LEVELS OF REPRESENTATION

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Abstract

This article describes a class of theories, the distinguishing characteristic of which is that elements of each of a series of representational systems (levels) are constructed from those of an immediately subordinate, qualitatively distinct, system. Each of these ascending levels of representation (LOR) succeeds in modeling attributes of the environment that are not captured by lower levels (emergent properties); and each ascending level provides correspondingly novel mechanisms for the control of behavior. The class of LOR theories has instantiations as diverse as Aristotle's multilevel conception of the soul, Pavlov's two signal systems, and Piaget's genetic epistemology. This article describes applications to human cognition and behavior of a 5-level LOR theory that is based on recent cognitive research.

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RUNNING HEAD: **Levels of representation**

LEVELS OF REPRESENTATION

Section I of this article describes a general framework for theories of mental representation. Some of the many theoretical precursors of this levels-of-representation (LOR) approach are reviewed in Section II. Section III presents a 5-level LOR theory that is proposed as a model of human representational abilities, and Section IV describes several applications of this theory. Section V contrasts the class of LOR theories with alternative paradigmatic frameworks for representation theory and notes further possibilities for application of this class of theories.

I. Representations and Levels

In simplest terms, representation is a relationship of reference between two entities, which can be designated representation and referent. Often, but not necessarily, the representation is produced from the referent, as an audio recording is from an orchestral performance, or a library catalog card from a book. The representation is typically more accessible than the referent, and therefore can serve as a proxy for the referent. (Considering a card in a library's catalog and the corresponding book on its shelves, the card generally serves as proxy for the book, even though the reversal of these roles is conceivable.) The sense in which a representation serves as proxy for its referent varies considerably, as is suggested by the following examples:

Referent	Representation
phoneme	letter
person	name of person
tables, chairs, etc.	word: "furniture"
scene	photograph
research observations	theoretical statements

Representational systems. Isolated referent-representation pairs are theoretically less interesting than are collections that involve similar reference relations. Some examples are the collection of cards that represent library books (a catalog), the collection of letters that represent phonemes (an alphabet), and the collection of words that represent objects, actions, attributes, etc. (a lexicon). In such systems of representations, each component representation has a relation not only to its referent, but also to other representation elements in the system. Because the relations among representations depend on characteristics of the medium in which they reside, a system of representations can have properties that its collection of referents lacks.

Representational media. A system of representations occupies some substrate, or medium. Properties of the medium afford operations that can be performed on its resident representations. Two representational systems that share the same name can be functionally very different because they reside in different media, and therefore afford very different operations. For the example of a library's catalog, the operations that can be performed on catalog elements residing in a digital electronic medium are very different from those that can be performed on cards in file drawers. Similarly, a digitally-recorded symphony can be manipulated in ways that are quite impossible for the same symphony in printed score form.

Operations. An operation can be described either as a process that converts one representation into another, or as an n-ary relationship that is specified as a set of n-tuples of elements, which can be understood as the operation's input(s) and output(s) (see Roberts, 1979). For example, the operation of adding 1 to a binary coded 4-bit integer can be described either (a) as a process, by starting at the rightmost (least significant) bit and changing ones to zeros until the first zero is encountered, which is changed to one, or (b) as the set of pairs {(0000,0001), (0001,0010), ..., (0111,1000), ..., (1110,1111)}. Between-medium operations transform a representation in one medium into a representation in another -- such as the operation of printing xa photographic negative from film to paper. Within-medium operations produce output in the same medium as the input resides -- for example, the adding-1 operation just described.

Emergent properties. Medium-afforded operations endow representations with functional properties. For example, frames of cinematic film can be subjected to the operation of projection onto a screen in sequence, producing for the viewer the property of an illusion of movement. Properties that result from operations on representations are emergent in one or both of two senses: (a) they are not apparent in the latent (non-operated-upon) state of the representational unit, and (b) there may be no corresponding property in the referent domain. For the film example, motion of the image in ordinary playback is emergent in the first sense. The use of numbers to represent dimensional attributes -- such as temperatures, lengths, or weights -- permits emergence in the second sense, of properties that are associated with arithmetic operations on numbers. For example, the average age of a group of persons is a property that emerges only by virtue of a system for numerically representing a sequence of days.[1]

Levels of Representation

The functions of a system of representations have been described as depending on two types of operations on the system's representational units: between-medium and within-medium operations. It is a third, and less familiar, type of operation with which this article is primarily concerned -- combinatorial operations on representations, functioning to construct relations between systems of representations. This third type of relation/operation affords the possibility of an interrelated hierarchy of representational systems -- in other words, the possibility of a system of levels of representation (an LOR system).

The units of the lowest level of an LOR system derive from a between-medium operation that links the representational system to its referent domain. Units of each higher level are produced by composition operations for which units of the immediately lower level serve as input. Composition operations are asymmetric, resulting in a hierarchical ordering of the levels. Elements of each composed (higher) level are mapped onto multiple elements of the composing (lower) level, and are thus more complex than those of the lower level.

Operations that apply to units of one level of an LOR system are (by definition of levels) different from those that apply to units of any other. (Units that are subject to the same operations are considered to be at the same level.) Accordingly, the composition operations that construct units of level $n+1$ from multiple units of level n are different from those that construct units of level n from multiple units of level $n-1$. As a consequence, units of level $n+1$ are qualitatively different from those of level n and have novel emergent properties. Three interrelated identifying characteristics of an LOR system are, then: (a) composition operations that combine multiple units of one level to form single units of the next higher level, (b) qualitatively distinct representational units at each level, and (c) novel emergent properties at each ascending level. A suitable format for describing an LOR system is one in which these three characteristics are indicated, as in Figure 1.

Figure 1. A generalized levels-of-representation system having 3 levels.

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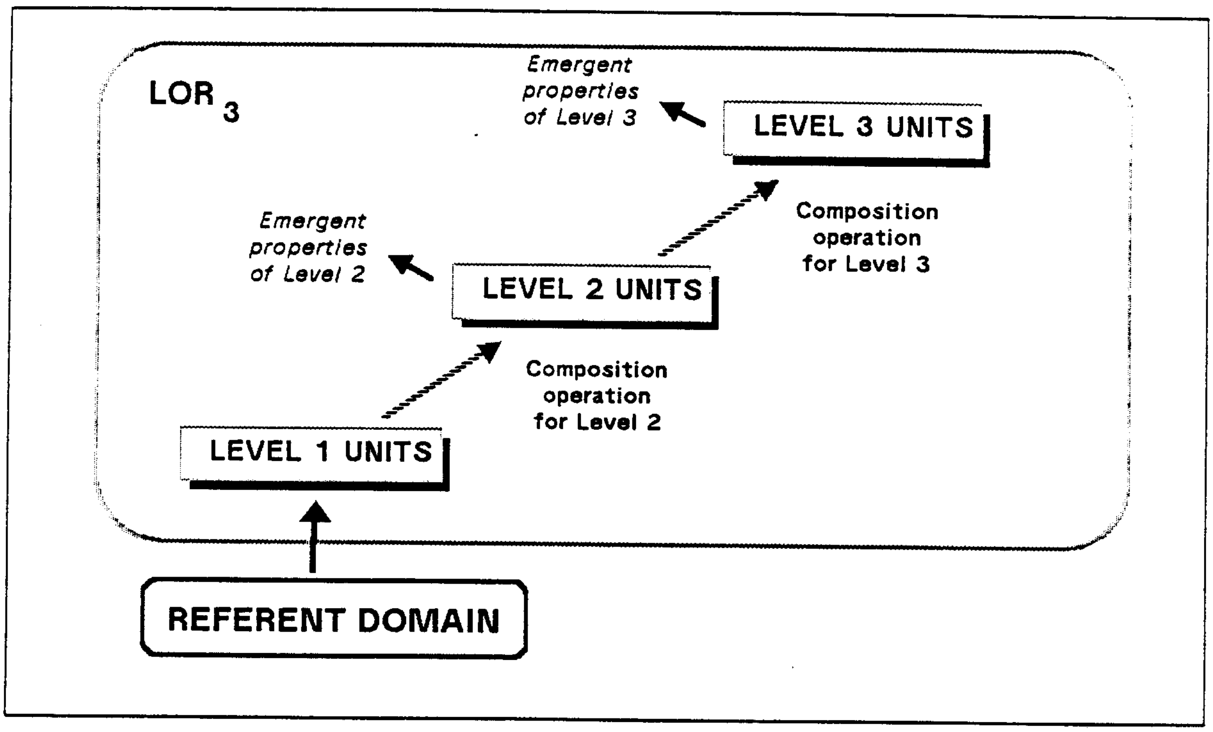
[1]The average telephone number in an office building is equally an emergent property of a numerical representation scheme, but it does not appear to be a useful one. There is a considerable body of theory, including some controversy, concerning the conditions under which statements about numerical representations are meaningful (see Michell, 1986).


