LOGICAL AND PSYCHOLOGICAL PARTITIONING OF MIND: DEPICTING THE SAME MAP?

Philip V. Kargopoulos
Aristotelian University of Thessaloniki, Greece &
Andreas Demetriou
University of Cyprus, Cyprus

Correspondence: Andreas Demetriou, Department of Education, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus.
Tel: +357 2 338881; Fax: +357 2 339064; email: **ademet@ucy.ac.cy**

Abstract

The aim of this paper is to demonstrate that empirically delimited structures of mind are also differentiable by means of systematic logical analysis. In the sake of this aim, the paper first summarizes Demetriou's theory of cognitive organization and growth. This theory assumes that the mind is a multistructural entity that develops across three fronts: the processing system that constrains processing potentials, a set of specialized structural systems (SSSs) that guide processing within different reality and knowledge domains, and a hypecognitive system that monitors and controls the functioning of all other systems. In the second part the paper focuses on the SSSs, which are the target of our logical analysis, and it summarizes a series of empirical studies demonstrating their autonomous operation. The third part develops the logical proof showing that each SSS involves a kernel element that cannot be reduced to standard logic or to any other SSS. The implications of this analysis for the general theory of knowledge and cognitive development are discussed in the concluding part of the paper.

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This paper, co-authored by a logician (Kargopoulos) and a cognitive developmentalist (Demetriou), is intended as a contribution to what we might call developmental cognitive science. For the sake of this aim, we will take a theory of cognitive development and try to show that the partition of mind proposed by this theory on the basis of developmental and psychometric-like evidence is sound from the point of view of logic as well. This is the theory developed by Demetriou and colleagues (Demetriou, 1983, 1993a, 1993b; Demetriou & Efklides, 1994; Demetriou, Efklides, & Platsidou, 1993a; Demetriou, Efklides, Papadaki, Papantoniou, & Economou, 1993; Demetriou, Platsidou, Efklides, Metallidou, & Shayer, 1991; Shayer, Demetriou, & Pervez, 1988). As a full theory of cognitive organization and growth, this theory involves propositions, assertions, and hypotheses about (a) the structural organisation of the human knowledge acquisition and problem solving devices and capabilities, (b) the causes and mechanisms which are responsible for the change of these devices and capabilities with age, (c) and their structural and functional properties at different ages. This paper will focus only on what the theory claims about the structural organization of human mind.

In the first part of the paper we will present in summary the structural systems and hierarchical levels of mind postulated by the theory and the laws governing their organisation and development. The second and the third part are both intended as a demonstration of how the empirical and the logical study of mind can be used jointly in order to substantiate the theory's postulates about the structural organization of human mind. Specifically, in the second part we will spell out the empirical implications of our structural assumptions and summarise a series of studies that were conducted with the aim to test these assumptions from the point of view of the developmental or the psychometric tradition. So far nothing particularly original is going on in the paper: as usual, a psychological theory is substantiated by the standard psychological means and methods. The originality of this paper, if it should be credited with any, resides in the third part -or better in the combination of the third part with the first two. Specifically, in the third part we will attempt to show by means of systematic logical analysis that the structures described and empirically demonstrated by the theory are logically distinct as well. That is, this part will attempt to show that the structures which appear to be developmentally and psychometrically distinct of each other also require different formal logical systems if their logical aspect is to be satisfactorily modeled. It may be said here that the reader who is familiar with our theory may skip part one and two and go directly to the third part of the paper.

In a sense, the line of our main argument is identical to that of Piaget but our conclusion is exactly the opposite of what he kept saying to us for more than half a century. He believed, as we believe, that there must be a basic equivalence between the psychological and the logical architecture of human intellect. However, he spent his whole life trying to show that the cognitive operations and processes at each of the successive stages of development spring from the same underlying structure d' ensemble which can be modelled by some kind of logic (the group of displacement, the logic of functions, the logic of the concrete operational of groupings and the logic of the lattice- and the INRC group structure at the stage of sensorimotor, preoperational, concrete and formal operational intelligence respectively). On the contrary, we will try to show that developmental and psychometric differentiation between cognitive functions and processes is not, as Piaget thought, plain noise in the functioning of the real psychological subject which has to be removed in order to uncover each stage's underlying ever-present unique logical structure. It is our opinion, that developmental and psychometric variation of cognitive functions and processes may indicate a deeper differentiation at the semantic and the logical level. In Piagetian terms, our position is that if there are multiple levels and multiple structures in the organization of the human mind these levels and structures must be able to be specified by different methods and means.

The Principles of Cognitive Organisation

The five principles to be presented below are regarded as the general laws which govern the relations of the mind with the environment and the relations between the various systems and subsystems of mind. In other words, the principles aim to capture the organisational forces whose operation results in the formation, operation, and development of various cognitive systems that humans use to represent and understand the world, themselves included and interact with it in adaptive ways. These are the domain specific systems and the domain free self-awareness and self-regulation system to be described below. Space considerations do not allow a full explication of the principles in this paper. Thus, they will only be stated in brief to facilitate the reader to follow our argumentation about the factors underlying the differentiation between systems. The reader interested in a full explication of the principles is referred to other sources (Demetriou, 1993b; Demetriou & Efklides, 1988, 1994; Demetriou et al., 1993a).

The principle of domain specificity. According to this principle, the person and reality are structurally tuned to each other. As a result, the person tends to organise his interactions with reality into domains of thought that preserve the dynamic and figural peculiarities of different reality domains. Thus, cognitive strategies, skills, and operations, like the various components of each of the SSSs described above, are integrated into the same functional system. These systems are therefore specialized in the sense that they originate from and they direct the person's interactions with special reality domains.

The principle of formal-procedural specificity. According to the first principle above, the SSSs are domains of thought mapped onto different reality domains. Therefore, the mental acts, operations, or processes characterising each of the SSSs must be able to extract, encode, store, recover, reproduce, or reconstruct the elements and relations that define the reality onto which each SSS is mapped. If this were not the case, reality domains might be confused by the thinker. This would lead to misapplication of SSSs, with all the ensuing negative consequence. Therefore, as problem solving devices, the various SSSs are characterised by different representational, operating, and functional properties.

This being the case, a further consequence is obtained. Specifically, the various SSSs constitute domains of thought involving different formal properties. These would have to be able to model how "truth" or success is constructed and evaluated within each SSS. Therefore, different formal systems, such as systems of logic, may be required in order to capture the defining properties of each SSS. We will attempt to show in this paper that this is indeed the case.

The principle of symbolic bias. According to this principle, each SSS is biased toward those symbolic systems or subsystems which are more conducive than others to (a) the representation of the properties and relations of each SSS's reality domain and (b) the efficient application of its own operating processes onto the elements of the reality domain concerned.

The principle of subjective equivalence-distinctness of abilities. According to this principle, cognitive experiences which differ between each other according to the three principles above are felt or cognized by the person as distinct from each other. Otherwise, they are felt or cognized as functionally similar or equivalent. These feelings and cognitions continually contribute to the creation, recreation, and expansion of a mental map of one's mind to which one might refer whenever the present moment's decisions need to be mindfully informed by the decisions made in the past.

The principle of developmental variation. According to this principle, it is unlikely that a person would either distribute his time evenly across different reality domains or never come across a given domain. Two implications follow from this assumption. On the one hand, intra- and inter-individual variation in the functional status of the SSSs would be the rule in development. On the other hand, naturally, there would exist a certain range to this variation. This range depends upon both the operation of the self-understanding and management factors noted above and the operation of constrains related to the processing potentials characterising a given individual in relation to other individuals or the same individual at different ages.

The Architecture of Developing Mind

The five principles provide for a multidimensionally organised mind. In particular, their joint operation would generate structures which would be domain, procedurally and -possibly- formally specific and symbolically biased. Moreover, there should be a self-awareness and self-regulation structural system. This system would, on the one hand, be autonomous of the structures referred to before and, on the other hand, would "know" and interact with these structures. Finally, the functioning and development of all of these structures would depend upon the constructional characteristics of the human mind. These are reflected in the ways information is stored and processed in the system. Below, we will present the SSSs in some detail as these are the focus of the present paper. The two general systems will be presented very briefly and only to the extend needed by the reader who is not familiar with the theory to acquire an idea about the full architecture of mind advocated by the theory so as to be able to follow the methodological specifications of the studies to be described below and the general discussion at the end about the dynamic relations between systems during development.

