $e+5$ makes the strategy first accessible at 11 and 12 years of age. Thus, 11- and 12-year-olds should produce the shortest latencies. Notice that the two key parameters must be boosted with mental attention (*M*), because for both there are misleading schemes that would induce error if parameters of Now! are not highly activated. The scheme Now1! (locate target prior to bumper) is contradicted by "bad" habits induced by Gestaltist misleading factors (*F*-operator, S-R compatibility) that lead participants to forget about location of targets until after releasing the handle. Scheme Now2! (open hand prior to bumper) has a similar "bad" habit interfering with it: not to open the hand until after touching the bumper. These *F*-facilitated misleading factors interfere with fast responding, making it necessary to boost the Now-parameters with *M*.

Rho Model 3 This simpler MTA lists only operatives that constitute the executive strategy or executive plan. Some analysts may prefer in some tasks to demarcate this executive plan (rho model 3) before attempting to model fully a step *M*-construction (like rho model 2) or a full executive *M*-dimensional formula. When rho model 2 is properly done, rho model 3 often becomes a sort of a summary of steps used in the former, as formula **f18** shows:

$$\text{TASKRho}^{L1}[\{\#\text{FAST}\}_{L1},\ \mathit{(1)PUSH{+}TURN{::}(2)LOCATE{::}(3)OPEN{::}(4)GO{+}HIT}] \rightarrow \text{\$RESPONSE} \qquad \textbf{(f18)}$$

Rho Performance Data The Rho task, with its four time-scores (RT, CT, PT, LT), was designed guided by a prior metasubjective analysis similar to the one we have presented. This MTA suggested that one should minimize, via intensive training, the unavoidable misleading factors that could affect performance (particularly the Now! parameters). Participants were given practice so that the obtained time-scores were their best after much training. We therefore expected the best performance-level children could produce after learning has taken place. We now briefly summarize results of Todor (1977), which we replicated, showing the performance level that children of different ages attained under these conditions. Findings support our analyses.

Figure 9.2 shows average mean latency (PT + LT) of mental problem-solving during the rho task. Children were administered thirty trials after an initial training practice, and mean latencies reported are an average of the last five trials during testing. PT and LT are, together, the time interval used during spatial location of the target, the opening of hand, and the going to target. The stagewise age trends shown in figure 9.2 were statistically significant (Todor, 1977). The data show that 5- and 6-year-olds, who should not be able to cope with passing strategy 1, in fact produced a very long mean latency, around 325 ms. In contrast, 7- and 8-year-olds, with the *M*-capacity to cope with passing strategy 1, show a significantly faster mean latency of about 260 ms. Similarly, the two other age groups (9 and 10 years and 11 and 12 years), who should be able to handle passing strategies 2 and 3, respectively, show a mean latency of about 225 ms and 170 ms. The *M*-capacity of all these children was measured by Todor (1977) using Pascual-Leone's CSVI (compound stimuli visual information task, Pascual-Leone, 1970), and all the children had attained the *M*-capacity predicted for their age group. It is important to note that (consistent with our theoretical model, see chapter 7) odd-even contiguous age-group differences (i.e., 5 to 6, 7 to 8, 9 to 10, 11 to 12) were not statistically significant, because these children have the same *M*-capacity. Equally important, the performance attained by 11- and 12-year-olds (in PT + LT mean time) does not in fact differ from that found in adults.

The MTA-predicted time-score pattern is fully recovered in these summary data, which yield a clear, decreasing step function. Resulting performance should express our rho MTA model, after task-learning has been maximized. In chapter 10 we again discuss

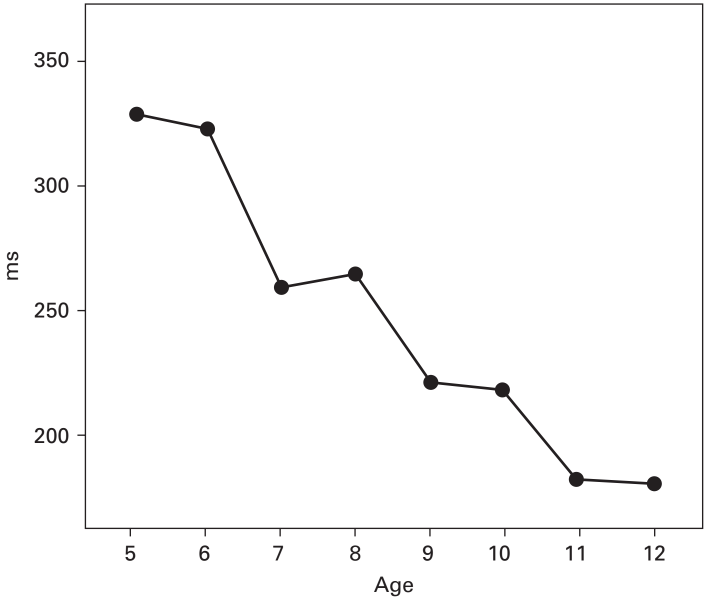

Figure 9.2

Average latency data on the mental-processing segment (PT + LT) of the rho task, as a function of chronological age. Reprinted with permission from Todor (1977, p. 226).

the rho task, and present data showing that this age-bound step function is generated by the left brain hemisphere and not by the right.

Conclusion

In this and the previous chapter we reviewed our method of metasubjective task analysis, its epistemological/ontological foundations, and notational rules. Use of congruent (iconic, epistemologically reflective) symbolic representation is important in this method, because it facilitates analysis, making easier mindful thinking on task processes. The MTA method helps to causally explain transitions between developmental stages, from infancy to adulthood, and helps to integrate cognition with affective/personal processes, and psychometric intelligence with developmental intelligence. In chapters 10 and 11, we address how it could help to integrate neuroscience with cognitive-developmental science.

The Working Mind

Meaning and Mental Attention in Human Development

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