LOR 3
Emergent properties of Level 3
LEVEL 3 UNITS
Composition operation for Level 3
Emergent properties of Level 2
LEVEL 2 UNITS
Composition operation for Level 2
LEVEL 1 UNITS
REFERENT DOMAIN

Computer Processor/Memory Example

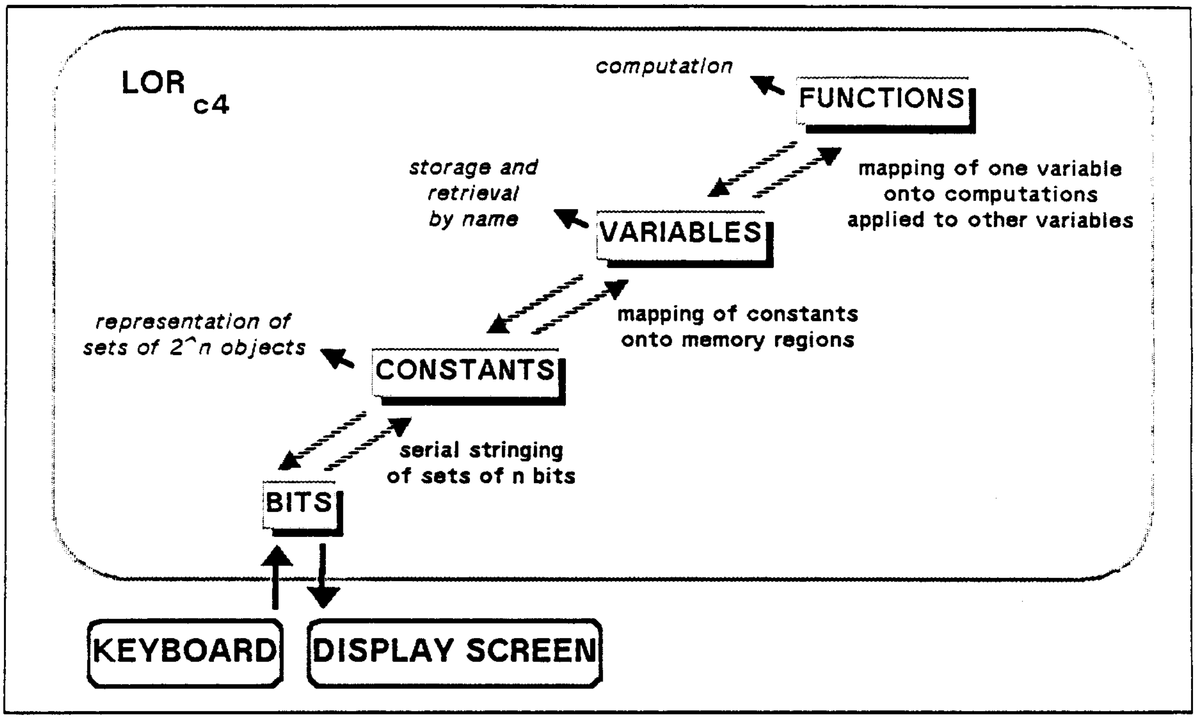
Perhaps the best known example of an LOR system is one for which the medium is a computer. Figure 2 summarizes the major characteristics of such a system, designated LOR$_{c4}$ ("c" is for computer, and "4" for the system's four levels). The units at the four levels of LOR$_{c4}$ are bits, constants, variables, and functions. The operations that define units at each ascending level combine multiple units of the immediately lower level, in a fashion afforded by the computer's hardware. These operations are described here briefly and informally in terms of transformations that can be performed by a computer.

Figure 2. Four levels of computer-system representation (LOR$_{c4}$).

Constants are composed by combining n positionally distinct bits (where n is typically 8, 16, or 32). This composition (of constants) is a factorial combination of the n bits, the result of which is that $2n$ possible elements at the bit level (i.e., a 0 or a 1 at each of the n positions) produce 2^n possible elements at the constant level. The composition operation for variables uses the computer's capability of shifting constants to and from memory registers (addresses) that are defined by a mapping of constants onto subregions of available storage space. A variable is therefore a relation of constants to a single memory address; the constants that are shifted in and out of that address are capable of playing the same role in computations. Although the number of elements at the variable level is potentially the same as that at the level of constants, the number of locations that serve as variables in most applications is typically much smaller than the number of constants. Functions are composed as relations among variables, which are implemented as sets of shifting and comparison processes on the contents of memory registers (i.e., on variables). For example, the division function is a relationship among variables that serve in the roles of dividend, divisor, and quotient.

Note that functions can be described quite adequately as relations among constants, rather than as relations among variables (e.g., Roberts, 1979, p. 42). As an example, the square function for decimal integers can be described as the infinite set of pairs of constants {(1,1), (2,4), (3,9), (4,16), ...}. Such description of LOR$_{c4}$'s 4th level (functions) in terms of relations among elements at its second level (constants) suggests that the 3rd level (variables) is unnecessary in this representational system. Although it is indeed not necessary, the level of variables is quite useful in describing the computer as a representational system. That is, functions are more aptly described as operating on the contents of specific memory registers, rather than as operations that work in some more direct sense on constants. Stated another way, describing the computer as a system that includes variables as a level intermediate between constants and functions can be useful in suggesting ways to construct such a machine. The possibility of omitting the variable level from the computer's description is equivalent to saying that the description of functions can be reduced from a description in terms of variables to one in terms of constants. Similarly, it is possible to reduce the description of functions to relations among positioned bits, undoing the LOR system entirely. These observations illustrate a general point: The number of levels in an LOR system is optional. This general point becomes significant in considering relations between multi-level systems and ones that use only a single form of representation, or none at all -- these relations are discussed in the final section of this article.

LOR$_{c4}$'s lowest level is associated not only with input from a keyboard, but also with output to a second domain, a display screen. Consequently, results of the computer's operation can be communicated to an external world; this communication can be construed as behavior of LOR$_{c4}$. Such behavior of a representational system requires descending-direction operations that are indicated by arrows in Figure 2.