The Specialised Structural Systems

The Qualitative-Analytic SSS

This SSS involves abilities which enable the individual to represent and process the qualitative aspects of reality. Specifically, this SSS is the basic production mechanism underlying the construction, representation, and processing of categorical structures. Therefore, this SSS is oriented to the processing of similarity-difference relations. That is, this is the system enabling the thinker to go from isolated properties of stimuli to the knowledge structures to which these properties are related. Evidently, the aim is to give meaning to the properties of reality elements presently observed in relation to relevant knowledge constructed in the past in order to help the organism make decisions which are important vis-a-vis a given goal.

As a processing system, this SSS is primarily analytical. That is, its functioning is based on the specification and disentangling of the various properties that may co-define the objects of reality. Once this is possible, the various properties can be treated as "pure" objects of thought activity. That is, as the building blocks which can be used by the mind in order to build conceptual systems which capture the semantic and logical relations between these properties and hence of the objects represented (e.g., the "greenness", or "redness", or the "squareness", or "circularness" of objects are combined to build the concepts of green squares, red squares, green circles, and red circles etc.).

As a representational system, the qualitative-analytic SSS is biased to figural representation or to the declarative aspects of language which seem able to encode the identifying properties of things as well as the relations between properties into class systems. An example in this regard is the "natural kind" terms (e.g., "cat", "animal", etc.) which are apt to reveal the class inclusion relations between categories belonging to the same class hierarchy.

The Quantitative-Relational SSS

Reality has clear quantitative properties which are independent of knowing systems -be they animals, humans, or robots. Reality elements, be they atoms, stones, humans, or stars tend to aggregate or separate so that they increase, decrease, devided or multiply in space or time. Thus, the quantitative-relational SSS is concerned with the representation and processing of these aspects of reality. As such, it is relational in nature because any quantity Q participates in other quantities $Q_{+}1$ and it exists only in relation to them. As an operating system, the quantitative-relational SSS involves abilities which enable the thinker to (re)construct the quantitative relations between reality elements varying along one or more dimensions as well as to inter-relate the dimensions themselves. As a representational system, the quantitative-relational SSS is biased to a symbolic medium which enables the thinker to focus on quantitative properties and relations and disregard those properties and relations which are irrelevant to quantitative processing. Thus, this system involves the following component of abilities.

Abilities of quantitative specification and representation. Counting acts, such as pointing, bringing in and removing, and sharing may be taken as the overt manifestations of these abilities. These enable the thinker to specify the basic quantitative relations mentioned above (i.e., increase, decrease, and redistribution). That is, to grasp and represent the relations which connect the single elements of reality once these are mentally deprived of all of their identifying properties. Evidently, these abilities enable the thinker to construct the notion of quantity Q as such, that is, as a construct that defines the meaning of the element which belongs to it and which is defined by these elements. The abilities below are secondary to these basic abilities and they help to specify the relations between quantities.

Abilities of dimensional-directional construction. They refer to operations enabling the person to specify different types of quantitative relations. For instance, increase or decrease which may be regular or irregular, linear or curvilinear, etc. These abilities underlie the dimensionalization of reality and they should be regarded as the building ground on which the concept of variable is constructed.

Abilities of dimensional-directional coordination. These enable the thinker to grasp and specify inter-dimensional relations. Thus, these abilities are the basis of complex mathematical thinking such as proportional reasoning.

It has been noted that the identifying properties of elements are irrelevant to the domain of relations onto which this SSS is mapped. Indeed, referring to identifying properties of elements may even interfere with the construction processes yielding quantitative concepts and dimensions. For these reasons, the quantitative-relational SSS is biased to symbol systems enabling the thinker to focus on, represent, and process the quantification-relevant aspects of reality and ignore all irrelevant aspects and properties. The arbitrary and unique mathematical symbolization does just this.

The Causal-Experimental SSS

The relations between objects and persons usually change. In this dynamic state of the world, some objects or persons sometimes function as the cause of change and others as the recipient of causal effects. Sometimes the cause-effect relations are clear and directly available to the senses. Frequently, however, causal relations are masked by the presence of unrelated elements. In fact, causal interactions may be so concealed (like the interactions between planets or particles within atoms) or conspicuous and immaterial (like the effects exerted on human behavior by desires, ambitions, evil or good feelings) that they would never strike onto the senses. The concealed interactive reality structures constitute the domain of the causal-experimental SSS. That is, this SSS is directed at disembodying cause-effect relations out of broader networks of phenomenally relevant but essentially irrelevant relations in regard to a phenomenon, and at building models representing these networks of relations. In the sake of this aim the following component abilities are involved.

Combinatorial abilities form the cornerstone of this SSS. This is so because they function as the means used by the person in order to exhaustively define the broader coexistence structure on which the person would have to operate.

Hypothesis formation abilities enable the person to induce predictions about possible causal connections on the basis of data patterns. The predictions must be taken by the person, at least implicitly, as propositions to be verified or falsified by experimentation.

Experimentation abilities enable the person to "materialise" hypotheses in the form of complementary experiments. This is equivalent to finding ways of giving actual form to the world of the possible. The isolation-of-variables ability is probably the best example of this set of abilities.

Model construction abilities enable the person to properly map the results of experimentation with the original hypothesis in order to arrive at an acceptable interpretative framework or theory.

As a representational system, the causal-experimental SSS has to be biased towards those aspects of symbolization which are conducive to the representation of the dynamic character of the interaction structures onto which it is mapped. That is, the cause-effect relations which by definition involve agents of action and recipients of action which has direction, strength, duration, etc. The dynamic-procedural components of language (e.g., prepositions, adverbs, verbs) and mental imagery seem apt to represent these kind of relations.

The Spatial-Imaginal SSS

This SSS is directed to those aspects of reality which can be visualised by the "mind's eye" (Kosslyn, 1978) as integral wholes and processed as such. Evidently, this SSS comes out of and directs the activities which are related to location and orientation in space. Therefore, its component abilities are applied within a mental space structured on the basis of topological relations and spatial coordinates which structure real space. Thus, this system involves cognitive abilities such as mental rotation, image integration, and image reconstruction. These abilities preserve on the mental level the actions that one can execute on real objects in space.

The symbolic bias of this SSS is more easily specified than that of the other SSSs. Mental imagery and related symbol systems (e.g., drawings, pictures, etc.) appear particularly pertinent to represent space and its contents.

The Verbal-Propositional SSS

All four SSSs presented above specialize on the representation and processing of real relations in the environment (i.e., categorical, quantitative, causal, and spatial, respectively). This SSS is concerned with the formal relations between mental operations rather than with the relations between the objects denoted by the propositions involved in a propositional argument. The identifying characteristic of this SSS is the ability to differentiate the contextual from the formal elements of a series of statements and operate on the latter. This is so because relations in other SSSs may directly be cued by the context in which the thinker operates. In the case of this SSS it is not the context but the type of relation between the propositions which is important. "In effect, the propositional processor may be conceived as a subjugation agent charged with two main duties. First, to selectively cut down those semantic networks which, being unrelated to the formally determined goal of the task at hand, will divert processing to probably sensible but logically irrelevant conclusions. Second, to assemble the defended elements of the argument so as to produce a logically valid conclusion. In other words, the propositional processor functions in both ways; it suppresses and creates meaning at the same time" (Demetriou & Efklides, 1988, p. 188).

As a representational system, the verbal-propositional SSS seems to have access to "a code of logical validity". This code may be conceived as a system of rules which defines, first, how the thinker can differentiate the logically relevant from the logically irrelevant components of the propositions involved in an argument (e.g., "focus on the words signifying logical relations -i.e., 'if...then', 'either...or', 'and', etc.- and ignore all other words in the argument". Second, it defines how one can separate the true from the false relations suggested by a sequence of logical terms (e.g., in an 'if...then' argument any of the cases p.q, -p.q, and -p.-q is true and the case p.-q is false. Therefore, the verbal-propositional SSS is biased to those aspects of natural language (e.g., conjunctions and quantifiers) or any other substitute of natural language (e.g., the symbols of logic) which facilitate the thinker to reject the logically irrelevant and process the logically relevant elements.