LOR c4
computation
FUNCTIONS
storage and retrieval by name
mapping of one variable onto computations applied to other variables
VARIABLES
representation of sets of 2^n objects
mapping of constants onto memory regions
CONSTANTS
serial stringing of sets of n bits
BITS
KEYBOARD
DISPLAY SCREEN

Some significant details. The computer-system example may seem inapt because the familiar structure of computer programs in high-level languages includes expressions that mix functions, variables, and constants. As an example, the BASIC-language expression

(SQR(SQR(A)) * B) + 5

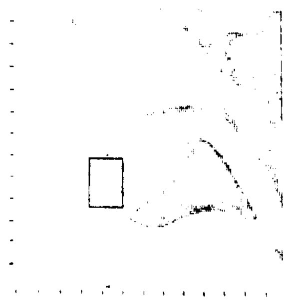
consists of one constant (5), two variables (A, B), and four functions (SQR [square root], SQR, * [multiplication], +). This expression appears to combine functions, variables, and constants as if they have interchangeable roles in computation. If functions, variables and constants do indeed play interchangeable roles in such expressions, then those three types of elements cannot be at different LOR levels, but must all be at the same LOR level (by virtue of the LOR definition that elements subject to the same operations are at the same level). Further examination makes clear, however, that expressions such as the one above do not consist of generally interchangeable elements. For example, although "B" in the above expression can be replaced by any constant, "A" can be replaced only by a nonnegative constant. Similarly, the inner square-root function can be replaced by a variable or a nonnegative constant, but the outer one cannot. A mixed-level formula such as the one above is in a state of partial evaluation; the evaluation process consists of replacing tokens of higher-level elements with ones for lower-level elements. It is not problematic for such a formula to contain tokens for elements at different levels when in a state of partial evaluation.

The apparent recursiveness of the above expression may also seem to be problematic from the LOR perspective. In "SQR(SQR(A))" it appears that an element of $LORc_4$'s function level is composed as a relation involving another element of that same level (rather than of the level just below). Again, the LOR-legitimacy of the expression can be understood in terms of the process of evaluating such expressions. In evaluating "SQR(SQR(A))" the inner square-root must be replaced by a lower-level expression before the outer one is evaluated. This interpretation of an apparent (but not actual) recursive function uses a device parallel to one that Russell (1908) introduced into mathematical logic in order to resolve paradoxes of self-reference in set theory -- his theory of types (i.e., levels).

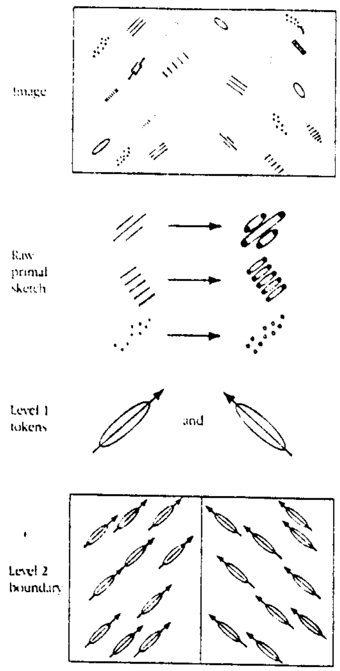
Visual System Example

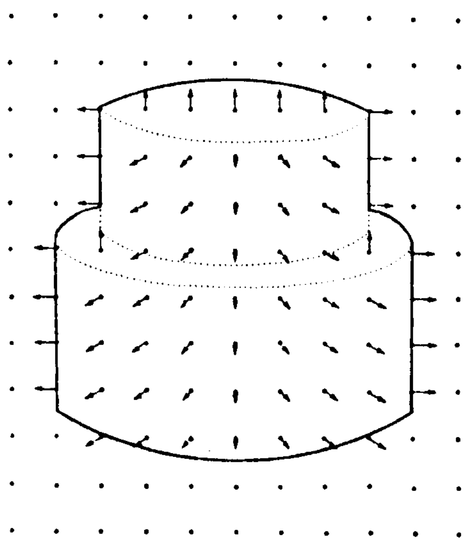
A 4-level visual LOR system (LOR_{v4}) has been described in Marr's (1982) computational analysis of vision. The four levels and their elements are illustrated in Figure 3. Each level uses a qualitatively different set of primitive units to represent a scene that is assumed to be sensed via an optical transduction (between-medium) operation such as video imaging. The medium in which LOR_{v4} resides is one that affords computational operations corresponding to Euclidean distance relations (and differentiation of light intensity functions over such distances, etc.).

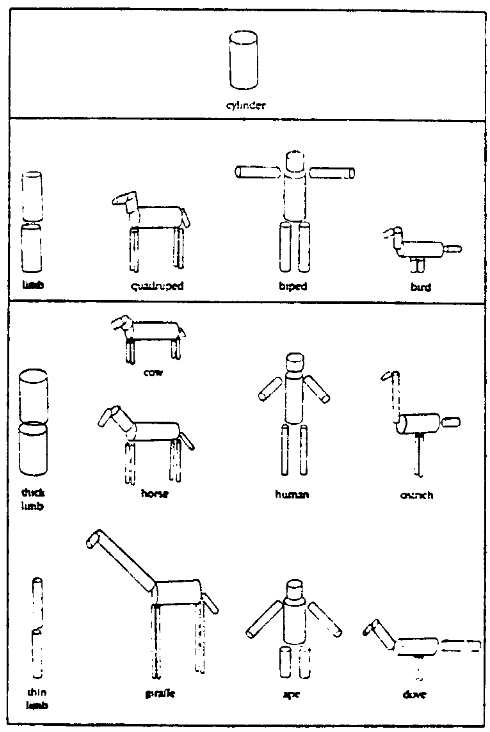
Figure 3. Four levels of visual-system representation (from Marr, 1982). The levels (with constitutent primitive elements in parentheses) are: (a) image (pixels, or intensities at each point indicated by numbers in the 2-dimensional array of points), (b) primal sketch (showing a transition from clusters of pixels [top], to the addition of terminators [small filled circles], to oriented tokens, to groups of similar tokens [bottom], between which boundaries are constructed), (c) 2½-D sketch (local surface orientations [short arrows], discontinuities in surface orientation [dotted lines] or depth [solid lines]), and distance from viewer [not indicated], and (d) 3-D model (axes to which generalized-cylinder volumetric primitives are attached).



X =	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Y																
58	171	169	167	167	166	165	166	164	167	171	171	174	174	175	173	171
57	168	168	168	167	166	167	167	165	169	168	174	176	175	175	175	172
56	168	167	167	165	166	166	167	167	168	170	178	177	176	174	174	173
55	168	168	165	169	167	168	167	165	168	175	177	177	175	175	172	171
54	169	170	167	169	169	168	163	166	172	169	174	173	175	178	173	173
53	171	169	170	168	169	168	169	168	168	170	175	173	175	177	178	176
52	172	171	170	168	169	169	167	168	173	172	173	177	174	175	178	176
51	172	174	171	170	166	168	167	168	172	172	172	177	179	172	175	175
50	171	167	176	169	170	169	168	169	171	172	174	174	173	173	174	178
49	174	172	173	173	173	174	171	171	172	174	172	172	172	169	173	173
48	173	173	173	176	178	172	171	174	174	173	175	175	175	173	173	171
47	173	175	178	173	173	171	171	175	175	177	178	175	174	173	175	178
46	178	175	174	169	173	175	177	175	177	177	174	175	176	177	177	174
45	173	175	173	174	172	173	174	175	174	171	173	174	175	174	172	171
44	177	174	175	175	172	171	172	176	172	173	172	172	173	170	170	175
43	173	171	174	168	176	172	173	173	173	174	171	174	175	173	174	174
42	175	173	171	172	170	171	176	175	178	172	174	175	175	175	175	172
41	181	179	177	172	170	170	169	179	175	174	175	174	172	175	174	175
40	188	184	179	178	176	176	176	174	172	178	172	174	173	172	174	173
39	195	191	188	186	185	183	180	177	178	175	174	176	175	174	176	176
38	200	199	197	193	190	187	185	180	176	175	180	177	175	175	176	177
37	202	202	199	202	199	194	187	180	175	179	177	176	174	175	176	173







Nonuniqueness of Descriptions of LOR Systems

The description of an LOR system might include computational specification of composition and within-level operations that define emergent properties. The plausibility of such specification is indicated by the success of Marr's analysis, from which LOR_{v4} was borrowed. However, computational descriptions of LOR operations are not unique. Rather, there is a mutual dependence between the choice of a structural description for representational units and the choice of a description for operations applied to those units (see Anderson, 1978, for a detailed example of this argument). For example, LOR_{v4}'s lowest-level pixel units might be described equivalently as intensities at locations in a Cartesian coordinate system (projections on vertical and horizontal axes), or in a polar coordinate system (distance and direction from an origin), or in any of a potentially infinite number of other 2-spaces. Further, intensity values at these points can be described with various alternative numerical scaling methods. For each type of characterization of locations and intensities of pixels there will be a corresponding method of describing the composition operations that constitute blobs, edges, and other level-2 primitives, etc.

Non-LOR Representational Hierarchies

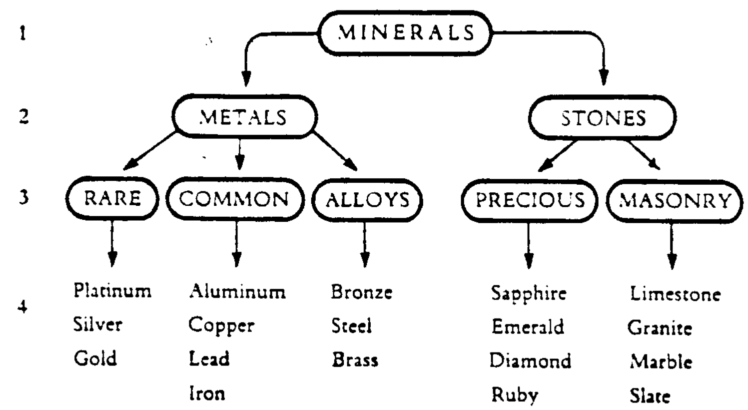
The concept of hierarchy in a representational system is well known in cognitive psychology. Some familiar representational hierarchies are shown in Figure 4. Importantly, none of the familiar hierarchies in Figure 4 is an LOR hierarchy. Rather, they are hierarchies in which the same composition relation joins each successive pair of levels. For each of the Figure 4 hierarchies, the several tiers collectively constitute just a single LOR level. The differences among the tiers of these hierarchies are differences in degree of representation of the same property. For example, in a taxonomic hierarchy such as that in Figure 4(a), higher tiers contain names of increasingly large subsets of the represented domain. Anywhere in the taxonomic hierarchy, a term designates a set that contains the sets (if any) linked to it in the downward direction and is contained within the set (if any) linked to it in the upward direction.

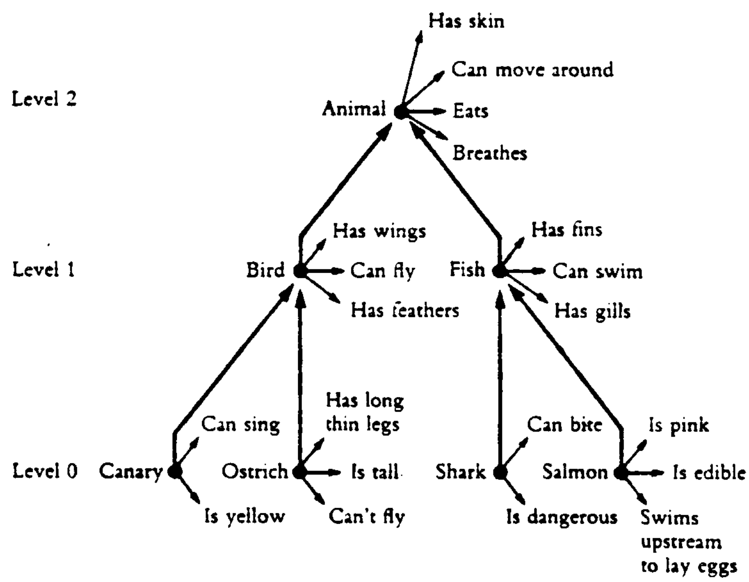
Figure 4. Examples of non-LOR representational hierarchies for (a) taxonomic classsification (from Bower, 1970), (b) a fragment of a semantic network (from Collins & Quillian, 1969), and (c) detail in visual representations using generalized-cylinder components (from Marr, 1982).

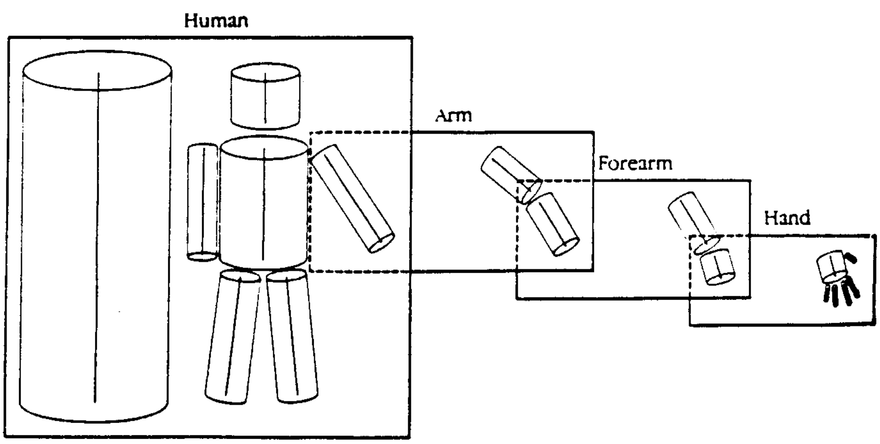
II. Levels of Representation in Psychological Theory

The LOR conception appears at least partially in many psychological theories. Accordingly, a brief survey such as the one given here cannot attempt to be comprehensive. This survey is intended only to establish that recent theoretical developments in several areas of psychology are evolving toward explicit development of the LOR form; this article's description of LOR as a general theoretical framework continues and extends a long tradition in psychological theory.

Philosophical roots. Perhaps the most distant identifiable precursor of the LOR framework is Aristotle's distinction (De Anima, Book II) among nutrition, appetite, sensation, locomotion, and thinking as a set of levels of functioning of the soul. Aristotle's levels of the soul were heirarchical in that (a) organisms did not necessarily possess all five of the functions, and (b) the presence of a given function implied the presence of the preceding ones. Some much more recent philosophical precursors are (a) the distinction, made by several associationist philosophers (notably Locke, Hume, and J. S. Mill) between impressions and ideas, the latter of which were more remote from experience, and (b) the related distinction between simple and complex impressions or ideas. In the "mental chemistry" of J. S. Mill (and, later, of Wundt and


1
MINERALS
2
METALS
STONES
3
RARE
COMMON
ALLOYS
PRECIOUS
MASONRY
4
Platinum
Silver
Gold
Aluminum
Copper
Lead
Iron
Bronze
Steel
Brass
Sapphire
Emerald
Diamond
Ruby
Limestone
Granite
Marble
Slate


Level 2
Animal
Has skin
Can move around
Eats
Breathes
Level 1
Bird
Has wings
Can fly
Has feathers
Fish
Has fins
Can swim
Has gills
Level 0
Canary
Can sing
Is yellow
Ostrich
Has long thin legs
Is tall
Can't fly
Shark
Can bite
Is dangerous
Salmon
Is pink
Is edible
Swims upstream to lay eggs


Human
Arm
Forearm
Hand

other structuralist psychologists), it was explicitly claimed that complex impressions or ideas have novel (i.e., emergent) properties that exceed those of their more elementary constituents.