The General Systems

The Hypercognitive System.

This system is responsible for self-monitoring, self-representation and, self-management. As such, this system may be viewed as the interface between (a) the person and the environment, (b) any of the SSSs or any other cognitive functions, and

(c) the various SSSs or cognitive functions and the processing system to be described below.

At a macrofunctional level, this system involves knowledge and action plans related to the three main aspects of cognitive functioning. First, it involves a model of cognitive organisation and functioning. This model may be seen as a mental map that involves information about different cognitive functions (e.g. attention, memory, reasoning, etc.) and different problem solving devices like the five SSSs described by our theory. It also involves information specifying what functions and/or SSSs may be used in response to the problems encountered, how they may be used and coordinated etc. Second, the hypercognitive system also involves a model of intelligence which specifies what is intelligent in a given environment and includes decision rules about how one may act intelligently. Finally, this system involves a model of cognitive self, which involves the person's self-representations and preferences as a cognitive and intelligent being. In a sense, the three models refer to the person's cognitive psychology, the person's psychology of intelligence and the person's psychology of herself.

At a microfunctional level, the hypercognitive system controls on line cognitive functioning. At this level, this system is involved in making decisions of three different kinds. First, decisions as to the SSS-task affiliation. These are decisions aiming to ensure that (a) the right SSS and (b) the most relevant task-specific schemes will be brought to bear on the task at hand. The second set of decisions underlies the appropriate and efficient use of these schemes in relation to the condition of the processing system and of other cognitive functions. The third set of decisions refers to the evaluation of the outcomes of processing and the projection of evaluations on the macrofunctional level. Thus, every problem solving attempt contributes to the refinement of the mind's hypercognitive maps which will be called upon during the problem solving attempts to follow.

The Processing System.

To be able to use any of the SSSs or to be able to monitor the use of the SSSs or any other skill or behavior, the person must possess a system in which information can be represented and processed. This system is considered to be a dynamic field that can be defined in terms of three dimensions: speed of processing -the minimum time required if a given mental act is to be effectively executed; control of processing -this is a mechanism that functions under the guidance of the task-goal like a filter which permits only goal-relevant schemes to enter processing space; and storage -which refers to the maximum number of schemes that the person can keep active and process at the same time.

The systems at the three levels of the cognitive architecture (i.e., the processing system, the SSSs, and the hypercognitive system) are considered to be at constant interplay during micro- and macrodevelopment. Their relations will be discussed in the concluding section of the paper.

Empirical Validation of Principles and SSSs

There are at least four different approaches that one would adopt to test the status of the SSSs described by the theory. The simplest one would involve tasks addressed to one or more component abilities of at least two SSSs. In this simple case, the tasks addressed to each SSS can be presented in the symbol system to which each of them is primarily biased. Under these conditions, exploratory or confirmatory factor analysis would have to yield factors that can be interpreted to stand for the SSSs represented by the tasks used in the study. This is the experimental design that we employed during the first phases of our research programme. In fact it was from studies of this kind that the five SSSs were induced (Demetriou, 1983; Demetriou & Efklides, 1981, 1985, 1989; Shayer, Demetriou, & Pervez, 1988).

A more complete test of the theory would have to involve the organizational principles. This is so because from an epistemological point of view, the principles reside on a higher level than the SSSs themselves. That is, assuming the principles implies that SSSs of some kind have to exist. However, by themselves, the principles do not dictate what systems are in existence. Hence, disproving any of the SSSs or discovering new systems does not falsify but that part of the theory that is concerned with the specialized systems. Nevertheless, rejecting the principles, would seriously undermine the theory as a whole because it would cast doubts on the underlying reasons of the multidimensionality of mind.

According to the analysis advanced above, each of the principles represents a particular kind of influences on cognitive organization and functioning. Therefore, a study that would aim to validate the operation of the organisational principles across SSSs would have to be able to demonstrate the power of each principle to chanellize performance on tasks independently of the power of other principles. Violating this assumption would imply that the principles may be reduced to each other. This would, in turn, indicate that each of the principles cannot be taken as an independent causal agent responsible for the patterns of performance observed.

Under the assumption above, the minimal design for the validation of organisational principles would have to involve tasks made to represent at least two principles. In turn, each of the principles would have to involve tasks representing at least two of the constructs (e.g., two domains of two symbol systems) that each of the principles is presumably able to differentiate. An example of this minimal design is shown in Table 1.

Insert Table 1

It can be seen in the model shown in this figure that there are four tasks addressed to one SSS and four tasks addressed to another SSS (SSS_1 and SSS_2 may stand for any of the five SSSs described by the theory). Two of the tasks addressed to SSS_1 and two of the tasks addressed to SSS_2 are biased to be represented and processed through a given symbolic system SYM_1 and the other two tasks addressed to each of the two SSSs are biased towards a different symbol system SYM_2 (SYM_1 and SYM_2 may stand for any symbol system such as language, mathematical symbolism, or pictorial-figural symbolism).

Under these specifications, the model that would fit performance on the eight tasks would have to involve four principle specific factors. Specifically, the two $\mathit{SSS_1}$-SYM_1 and the two $\mathit{SSS_1}$-SYM_2 tasks would have to load on one factor that would stand for $\mathit{SSS_1}$. The two $\mathit{SSS_2}$-SYM_1 and the two $\mathit{SSS_2}$-SYM_2 tasks would have to load on another factor that would stand for $\mathit{SSS_2}$. Also, the SSS_1-$\mathit{SYM_1}$ and the SSS_2-$\mathit{SYM_1}$ tasks would have to load on a third factor that would represent $\mathit{SYM_1}$ and the SSS_1-$\mathit{SYM_2}$ and SSS_2-$\mathit{SYM_2}$ tasks would have to load on a fourth factor that would represent the $\mathit{SYM_2}$ symbolic factor, respectively. In such a model, the SSS_1 and the SSS_2 factors may be taken as an index of the power of the principle of domain specificity to differentiate between groups of tasks presumably addressed to different domains. Likewise, the SYM_1 and the SYM_2 factors may be taken as an index of the power of the principle of symbolic bias to systematically affect performance over and above the forces related to the structure of domains. Finally, all eight tasks would have to be related to a common general factor. This would represent the operation of two domain-free systems invoked by the theory.

This model was validated in several studies that involved different SSSs and different symbolic systems. Specifically, the first of the studies presented in Demetriou, et al. (1993a) involved two SSSs (the quantitative-relational and the causal-experimental) and two symbol systems (the numerical and the imaginal). The three studies presented in Demetriou, Efklides, & Platsidou (in preparation) involved three SSSs, namely the qualitative-analytic, the quantitative-relational, and the causal-experimental, and three symbol systems, namely, the verbal, the numerical, and the imaginal. The confirmatory factor models models tested on the basis of the general model shown in Table1 were all found to have an excellent fit to the data.

It is a commonplace in psychology that correlational evidence, even as thorough and systematic as the evidence generated by modern causal modeling, should be taken with caution as an index of the existence of presumed underlying structures and dimensions. Direct experimental manipulations of these structures and dimensions would be a stricter test of their status. In the present context, training is the manipulation of choice as a test of the functional autonomy of the SSSs. Specifically, a training study can test the two basic assumptions following: "First, if they are autonomous, then each SSS should display a distinct pattern of change in response to training, thus indicating developmental/functional peculiarities. Second, transfer of training from one SSS to the other should be limited. This is so because training is received through a particular procedural/conceptual/symbolic system rather than through an abstract operational structure such as those described by Piaget. If the systems were functionally interchangeable, any effects of training would transfer fully from the one SSS to the other." (Demetriou et al., 1993a, p.59). We did test these assumptions in a study that involved the quantitative-relational and the causal-experimental SSS. In this study, subjects of 10, 12, 14, and 16 years of age were pretested on the two SSSs and, on the basis of their pretest performance were allocated to the quantitative-relational SSSs training group, the causal-experimental SSS training group, and a control group which received no training. The subjects in the two experimental groups were trained on tasks one level above their pretest level. The results came in full support of the assumptions above. That is, the size and patterns of change observed in response to training were considerably different between the two SSSs, indicating differences in their organization. Moreover, the transfer of change within each of the two SSSs was satisfactory and much more extended than across SSS transfer, indicating that there are boundaries between SSSs which cannot be crossed automatically (Demetriou et al., 1993a; Efklides, Demetriou, & Gustafsson, 1992).

The fourth approach is concerned with the principle of subjective equivalence-distinction of abilities and the ensuing functioning of the hypercognitive system. Specifically, this principle states that cognitive functioning continually contributes to the creation and refinement of a mental map of cognitive functions and SSSs. This map may be used by one during on-line processing when one needs to make decisions about the appropriate course of action. Therefore, this map must reflect the objective structure of the cognitive system. It is only under this condition that the hypercognitive system would be able to function as the interface between SSSs and reality or among any of the SSSs. The empirical implication of this assumption is clear. Scores given by subjects as indexes of their metacognitive evaluation of several aspects of performance on tasks representing different SSSs, such as subjective difficulty, subjective success, or subjective similarity between tasks, would have to yield factors corresponding to the SSSs represented by the tasks involved. This would indicate that the forces underlying real cognitive performance are projected on and used by the hypercognitive system when needed to make decisions about the best course of action depending upon the task at hand. A series of studies that involved all SSSs (Demetriou & Efklides, 1985, 1989; Demetriou et al, 1993a, Study 3; Demetriou, Macris, & Adecoya, 1992) showed clearly that the hypercognitive map of mind does involve the five SSSs as distinct constructs.

Logical Validation of the SSSs

The Context and Aims of Analysis

As stated at the outset, this theory aspires to more than simply accomodate the data indicating systematic variation in individual differences: its ultimate aim is to provide an account of the architecture of the mind, and it maintains, based on the evidence summarized above, that at mid-level architecture there are good grounds for proposing a division of cognitive abilities into five independent structural systems. Such a theoretical claim cannot be established by empirical grounds alone, especially in view of the fact that the tasks devised are already deemed to be testing different kinds of abilities. It is at this point that some support of an a priori nature is called for. As anticipated in the introduction we shall employ logical analysis to show that indeed there are different logics appropriate to different intellectual tasks belonging to different SSSs.

Let us begin by sketching out what logical analysis can do for the theory. In the best-case-scenario, logic could offer proof that there are exactly five different logical systems (even though for each system there can be many equivalent systems) each irreducible to the rest and each suited to handle a different aspect of reality. Each such logical system would correspond to a possible formalization of an SSS. Such a proof we are not able to offer, but it is important to keep in mind the optimum so that we can evaluate our progress comparatively. It is equally important to keep in mind the worst case scenarios, that is, eventualities that would show the theory to be completely wrong. Since the heart of the theory is the division of mind into five separate SSSs, there can be many worst case scenarios which condence into two general kinds:

The first worst-case-scenario would be realized if it were shown that all the SSSs could be reduced to one SSS which would be the fundamental SSS. This possibility, which might fulfill an old philosophers' or even Piaget's dream, would imply that the presumed independence of the various SSSs is a subjective illusion. From a cognitive science viewpoint it might fulfill some demand for unification of structure, but then other factors must be employed to explain systematic variation in individual cognitive abilities.

The second worst-case-scenario, and equally catastrophic for the theory, runs in the opposite direction. Instead of five identifiable independent cognitive systems, it expects that an indefinite number of such systems exists corresponding to a plethora of different cognitive abilities. In this case not only would there be a different cognitive ability for mathematics and for science, but even for different areas of mathematics and for different areas of science, a different logic for poker and a different logic for bridge and a different logic for chess. In principle such different logics could even be relativized to the person with even more disquieting results. Let us state in advance that such a nightmare is not supported by the data or by logic.

Our argument will try to show that the logical systems underlying the five SSSs are such that are not reducible to one SSS. In this way we appear to be arguing only against the first worst-case-scenario, yet the analysis of each system indicates both common points and differences between systems. This lends support to the best-case-scenario and makes the second worst-case-scenario highly improbable.

For reasons that will become clear in the discussion, we take as fundamental the verbal-propositional SSS, about which there is little doubt as to its logical analysis. It is implicit in the computational approach to the mind that if there is one system to which others could be reduced, this has to be the system of sentential and predicate calculus that makes up the kernel of accepted logical theory. One doesn't have to be a rationalist to consider it plausible that all other cognitive systems could be reduced to logical relations between propositions. Thus, one could plausibly expect that the causal-experimental SSS which analyzes causes as necessary and/or sufficient conditions can be neatly expressed by the logic of the material conditional of sentential calculus or the "all" and "only" constructions of predicate calculus.

To the extend that knowledge in other fields of cognitive activity is reducible to propositions and relations of propositions, one could argue that the above results can be extended mutatis mutandis to cover the remaining SSSs, with the sole exception of the spatial-imaginal SSS. But even in this last case, the well known dispute between descriptionists (like Pylyshyn, 1986) and pictorialists (like Kosslyn, 1980) might give hope for an eventual prevailing of the former over the latter. In such a case no need for a reduction of this SSS would be required: the SSS in question would have been explained away.

We identified the logic of the verbal-propositional SSS with that best established part of logical theory: sentential calculus and predicate calculus (henseforth "SLT" for "Standard Logical Theory"). Both these parts of logic are consistent and complete, and all of the former and much of the latter is decidable. We should not however miss sight of the fact that not all inferences that are intuitively accepted as valid can be easily handled by sentential calculus and predicate calculus. Well known examples are inferences that involve time which are not handled by the notoriously a-temporal sentential calculus and predicate calculus, which does not distinguish between "They got married and she got pregnant" and "She got pregnant and they got married". Similarly adverbial inferences are out of range of theory, since "she knits quickly" which implies "she knits" is expressed by two different predicates in logic which would mask the implication. These shortcomings of the theory are being dealt with by well known extensions of the theory into tense logic and adverbial logic, while other shortcomings lead to further excursions into deontic logic and epistemic logic, but none of these extensions of the theory is expected to have the revolutionary impact that would replace sentential calculus and predicate calculus from the heart of standard logical theory.

Before proceeding into the question of reducing the other SSSs to logical theories one important point about logic must be born in mind. This point has to do with the relations between deductive and inductive inference. Our choice of sentential calculus and predicate calculus indicate that we would like to limit our analysis to deductive logic because of both, substantial reasons and space considerations. However, we accept that induction may be used by all five SSSs and the two general systems. We will embark on the problem of the relations between the systems described by our theory and induction in a future paper. Thus, we shall limit the logic of the verbal-propositional SSS to standard deductive logical theory and leave the question of the placement of induction for later. We turn thus to the other SSSs and ask the question whether they can be reduced to standard logical theory.

Logical Analysis of the SSSs

The Qualitative-Analytic SSS

This SSS is chiefly responsible for the categorization of the world into objects, kinds, and properties. This SSS, one might think, should be easily reducible to logic in two important ways. In the first place, the basic relation that is employed, that of similarity (and dissimilarity), can be characterized logically by reflexivity, symmetry and non-transitivity (ie aSa, aSb=bSa, -{(aSb)&(bSc)⊃(aSc)}.

In the second place, once terms are formed they can be related to one another by an algebra of terms that has the same structure as Boolean Algebra. Finally, one might also argue all knowledge of terms and concepts is easily translated into the well known categorical sentences of Aristotelian logic, so that some such reduction to standard logical theory is possible. If any of these possibilities is realized the independence of this SSS is in question. Let us examine them one at a time.