Learning theorists. In the hands of Thorndike and Watson, behaviorism was, by design, a system that used a single level of explanation -- that of associations between stimuli and responses. Pavlov (1955) applied the associative relation to a second level -- his second signalling system. In the second-signal system, words (second-level conditioned stimuli) stand in the same relation to ordinary (first-level) conditioned stimuli as the latter do to unconditioned stimuli. Hebb's (1949) concepts of cell assembly and phase sequence similarly described two levels of "conceptual" nervous system organization in terms of structures at two levels of abstraction from experience. In the neobehaviorist theories of Hull (1943) and Spence (1956), fractional anticipatory responses -- which, by virtue of their stimulus feedback, could represent imminent events -- provided a means of specifying a second level of representation. Osgood (e.g., 1957) extended the fractional anticipatory response concept into the domain of word meaning. Each of the learning-theory systems just mentioned acknowledged two levels of representation of stimulus events. Although the operations or relations forming the second level were not always explicitly distinguished from those for the first level, novel emergent properties were generally credited to the higher level. One neobehaviorist system that made a point of identifying qualitatively distinct levels was Kendler's (1979) theoretical distinction between associations and hypotheses as "levels of functioning."

Developmentalists. Karl Buhler (1930), noting that "Aristotle has anticipated us in the general idea of a sucession of levels in the psychic sphere" (p. 16), observed that

> On examining all ... purposeful modes of behaviour displayed by man and animals, we find a very simple and obvious structure consisting of three great stages in ascending order; these three stages are called instinct, training and intellect. (p. 2)

Not only among developmentalists, but certainly also among all psychological theorists, Piaget (e.g., 1954; Inhelder & Piaget, 1956) has provided the most thoroughgoing conception of levels of representational activity. In Piaget's theory of cognitive development, the child is understood to progress from sensorimotor intelligence (first two years), through pre-operational thought (approximately ages 3-6), and concrete operations (7-12), to formal operations (over 13). The phenomena represented by the child not only increase in complexity through these four stages, but also the types of mental operations that are applied to the concepts change qualitatively and dramatically. A sign of the influence of Piaget's developmental theory is the number of subsequent writers who have suggested revisions (see, e.g., the review by Gelman & Baillargeon, 1983). Prominent among these, Bruner (1966) suggested a reformulation of the preoperational period (through age 6) into three (rather than two) stages, with successive development of enactive, iconic, and symbolic representation systems.

Cognitive hierarches. The concept of hierarchy has been central to some of the major works of cognitive psychology (e.g., Miller, Galanter, & Pribram, 1960; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Selfridge, 1959; Simon, 1962). Accordingly, the principle that representations vary in their level of abstraction has become very familiar (see Figure 4). Until recently (see the second paragraph below), however, cognitive theorists made little use of the possibility of qualitatively different composition relations for units at successive stages of abstraction. For example, both Miller, 1956, and Simon, 1974, referred to the abstraction operation, regardless of its hierarchical level, by means of the single label, chunking. A major integrative application of the idea of hierarchical cognitive structure, merging contributions from perceptual and physiological psychology, appeared in Konorski's (1967) development of the concept of gnostic units.

Information processing stages. The concept of an ordered series of stages of information processing was an early theoretical accomplishment of modern cognitive psychology, established by the work of Broadbent (1958), Sperling (1967), Sternberg (1967), Neisser (1967), Norman (1968), and Smith (1968). The concept of stages was initially associated with a multistore conception of memory (sensory buffering, short term memory, long term memory), but has more recently developed into the conception of a succession of increasingly complex analytic operations applied to stimuli. This changing conception of stages can be seen, for example, in the evolution of the theory of levels of processing from Craik and Lockhart (1972), to Craik and Tulving (1975), to Craik (1983). A shared characteristic of several of the multistage theories is the distinction between a preattentive stage of processing, which occurs outside of consciousness and with (relatively) unlimited capacity, and attentional processing that is limited in capacity (see especially Neisser, 1967; also Treisman & Gelade, 1980, and Posner, 1985, for extensions of this distinction).

Qualitative differences among representational systems. Explicit accounts of coexisting, qualitatively different representational systems have been offered in several theoretical treatments of human memory (e.g., Johnson, 1983; Sherry & Schacter, 1987; Tulving, 1983; see Tulving, 1985, for a review). Kosslyn's (1981) analysis of imagery appeals to three qualitatively different representational systems -- literal, propositional, and imaginal. (See Anderson, 1978; Johnson-Laird, 1983; Palmer, 1978; Pylyshyn, 1973; and Shepard, 1978, for other analyses of representation that are designed to accommodate phenomena of mental imagery.) Several recent treatments have attempted to identify sets of elements (e.g., geons in Biederman, 1987; and features in Treisman & Gormican, 1988) that are subordinate to the visual perception of objects. The concepts of procedural and declarative knowledge as qualitatively distinct forms of representation has been developed both in research on artificial intelligence (e.g., Anderson, 1983) and in analyses of the limited learning capabilities of various types of amnesics, particularly Korsakoff-syndrome patients (e.g., Graf, Squire, & Mandler, 1984; Jacoby & Witherspoon, 1982). Tulving (1985) has integrated a number of these developments into a theory in which memory is described as a tripartite system that is hierarchical in form:

> The system at the lowest level of the hierarchy, procedural memory, contains semantic memory as its single specialized subsystem, and semantic memory, in turn, contains episodic memory as its single specialized subsystem. In this scheme, each higher system depends on, and is supported by, the lower system or systems, but it possesses unique capabilities not possessed by the lower systems. (p. 387, emphasis added)

This brief survey establishes that a great variety of psychological theories appeal to hierarchical systems of representational levels (some other related theories are considered in the final section of this article). In many of these theories, the representational units at different levels are qualitatively distinct, as in an LOR system. However, there is little consensus among theorists regarding the number or identity of levels.

III. A Five-Level System of Psychological Representations

Figure 5 summarizes a 5-level system (LOR_{h5} -- "h" for human) that is discussed in the remainder of this article. The five levels of LOR_{h5} are features, objects, categories, propositions, and schemata. A brief and somewhat intuitive description of each level's composition operations and emergent properties is followed by more careful descriptions of the five levels.

The first level, features, consists of primitive sensory qualities such as pitch, hue, brightness, loudness, odor, and taste, along with properties that constitute the building blocks of visual, tactile, and auditory pattern (e.g., linearity, angularity, curvature, sharpness, voicedness, nasality). Features constitute LOR_{h5}'s lowest level, and are not compounds of more primitive units; they are the elementary properties that are sensed by LOR_{h5}.

Figure 5. Five levels of human mental representation (LOR_{h5}).

Objects in visual space are composed of features that move together in rigid groupings relative to a background. The composition operations for objects can be described intuitively by gestalt grouping relations such as proximity, similarity, and common fate of features (Koffka, 1935). The chief emergent property of the object level is physical identity, the conservation of object-ness through physical transformations of features such as rotation, occlusion, and change of illumination.

Object representations are combined by the relation of class membership into categories. Establishment of categories must be aided by adults' behavior, in the presence of children, of pointing to and providing (category) names for objects, as well as by the process of contextual generalization that was described by Braine (1963). The major emergent property of the system of category representations is abstract identity, the relation between objects that share category membership. An emergent property that depends jointly on category and object representation is number, which is a property of collections of objects that are identical at the category level (e.g., apples) but distinct at the object level.

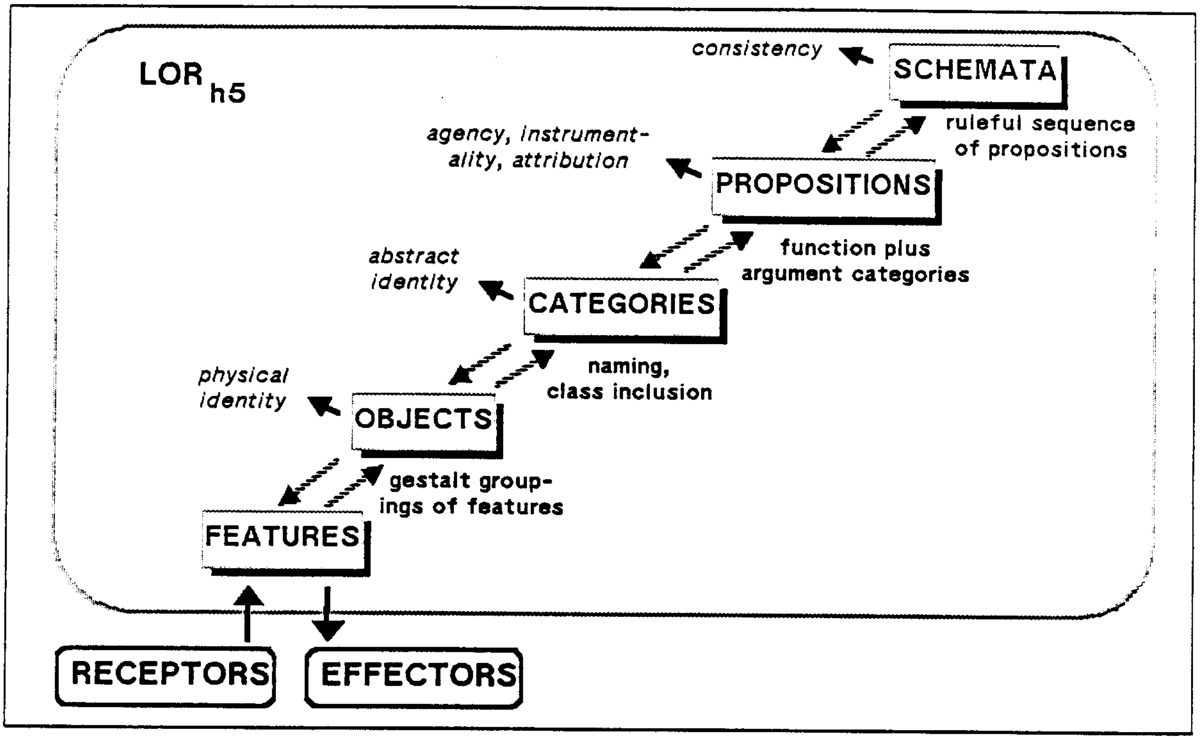
Propositions combine a function (e.g., action) category together with a suitable set of argument (e.g., agent, object, instrument, attribute) categories. It is plausible that proposition representations develop in association with adults' use, in the presence of a child, of word strings to accompany their own, others', or the child's behavior. Emergent properties of the system of propositional representations are denoted by terms that describe relations among the categories that consitute a proposition -- for example, agency (the relation between actor and action) and instrumentality (the relation between object and action).

There are several familiar types of relationships among propositions that define schemata. Script schemata (Schank & Abelson, 1977) consist of propositions in sequences that are appropriate for narrative descriptions; frame (Minsky, 1975) or model (Johnson-Laird, 1983) schemata are coherent sets of propositions that describe attributes of an object or situation; causal schemata consist of propositions in a plausible causal ordering; and logical schemata are propositions in sequences that adhere to the formal rules of an axiomatic system. Consistency is a general designation for the class of emergent properties of schema representation; propositions that are eligible to co-participate in a schema are mutually consistent. Among the great variety of forms of consistency for different types of schemata are narrative coherence, analogy, logical proof, cognitive consonance (Festinger, 1957), cognitive balance, (Heider, 1958), self-consistency (Lecky, 1945), legality (consistency with a body of laws or rules), and empirical validity (consistency with a body of data).

Similarity and Levels of Representation

By virtue of their distinctive representational units and relations, each level of LOR_{h5} supports a different basis for identifying equivalence and similarity between events. For example, changing the color of light in which a white chair is seen creates a difference at the feature level, but not at the object level. Two wooden chairs are different at the object level but equivalent at the category level. Etc. By well-established convention, similarity judgments are understood to reveal mental structure (e.g., Shepard, 1980; Tversky, 1977). Accordingly, conclusions about mental structure based on similarity judgments should depend importantly on the level of representation that research participants, by virtue of ability, materials, or instructions, apply to the analysis of stimuli presented for similarity judgments.

At the feature level, the basis for similarity is stimulus generalization, which can be understood as a measure of the overlap of features activated by two events, expressible as distance in multidimensional space (see Shepard, 1987). At the level of objects, similarity in the form of object identity occurs when spatiotemporally separated feature collections activate the


LOR h5
consistency
SCHEMATA
ruleful sequence of propositions
agency, instrument-ality, attribution
PROPOSITIONS
function plus argument categories
abstract identity
CATEGORIES
naming, class inclusion
physical identity
OBJECTS
gestalt group-ings of features
FEATURES
RECEPTORS
EFFECTORS

same object representation. Among category representations equivalence occurs in the form of abstract identity, by which physically nonidentical objects are treated as equivalent. Scenes or events may be said to have functional identity when they share a propositional representation. Formal identity occurs when different sets of propositions are schematically equivalent, as when two logical arguments use the same form of syllogism.

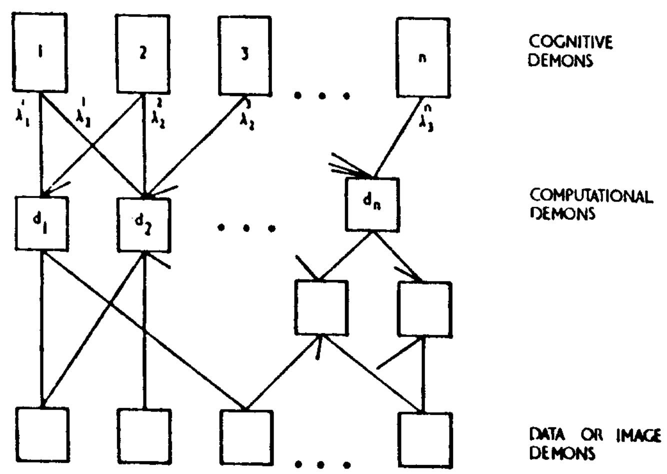
A puzzling task-dependent reversal in the asymmetry of similarity judgments may be explained by appealing to task differences in level of representations. In the task of searching for a figure in a uniform background of different figures (Treisman & Gormican, 1988), deviant-from-prototype figures "pop out" from backgrounds textured by a prototypical figure, but not vice versa; in this task, the deviant element (e.g., an ellipse) appears more different (pops out) from a prototypical element (e.g., a circle) than vice versa. However, in verbal judgment tasks (e.g., Rosch, 1975; Tversky, 1977) exactly the reverse pattern is found, with the deviant element being judged more similar to the prototypical one than vice versa. This paradoxical difference between tasks may be explained by assuming that the visual search and verbal similarity-judgment tasks employ qualitatively different systems of representations (presumably, feature and category levels, respectively).