It is an accepted commonplace that similarity is a vague relation. A case can be made that anything is similar to anything else and, at the same breath, that nothing is similar to anything except itself. So in the first place to speak of similarity in abstracto is incomplete: one must always specify similarity-in-what-respect. But even with that, not all similarities can form basis of categorization: despite obvious similarities wolves are categorized in a different kind from Alsatian dogs who are categorized in the same kind with pekineze dogs despite obvious dissimilatities. Lurking behind such oddities is a notion of natural kinds, which makes some similarities more appropriate than others. Yet the notion of a natural kind cannot rest on similarity.

Concerning the logic of terms, the old Aristotelian intuitive account can be supplemented by a modern extension. Here the best candidate is the general structure of a Boolean Algebra, a point advocated also by Langford and Hunting (1994). In such an algebra of elements ÷ and complement ÷' of elements, we define two operations product . and sum + implicitly by the following axioms:

÷.ø=ø.÷
÷+ø=ø+÷
÷.1=÷
÷+0=÷
÷.÷'=0
÷+÷'=1
÷.(ø+z)=(÷.ø)+(÷.z)
÷+(ø.z)=(÷+ø).(÷+z)

Easily such a structure is interpreted as an algebra of classes of things with a letter F standing for a class of things and the negation -F standing for the complement of that class. By designating 0 to stand for the null class and 1 to stand for the class of everything, we see that the product operation becomes the intersection of two classes (i.e., set of common members) and the sum becomes the union. Equality of course now is identity of classes. From here it is a short step to full reduction to predicate calculus as disjuction can take the place of the sum, conjuction the place of the product and the 0 and 1 in the equations are now the negation of the existential quantifier in front of a sentence -(∃÷) and -(∃÷)- respectively (Quine, 1974).

The problem with the above logical reductions is that they fail to capture the basic aspects of categorization, that is to say, this logic is usable once categorization is achieved. The logically interesting question is how the mind achieves "correct" categorizations and not how it handles categories once it has achieved them. Such a task cannot rest on an abstract account of similarity of terms. What is needed instead is a basic distinction between essential and non-essential (accidental) characteristics. This in turn requires an extension of logical terms into modalities where some properties are attributed necessarily while others are attributed contingently.

Such a division does make intuitive sense. Even though all pieces of gold found may be less than 10 tons in weight, still such a property is considered accidental, while the property of having atomic number 79 is considered essential. Intuitively we justify this particular distinction by saying that if we found a piece of gold weighting more than 10t, we would still call it gold, while an element with an atomic number different than 79 would not be considered gold even if it had all other apparent properties similar to those of gold.

This reasoning however makes appeal to counterfactual conditionals which stand outside of logical theory proper. Logical theory would tell us that all such conditionals with false antecedents are true, but we would like to distinguish between "true" counterfactuals and "false" counterfactuals. The task however goes clearly beyond logic.

At the same time the sheer idea of distinguishing between truths that are necessary and truths that aren't makes sense only with respect to logical relation to other sentences. When instead we speak of essential properties of objects and accidental properties, we are attributing properties in two different ways and the difference is not clear given that both properties happen to be true of the object. As Quine (1960) notes, if one describes John as a cyclist, then he is essentially bipedal and accidentally rational; if one describes him as a mathematician he is essentially rational and accidentally bipedal. Given that he is both, what sense can there be of the real essential properties of John as opposed to his accidental ones?

The extension of logic into modalities makes good sense when what is discussed is logical possibility or necessity, in other words when they are modalities de dicto and not de re. Yet what is required for categorization is de re modality, which has to do with the mode in which properties are attributed to objects. This task that seeks logical structure inside a sentence, is carried out by Quantified Modal Logic (QML). The problem with QML is that it is not accepted by all logicians as a fair extension of logic. The reasons are many. QML appears to violate well establish first order theorems of the Principia Mathematica like:

* 14.12 E! (i÷) Ö÷.⊃:Ö÷.Öø.⊃$_{÷ø}$ ÷=ø.

It also violates well known extensions of the standard theory into second-order such as the law of indiscernibility of identicals:

(÷) (ø) [(÷=ø)⊃(P) (P÷≡Pø)]

It raises questions as to substitution of variables and leads to the counter intuitive conclusion that all identities are necessary. This is shown by starting from a first order version of the above law: (÷) (ø) (÷=ø.⊃.F÷≡Fø)
and by substituting (÷=) for F we obtain

(÷) (ø) [÷=ø.⊃. (÷=÷) ≡ (÷=ø)]

But since if any sentence is necessary, ÷=÷ has to be necessary, we drop the (÷=÷) as true from the above formula and have:

(÷) (ø) [÷=ø.⊃. (÷=ø)]

The above considerations (see Quine, 1981) are not meant to advocate or discourage extensions into QML, but rather to point out the incompatibilities between QML and SLT. It is clear that whatever logical system underlies the qualitative-analytic SSS is not reducible to the SLT which we took to be the system that underlies SSS.

<u>The Quantitative-Relational SSS</u>

Passing onto the quantitative-relational SSS one might expect that this, if any SSS, would be reducible to logic, given the old worn out idea that mathematics is inconceivable without the notion of logical proof. Here two important traditions in mathematical logic, logicism (going back to Frege & Russell) and formalism (going back to Hilbert) consider mathematics as reducible to logic. If such a dream were realized not only would mathematics be out of its foundational crisis but also we would automatically have one SSS reduced to another.

A first aristotelian objection to such a program might point out that mathematics is not only a science of logical proof but above all a science of quantities. So it would be necessary for quantities to be handled completely by logic before such a reduction might be possible. Here however we encounter difficulties. Of all the various areas of mathematics two have an especially crucial role to play in this project. Basic arithmetic is considered as the most established part, so one would expect that the complete axiomatization of arithmetic would be the first to be accomplished. On the other hand the absolute common basis of all mathematical ideas (including the geometrical ones) is set theory. This would be the logical basis of all mathematics. Its logical analysis should provide the last stage in a reduction of mathematics to logic.

In the first case, that of arithmetic, Peano's axiomatization is the best established mathematical theory. Even extensions into non-standard arithmetics can be proven to contain the Peano arithmetic as a kernel. The analogous axiomatization of set theory by Zermelo-Fraenkel is considered as acceptable basis for all axiomatization of mathematics.

Unfortunately both areas, as well as the attending program of reduction, have been put into question by two celebrated theorems proven in the Thirties. The Godel theorem shows that a theory that is strong enough to contain standard Peano arithmetic is necessarily incomplete. This means that there will always be truths expressible in the theory yet unprovable by the theory.

The Lowenheim-Skolem theorem, on the other hand, has shown that any axiomatic theory that has a model, has a denumerable model. This means that any part of mathematical theory which involves non-denumerable infinities (like those involving the continuum, for example) will, by the Lowenheim-Sholem theorem, also have a denumerable model. This means that not only can we not expect our theories to be categorical, but we cannot expect them to be monomorphic, since by definition a denumerable model and an indenumerable one cannot be isomorphic. Given that categoricity and its compromise substitute, monomorphicity, are the closest we can come to a determination of reality by a theory, the result of the theory is disquieting for all of the human scientific endeavor to the extent that the latter is considered as resting on proof. For our special problem the theorem plays havoc with set theory because it puts into question our understanding of the basic relation "ε" or "is a member of" of set theory. We can no longer consider that membership is completely defined by implicit definition by a set of axioms since, as the theorem shows, these axioms define not only an equivalence class of models but also other models that are clearly non-equivalent to the former.

For our purposes the argument works as follows: To reduce mathematical thinking to other thinking, like logical thought as captured by SLT, it is a necessary step to reduce all of mathematics first to set theory. Then a second step would reduce set theory to logic. To accomplish the second step an axiomatization of set theory that would completely capture the key relationship of membership is needed. The Lowenheim-Skolem theorem tells us that no such axiomatization will capture membership, that is, would reduce ε to logic and nothing else. This means that an element of intuitive understanding of membership will always be left as something that the mathematician understands, communicates somehow, yet is unable to axiomatically determine. This element cannot be done away logically. That much is sufficient to establish our contention that despite its logical structure, mathematics retain elements that are unique to it and presuppose an intuitive grasp. The logic that underlies quantitative-relational SSS is certainly more than the logic that underlies verbal-propositional SSS.