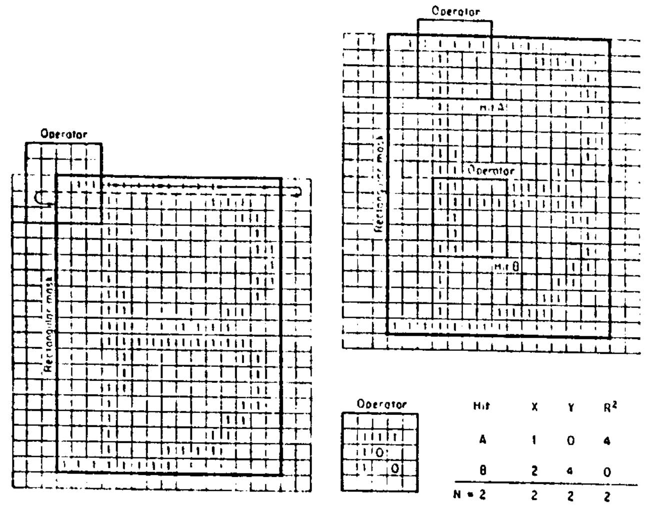
Specification of LOR_{h5}'s Interlevel Relations

Relations among the elements of a given LOR level constitute both the representational properties of that level and the elements of the next higher level. Because the domain of LOR_{h5} encompasses virtually all of psychology, it is not surprising that each of LOR_{h5}'s four interlevel relations corresponds to an extensive body of existing research. The present descriptions of interlevel relations proceed by considering various existing approaches to these interlevel relations, and attempting to extract their shared structural properties. Because of the magnitude of relevant prior work, citations of previous works that have influenced this analysis can only be superficial.

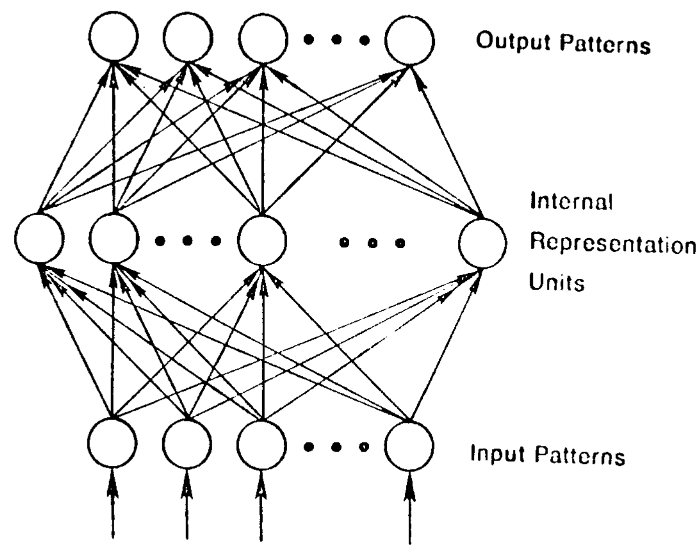
Figure 6. Structural models of the composition of objects from features. (a) Selfridge's (1959) Pandemonium model (features = "data demons"; objects = "cognitive demons"), (b) Uhr and Vossler's (1963) pattern-recognition program showing an operator (feature) being applied to a to-be-classified image (the operator is matched to all possible locations on the image at left; two matches are described in terms of measures of their horizontal position [X], vertical position [Y], and squared radial distance from the center of the image [R^2]), (c) Jakobson and Halle's (1956) construction of English-language phonemes from distinctive features (from Gibson, 1969), and (d) Rumelhart, Hinton, and Williams's (1986) connectionist multilayer network for pattern analysis ("input patterns" = features; "output patterns" = objects).

Features to objects. Identities of elementary features hypothesized to be involved in construction of objects have been described for printed letters (Gibson, 1969, Neisser, 1967), speech (Jakobson & Halle, 1956), solid objects (Biederman, 1987; Julesz & Bergen, 1983; Marr, 1982), moving rigid objects (Shepard, 1979), and moving organisms (Johansson, 1973). Theorizing about the form of composition relations for object perception has been given (to mention just a few) by Garner (1974), Selfridge (1959), Morton (1969), Uhr and Vossler (1963), and Shepard (1987), and is proliferating in recent work on parallel distributed processing (connectionism; see Rumelhart, McClelland and the PDP Research Group, 1986). The common structural property in theoretical interpretations of the composition of features into objects is an associative network, some portrayals of which are given in Figure 6. A single-layer





	o	a	e	u	ə	i	l	ŋ	ʃ	$\hat{ʃ}$	k	ʒ	$\hat{ʒ}$	g	m	f	p	v	b	n	s	θ	t	z	ð	d	h	#
1. Vocalic/non-vocalic	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2. Consonantal/non-consonantal	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–
3. Compact/diffuse	+	+	+	–	–	–		+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–		
4. Grave/acute	+	+	–	+	+	–									+	+	+	+	+	–	–	–	–	–	–	–		
5. Flat/plain	+	–		+	–																							
6. Nasal/oral								+	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	–		
7. Tense/lax									+	+	+	–	–	–		+	+	–	–		+	+	+	–	–	–	+	–
8. Continuant/interrupted									+	–	–	+	–	–		+	–	+	–		+	+	–	+	+	–		
9. Strident/mellow										+	–		+	–							+	–		+	–			



network is easily described as a 2-dimensional matrix, in which rows represent input features and columns represent objects. Although this matrix description is easily generalized to multiple layers (with outputs of one layer becoming inputs of the next), multilayer matrix structures are not as clearly displayable as are formally equivalent node and arc structures (two examples of which are shown in Figure 6).

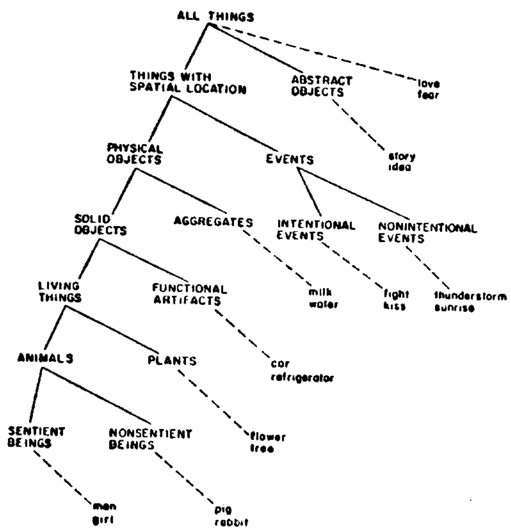
Objects to categories. In various theoretical treatments, categories are assumed to be constructed as (a) points or regions in a multidimensional feature space, (b) lists of propositions, or (c) collections of objects (see the review by Smith & Medin, 1981). The multi-feature interpretation of categories uses the structure just described for feature-to-object relations, and the proposition-list interpretation uses a structure that is described below for proposition-to-schema relations. The interpretation of categories as collections of objects (the "multiexemplar" view as identified by Smith & Medin, 1981) is the one adopted here for LOR_{h5}. Some portrayals based on the collection-of-objects interpretation are shown in Figure 7. The critical property of Figure 7's representation is an n:1 (members:category) structure. This n:1 tree structure contrasts with the n:m (features:objects) associative network structure of Figure 6. One consequence of the structural difference is that a 1-layer, n-element collection of (binary) features can encode a maximum of 2^n objects, whereas a 1-layer, n-element collection of objects can encode, at the maximum, only a somewhat smaller nimner (2^n-n-1) of categories (assuming a minimum category size of 2 objects). Although these theoretical limits suggest that object:feature ratios are only slightly greater than category:object ratios, in practice the ratios are vastly different. For example, spoken English can be analyzed into a 2-layer feature-to-object structure, with fewer than 10 articulatory distinctive features combining into about 30 phonemes (see Figure 6), and these combining into vocabularies of more than 10,000 words for adult speakers, indicating an object:feature ratio in excess of 1000:1. In contrast, it is difficult to think of more than a few categorizations for the objects in familiar medium-sized collections (such as the letters of the English alphabet, the musical instruments in an orchestra, or the objects in a living room), suggesting that typical category:object ratios are lower than 1:1.