The Causal-Experimental SSS

Analogous difficulties arise with the reducibility of the causal-experimental SSS to SLT. For a long tradition of thinkers, beginning as early as Aristotle, causes were thought of as application of logical principles to reality. Of course another tradition, as old as the previous one, saw in causes the functioning of mechanisms of nature independently of human logic. Still development of logic a century ago gave us measured hope for a complete logical analysis of causation that would use the necessary and/or the sufficient condition as the chief analysans. Thus, cause as a sufficient condition in "cyonide causes death" and as a necessary condition as in "sexual intercourse causes pregnancy" can be both analyzed by employing the conditional "$p \supset q$", taking the antecedent as sufficient and the consequent as necessary. Similar results are obtained in predicate calculus by using the "all" or "only" construction for sufficient and necessary conditions respectively.

From the time of Hume's famous criticism of causality two lines of approach to causality are employed in philosophy. Those who follow Hume are trying to analyze causality without appeal to a primitive notion of causal necessity. The others maintain that it is impossible to adequately define causality without some appeal to necessity.

If the second approach is correct, it is clear that causality cannot be reduced to logic, because at the heart of it shall remain a kernel notion that is modal, so for the reasons developed in our discussion of the qualitative-analytic SSS, it would not be possible to consider causality as an obvious extension of logic.

Turning to the first kind of approach, if we show that even that one has to appeal to a notion that cannot be analyzed by SLT, then the task is completed. Typically in the Hume-inspired ideas of causation, in addition to temporal precedence of cause over effect and spatial contiguity of the two, a third condition is added that can be as weak and simple as "'constant conjuction' of the two phenomena in the past" of Hume, or as complicated as "insufficient but necessary part of a condition which is itself unnecessary but sufficient for the result", the famous INUS condition of Mackie (1974). The trouble with all such approaches is that in addition to a precedes b, a is contiguous with b and a has been followed by b in the past, we used two added strong conditions, one of universality (a is followed by b always) and a strong condition of necessity (b would not have happened if a had not happened). It is those two extra conditions that Mackie's complex analysans is aiming to capture. Another way to do it is to say that the "a is followed by b" is a law of nature (Danto, 1973). This makes clear the dependence of the analysis on modalities, because in order to spell out what a law is one cannot be limited to the generalization formula (÷) (F÷⊃G÷), which is shared by law-like and accidental generalizations alike. The standard way of distinguisthing the two, makes appeal to counterfactuals: law-like are those generalizations that would support counterfactual inferences. We saw earlier that appeal to counterfactuals is tantamount to admitting that there is no simple reduction to SLT.

The Spatial-Imaginal SSS

The last remaining SSS, the spatial-imaginal, can be shown, a fortiori to be irreducible to the Logical-Propositional. As opposed to a logic of categorization, or a logic of proof, or a logic of causation, we have no idea what a logic of pictures would be. The long standing debate on mental imagery is a clear indication in that direction. Somehow pictures and sentences cannot be reduced to one another. There are far too many elements which distinguish images from other forms of representation like the linguistic ones. Images are immediate, they represent by every part of their structure, they have physical similarity to the depicted, they always contain aspectual elements, and they retain a strict part-whole relationship with what they depict. In contrast to the above, the symbols envisioned by other SSSs contain elements that are arbitrary, they do not represent by every part of their symbolic structure, they normally bear no similarity to the symbolized, they have no aspectual element and have a markedly different structural relation than a one to one correspondence between parts of the symbol and parts of the symbolized. It follows from the above that the spatial-imaginal SSS cannot be reduced to the verbal-propositional SSS or to its underlying SLT or to any of the other SSSs.

Let us now take stock of what has and what has not been established in this part. Strictly speaking what has been established is that the kind of thinking involved in the various SSSs cannot be reduced to that part of logical theory that forms the basis of the verbal-propositional SSS. In case after case, we saw that inspite of some well-known connections with logic, still there is always in each SSS a unique element that is characteristic of the domain, but is unanalyzable by logic (that is, the specification of essential characteristics, the inclusion of an element to a broader quantitative construct, causal necessity, and the representation of wholeness and the analogue nature of representation for the qualitative-analytic, the quantitative-relational, the causal-experimental, and the spatial-imaginal SSS, respectively). Moreover, this unique essential element is readily handled by intuition.

The above arguments do not constitute a proof that there are exactly five SSSs as the theory maintains, which would have been a fullfilment of the best-case-scenario. What we have shown instead however, is that both worst-case-scenarios (i.e., one unified cognitive system or indefinitely many cognitive systems) are highly unlikely if not impossible. Let us examine these cases one at a time.

Concerning the possibility of one basic cognitive system, we have shown that categorization, mathematical thinking, causal thinking, and pictorial thinking all have at least one unique "kernel" element that cannot be fully analyzed by the standard logic underlying the verbal-propositional SSS. So the corresponding SSS cannot be reduced to the verbal-propositional.

One might argue at this point that we have not shown that no other reduction is possible; we have only shown that reduction-to-logic as we know it, is not possible. This counterargument implies two added requirements. We have to show that (a) it is not possible that a more fundamental system of thought will be developed, perhaps a real primitive language of thought, to which all SSSs could be reduced and (b) it is not possible to reduce the SSSs to any one SSS (and not only to the verbal-propositional SSS).

With respect to the first alternative no such eventuallity can in principle be excluded: how could anyone argue that some such system will not be found? In all such cases however there is a "hic Rhodes, hic salta" counterargument. Moreover, the proponent would have to show to us how the Godel and Lowenheim-Skolem metatheorems would be bypassed.

With respect to the second possibility, there is a good argument in defense of our position. If it is not possible to reduce other cognitive systems to logic, then a fortiori it will not be possible to reduce logic and the other SSSs to some one of the SSSs other than the verbal-propositional SSS. This is so because of all the SSSs the verbal-propositional, and especially the SLT underlying it, is the most formal one. It is precicely this content-free quality of logic that accounts for its usefulness in reducing other interpreted systems to logic. This formal quality of logic is so content-free that it allows mechanization of reasoning, a fact attested to by the development of computers. All the other areas of cognition contain a kernel notion that is understood intuitively yet unanalyzable logically. How could any one of such systems be used as the basis of reduction? And would that reduction be a logical one? So this possibility is shown to be highly unlikely.

The reason we call it only "highly unlikely" and not "utterly impossible", is a long existing intellectual tradition of inductivism that wishes to explain even logic itself by inductive means. This tradition passes through a series of historical stages (empiricism, inductivism, associationism, behaviorism, connectionism) and cannot be dismissed so easily. Let us sketch how such a position could be shown to be plausible. In the first place one has to cast doubt over logical theory. Here one has a lot of psychological evidence to show that SLT is mainly an artificial theory, which despite its correctness, is never used by people when thinking. In the second place, induction has to be moved away from logic to either the quantitative-relational or to the causal-experimental SSS or to an entirely separate system of its own (to be identified with general learning system or rules of training networks). Thirdly, one has to show that all types of thinking finally reduce, at least psychologically, to induction -because logically one cannot reduce logic or mathematics to induction. Of course the absence of a theory of induction does not speak well of this possibility, but if an artificial intelligence inductive program is developed that does the kinds of thoughts involved in other SSS, then the inductivist would have done much to establish his case. Here computers who are based on SLT will understandably fail, since there is no logical theory of induction, but one can place many hopes on parallel distributed processing networks.

This possibility cannot be ruled out. Nor should it be ruled out because it must be fully explored. Yet against this naturalistic program there are some a priori arguments which come from the field of linguistics. Most linguists, most cognitive scientists, many philosophers and many psychologists are convinced by Chomsky's arguments against inductivism in language. If these arguments do show the formal character of a mental grammar and the innate character of a universal grammar, then the inductivist program is doomed to failure in all fields, given the centrality of language for cognition.

With respect to the second worse-case-scenario, namely the possibility that the number of independent cognitive systems may turn to be unmanageably high, two things must be notice at the start: (a) the number (5) of the SSSs came not a priori but as a result of empirical search that forced us to group abilities since we find them grouped analogously in the performance of various individuals. So a posteriori grounds advocate a negative reply to this possibility. (b) At the same time however, one should notice that with the exception of the imaginal SSS, the other SSSs in addition to the unique kernel element do share much of common logical structure. For anyone to show that there are indefinitely many different areas of cognition, it is necessary to show that each one of the areas is irreducible to one of the SSSs or to a combination of SSS. Our arguments have shown that some such independent realms of thought exist, but they are few. To show that there are a few more would not seriously harm the theory but the expectation that this would be an unamanageably high number is an unrealistic expectation. What kind of thinking can be shown to be such that it does not reduce to one of the five SSSs or to a combination of them?

Conclusions: From Reasoning to Logic and Mind

It seems that we have fulfilled the aim that motivated the writing of this paper. That is, we succeeded to show, as anticipated in the introduction, that the SSSs proposed by our theory on the basis of empirical evidence are logically distinct as well. This conclusion bears serious implications for the general theory of knowledge and the theory of cognitive development. These implications will only be sketched here and fully discussed latter. They are concerned with the problem of structure selection, the relations between general and domain-specific reasoning processes, and the origin of logical reasoning as a process that must be distinguished from plain inference.

Structure Selection

How does the thinker manage to activate the right structures and processes among the many alternatives throughout the problem solving process? The problem of structure selection arises for any theory, like ours, which assumes that the mind involves multiple structures. Given the assumption that there are alternative structures which may compete for the input, one must explain how the thinker is able to activate the most appropriate structures, given the goals and needs of the moment. Structure selection is not a problem for theories, like Piaget's theory, which assume that the mind is unistructural, because the only structure available to the thinker will somehow apply on the input. It needs to be stressed, however, that these theories pay a very high price for this apparent simplicity in regard to the problem of structure selection. They fail to explain intra- and inter-individual variation of performance and development and, as shown here, they are not even compatible with the results of systematic logical analysis -something which was once thought to be their strong point.

According to our theory, structure selection occurs at a succession of points during problem solving. At the very beginning of the person-task encounter an SSS must be activated. The theory assumes that selection at this point is directly associated with the notion of environment-person tuning, which constitutes the basis of the principle of domain specificity. That is, specific patterns of stimuli in the environment, once present and attended as such, will activate the SSS which is mapped onto them. In other words, it is assumed that "differentiable and thus recognizable knowledge resides in the patterns of interaction qua interaction with the different domains of the environment" (Demetriou et al., 1993b, p. 199). It may be noted here that the notion of the person-environment tuning as defined by our theory reminds one of Gibson's (1979) theory of affortances, Campbell and Bickhard's (1986) interactive theory of representation, and Karmiloff-Smith' (1991) recent definition of the modularity of knowledge structures as attention biases. That is, all of these theories assume that there are inbuild structures in the human knowing system that abstract specific types of meaning from corresponding information structures once a minimal set of conditions are met. This interpretation of structure selection is consistent with modern infant research which suggests that the fundamentals of categorical (Soja, Carey, & Spelke, 1991), quantitative (Gelman & Gallistel, 1992), causal (Starkey, Spelke, & Gelman, 1990), and spatial thought (Landau, Spelke, & Gleitman, 1984) are present from the very first months of life. In conclusion, it is proposed here that the logical essential of each SSS as suggested by the logical analysis attempted in this paper may directly be activated once a minimal set of conditions are present in the input.

The repeated contact of an SSS's attention biases with the corresponding patterns of stimulus organization gradually generates intuitors which frequently direct the subject how to process the input after the initial SSS-task mapping: "an intuitor can be defined as a readily available conceptual block that functions as an organizer of information coming into the processing space via either a bottom-up or a top-down channel and that generates solutions to problems once some minimum conditions are identified in the problem representation" (Demetriou at al., 1993a, p. 53). We propose here that the intuitors in each of the environment oriented SSSs (i.e., the qualitative-analytic, the quantitative-relational, the causal-experimental and the spatial-imaginal) somehow replicate each SSS's kernel element that is specific to this and only this SSS.

Activating an SSS is not tantamount to running an SSS, especially if no intuitors are readily available. The SSSs are "dynamic multilayered and multidimensional entities that involve very general, ever-present core operators, subfield operators, and processing skills as well as the products of their past operations" (Demetriou et all., 1993b, p. 193). Thus, the subject frequently needs a system that will enable her to make appropriate decisions as to which SSS-specific processes are more relevant to the task at hand compared to other SSS-specific processes. Such a system is equally needed in the case of complex tasks which require the concerted application of more that one SSS. In those cases the subject frequently has to shift from the one SSS to the other a number of times during the same problem solving attempt. According to our theory, it is the hypercognitive system that guides structure selection in these cases. That is, this system directs the mind, when the latter is in a state of uncertainty to select a course of action that seems the more relevant and promising in the light of the current representation(s) of the problem goal and the experiences generated by and the solutions given to similar or analogous problem encountered in the past. The finding that the hypercognitive system possesses a map of cognitive systems and functions that is very close to the objective structure of mind as indicated by empirical evidence and logical analysis suggests that this system is able to function as the thinker's guide to the problem solving endeavor.

General vs. Specific Logical Processes

The focus of this paper on the specification of the idiosyncratic logical characteristics of each of the SSSs might have deceived the reader that our theory underestimates the role of general logical processes. This is not the case. In fact, recent research in our laboratory (Gonida, Kordas, & Langford, 1994) has attempted to specify the possible place of general reasoning processes, namely deduction and induction, within the general architecture of mind proposed by our theory. This research has shown that deduction and induction cannot be equated either with the two domain-free systems (that is, hypercognition and the processing system) or the five SSSs advocated by the theory. In fact, we have recently recognized (Demetriou & Kazis, 1994; Gonida et al., 1994) that we may need an extra level of domain-free processes in our model of cognitive architecture. This level would be allocated to general reasoning processes and it would thus represent the general computing software available to the thinker. The assumption is that this software is used under the control of the hypercognitive system and the constraints of the processing system for the sake of attaining SSS-specific goals.

These assumptions are in line with the logical analysis attempted in this paper. The reader is reminded that each of the SSSs involves essential characteristics which are logically unique. At the same time, however, it was also found that all SSSs do share common logical processes. These may take prominence over domain-specific processes after an SSS is selected and allowed to dominate processing. In these cases, with problem goals and sub-goals set by the thinker in premises or other forms of meaning-carrying representations, the general inferential mechanisms are activated allowing the thinker to inspect and decide on whether these elements are consistent with one another, with the problem solving actions planned or applied, and with the results engendered by these actions.

Our recent studies mentioned above (Gonida et al., 1994) indicated that each of the SSSs is differentially biased to deduction and induction. For example, it was found that the qualitative-analytic SSS uses deductive processes more that inductive processes whereas the causal-experimental SSS is biased to induction more than it is biased to deduction. However, we know next to nothing about how each of the components of the various SSSs make use of general reasoning processes at the successive phases of a problem solving cycle, at the different phases of development, and for different types of problems.

The Origin of Logical Reasoning

Where does logical reasoning come from? The answer to this question depends upon the fundamental epistemological assumptions espoused by a theory. For Piaget, who believed that mind is governed by a single structure d' ensemble at each of the successive stages of development, the status of logical reasoning at each stage was associated with the organization of each stage's structure. The more it obeys the laws of reversibility the more consistent and logical it becomes. The movement to the ideally reversible structures of formal thought is attained through a process of reflective abstraction which generates ever more powerful reasoning schemes by throwing content away, removing inconsistencies, and restructuring at higher levels of abstraction. According to Piaget, the structures generated by this process are increasingly more logical. This is affirmed on the basis of both internal and external criteria. In as far as the first is concerned, the higher a structure is on the hierarchy of stages the more its functioning is associated with the feeling of logical necessity which is taken to indicate the closure of a structure. In as far as the external criteria are concerned, the higher a structure is the more fully it can be modelled by standard logical systems such as symbolic logic (Inhelder & Piaget, 1958; Piaget, 1973).

This account of logical development faces two serious problems. First, it cannot account for two apparently contradictory findings. On the one hand, very young infants use powerful inferential processes that enable them to understand nonobvious relations (Baldwin, Markman, & Melartin, 1993). On the other hand, adults and even logicians frequently fail to apply simple inferential schemes for which they have special training (Wason, 1968). The second problem is equally important and, to our knowledge, it has not been noted before. Specifically, neither Piaget nor other students of cognitive development have noted that the inferential processes underlying the lower stages of cognitive development cannot be differentiated from the inferential processes of higher stages on the basis of logical criteria. For instance, we see no difference between the reasoning of a nonconserver and a conserver. The first child starts from the (wrong) premise that longer beakers contain more liquid. Naturally, given this premise, when the liquid of one of the two original beakers is transferred to a longer one, the child has to conclude that it contains more in order to be consistent with the premise she started with. The second child starts with the (right) premise that initially equal quantities of liquid remain equal if nothing is added or taken away. Thus, given that this is the case in the standard conservation task, the child has to conclude that the two quantities are still the same. From the point of view of logic, reasoning is identical in the two examples. It is modus ponens in both cases. Therefore, development from non conservation to conservation does not signify logical development but simply development in the child's ability to select the right premises to start with. Important as the construction of this ability might be, it must remain distinct from the development of logic per se.

However, Piaget's commitment to the assumption that the mind is unistructural provided him with no other alternative than to assume that logic gradually emanates from the stage to stage reorganization of the sole *structure d' ensemble* available to his epistemic subject. Admittedly, Piaget recognized that structural reorganization results from the resolution of conflicts between mental schemes or between mental schemes and reality which gradually leads to "the grasp of consiousness" (Piaget, 1976). However, in Piaget's theory "the grasp of consciousness is never there when needed, because each stage can become the object of consciousness only at the subsequent stages. Thus, from the point of view of the utility of consciousness, the developing person in Piagetian theory is condemned to chasing his tail for ever." Demetriou et al., 1993a, p. 12). In our view, Piaget faces this problem because he considered awareness and self-sensiveness as a by-product of cognitive functioning and development and not as an autononous part of cognitive architecture. It is to be noted here that modern theories of cognitive development (Case, 1992; Fischer, 1988; Halford, 1988; Pascual-Leone, 1988) do not even ask where logic comes from. These theories assume that successive levels of logical reasoning will somehow be acquired once the necessary computing space and related experience is acquired.

Our theory does not face the problems faced by Piaget and other cognitive developmental theorists because it assumes that the mind is a multistructural and multilevel construct whose structures and levels are in direct liaison with the environment and with each other. Thus, according to our theory, logic is the product of the interaction between the various structures and hierarchical levels of mind.

Specifically, the fundamental element of logic is the ability to make inferences that make use of the regularities in the environment observed in the past in order to connect a series of states either observed or imagined in the present in a way that is consistent with the subject's representation of the world. Regularities may refer to all kinds of relations: categorical (similarity), quantitative, causal, and spatial. In this sense, the ability to make inferences looks as though it exists on a level higher than the domains. However, it does not take place independently of the domains until very late in development and for only a few people (i.e., logicians and cognitive or developmental scientists trying to understand this very process). Thus, it is the functioning of the domains which generates patterns of inference along development. However, inferential processes are not necessarily logical. It is trivial to ascertain that many other living beings but humans make some kind of domain-specific inferences and still cannot be accredited with logic. To be considered logical, a given pattern of inference must be virtually evaluable by the thinking person herself as per its relevance and validity. Evidently, plain possession of stimulus driven inference patterns and even plain representation of regularities is not enough to allow for the evaluation of consistency between an inference pattern and a present representation and the initiation of correctives acts when inconsistencies are noted. To be able to embark on any kind of evaluative and corrective acts, the thinker must possesses some kind of meta-representation to which both the inference pattern activated and the representation of the present series of states could be compared in order to see whether they fit each other. In other words, there can be no evaluation of the validity of inference patterns and, therefore, no logic unless there is meta-representation which provides criteria for validity and consistency.

How are meta-representations formed? We propose that they are the by-product of the functioning of the hypercognitive system. The reader is reminded that the hypercognitive system involves models and maps about intelligence, cognition, and the self which are used by the thinker to guide on-line process selection, application, adaptation, and evaluation. Thus, the macro-functional models and maps direct the functioning of the on-line system which intervenes in the functioning of the SSSs. In turn, the interactions between on-line hypercognition and the SSS running at a given period of time feed back onto the macro-functional models causing their update and refinement. Thus, in our theory, the hypercognitive system is a hierarchical construct that affects and is affected by the flow of inferences which take place during domain-specific problem solving. These effects, as they are carried over from the one level of cognitive organization to the other, are "formalized" as systems of action schemes or criteria that become available for future use. In other words, the hypercognitive system is the locus where representations about past logical performance (i.e., meta-representations) recite as criteria for logical validity and necessity that can be used by the thinker in order to direct and evaluate his present logical performance.

Our recent studies (Efklides, Demetriou, & Metallidou, 1994, in preparation) of the verbal-propositional SSS provided evidence directly in line with these assumptions about the logical reasoning-hypercognition relations. Specifically, we have shown that by early adolescence, the reasoner is able to solve standard syllogisms representing all types of logical relations (i.e., transitivity, implication, equivalence, conjunction, negajunction, and disjunction) if they are stated as valid syllogisms which preserve the normal structure of each type of relations (e.g., if p then q, p =>q). However, the invalid versions of the same types of relations (e.g., if p then q, q =>p) are solved only by those reasoners who are aware about several aspects of their own reasoning performance (e.g., difficulty or similarity of various types of logical relations) and about the formal aspects of the reasoning schemes themselves (e.g., the role and the meaning of connectives). The reasoners lacking this awareness usually take invalid syllogisms as equivalent to their valid form and they err accordingly. These findings suggest that when no directly relevant mental scheme for a given type of logical relation is available, the reasoner must first have the sensitivity to recognize this unavailability, then build alternative representations of the logical relation possibly suggested by the information given and, finally, select the most appropriate one. This very process implies that the reasoner possesses a meta-representational system that directs the internal dialogue underlying the construction, rejection, and application of differentiated reasoning schemes.

Any kind of dialogue needs a language. Therefore, natural language is the medium *par excellence* in which the meta-representational dialogue can be held because it involves the means for the recording, storing, and formalization of representations and meta-representations. Thus, the verbal-propositional SSS naturally becomes the pool where the hypercognitive system looks for codes for the meta-representations it creates about all other SSSs and where it subsequently stores these meta-representations. It may now be clear for the reader why in our logical analysis we took the verbal-propositional SSS as the fundamental one and tried to see if the other SSSs are reducible to it. We may add here that we found the reality-oriented SSSs not to be reducible to the verbal-propositional SSS for a very simple reason. As this SSS is used by the hypercognitive system as the pool and the formalization agent of the relations and processes characteristic of all other SSSs it could not help but preserve both their logical similarities and differences.

It may be noted here that the process of meta-representation may not necessarily be an intra-personal process. That is, the representations of others (i.e., parents, peers, and teachers) once used as a means for showing to the thinker that the validity of his inferences is wanting take the function of the personal meta-representations discussed above. Evidently, when the representations of others are internalised are becoming meta-representations in the direct sense of the word. Thus, according to our theory, the origin of logic resides both within and between persons.

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Table 1

The model fitting the assumptions of the theory about organizational principles and specialized structural systems

	Factors				
Tasks	General	SSS_1	SSS_2	SYM_1	SYM_2
SSS_1-SYM_1-I	*	*		*	
SSS_1-SYM_1-II	*	*		*	
SSS_1-SYM_2-I	*	*			*
SSS_1-SYM_2-II	*	*			*
SSS_2-SYM_1-I	*		*	*	
SSS_2-SYM_1-II	*		*	*	
SSS_2-SYM_2-I	*		*		*
SSS_2-SYM_2-II	*		*		*

Note: Asterisks indicate the factors on which each task must be prescribed to load. The symbols SSS and SYM stand for specialized structural systems and symbolic systems, respectively. Latin numerals refer to different tasks.