Figure 7. Structural models of the composition of categories from objects. (a) Rosch's (1978) hierarchy of subordinate, basic-level, and superordinate categories, (b) Keil's (1979) ontological tree, and (c) Sattath and Tversky's (1977) empirically derived tree structure for mammals, based on similarity data from Henley (1969).

Categories to propositions. Importantly influenced by Fillmore's (1968) analysis of grammar, recent work in cognitive psychology and psycholinguistics has increasingly conceived the composition of propositions in terms of verb-centered case structures, rather than the previously favored subject-predicate structures. Although notations vary considerably, the verb-centered structure -- which might also be described as a function-plus-arguments structure -- is discernible in the structural formats for propositions that are illustrated in Figure 8.

Propositions to schemata. Schematic representation is assumed to support the broad range of accomplishments that are characterized as human rationality. Although there are many existing analyses of processes that are schematic (in the LOR_{h5} sense), in relatively few of these have there been clear distinctions between propositional and schematic relations (an exception is Schank and Abelson's, 1977, distinction between conceptualizations [propositions] and conceptual dependencies [schemata]). The relations that define schemata can be formulated as sets of rules (i.e., of propositions) that describe the dependency of one proposition's content on the content of one or more other propositions. Some examples of schema-forming rules are given in Figure 9.

Superordinate	Basic Level	Subordinate
Furniture	Chair	Kitchen chair
		Living-room chair
	Table	Kitchen table
		Dining-room table
	Lamp	Floor lamp
		Desk lamp
tree	Oak	White oak
		Red oak
	Maple	Silver maple
		Sugar maple
	Birch	River birch
		White birch



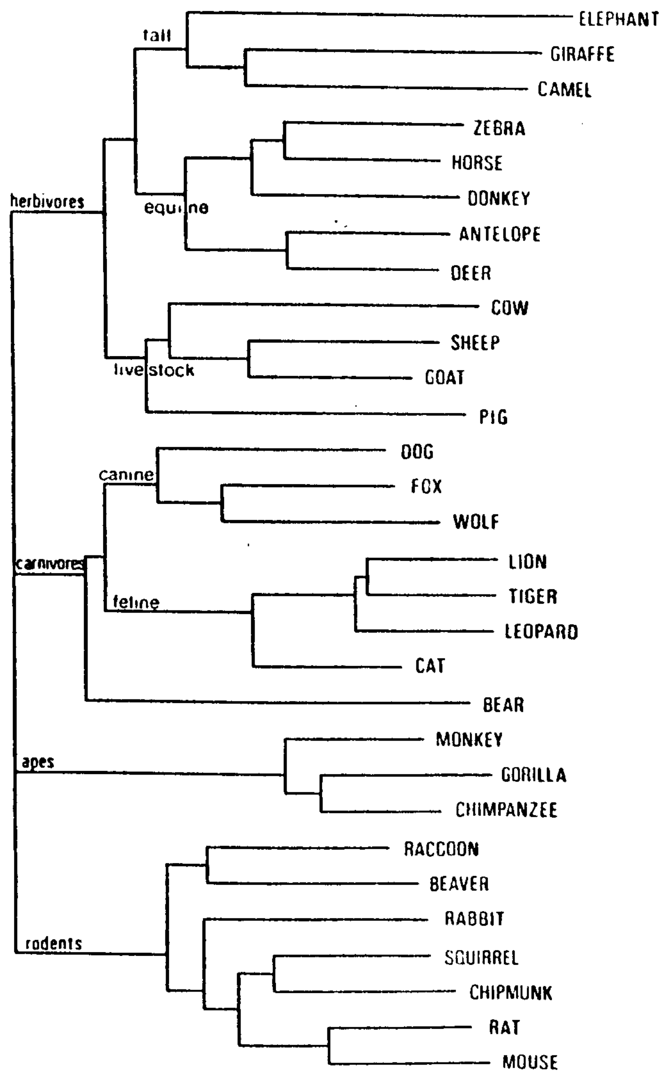


Figure 8. Structural models of the composition of propositions from categories. (a) Schank and Abelson's (1977) description of active and stative conceptualization (proposition) forms, (b) Norman, Rumelhart, and the LNR Research Group's (1975) notation for n-ary relations, illustrated with the sentence, "Mary told Helen that she gave John a dollar" (the give proposition is the object of the tell proposition), (c) Anderson's (1980) 2-proposition representation of "The early bird catches the worm" (the oval symbols represent the proposition units), and (d) Kintsch's (1974) 8-proposition representation of the sentence-text, "Cleopatra's downfall lay in her foolish trust in the political figures of the Roman world."

Figure 9. Structural models of the composition of schemata from propositions. (a) notations for causal links between propositions and an example of their use ("rE" indicates the "r" and "E" relations in succession, with the intermediate state not shown), from Schank and Abelson (1977), (b) the balance schema for relations among three propositions, each denoting a liking (+) or disliking (-) relation (represented as a directed link) from a person (Perceiver or Other) to an object (O or X) (the set of three relations is consistent with the balance-theory schema when there are either 0 or 2 disliking relations), based on Heider (1946), and (c) schemata for the valid syllogisms of traditional logic (A, E, I, and O designate forms of propositions, e.g., "A" is a uniform affirmative such as "Every X is a Y"; the four "figures" are forms of distributing the major term, minor term, and middle term among the roles of subject and predicate in the two premises; and the "names" are mnemonics that encode the order of proposition forms in each syllogism) from Brody (1967); see also Prior (1967).

Operations and Emergent Properties

The representational structures at each level afford operations that properly analyze partial or noisy information. These operations are of the sort that Bruner (1957a; 1957b) identified as "perceptual readiness" and "going beyond the information given." A greater theoretical challenge is to describe operations that explain each level's emergent properties.

Object level. The structure that supports object representation must explain various imaginal abilities, such as mental rotation and melody transposition, and the ability to conserve object identity through changes in perspective and partial or complete occlusion. These feats appear to require structures that can extract dimensional information and compute transformations along these dimensions. Suitable representational machinery is found in work on scaling (see Shepard, 1980, for an overview). But it may require substantial theoretical work to integrate the feature-based network structure (cf. Figure 6) with the capability for geometric transformations.

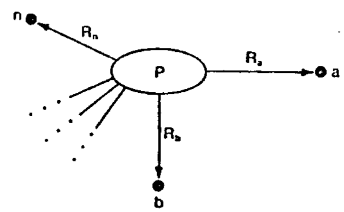
Category level. The basic operation afforded by category representation is abstraction (finding a category to which an object belongs). Other operations that provide for emergent properties of the structure are (a) instantiation (finding a member of a category), (b) finding a co-member (abstraction followed by instantiation), and (c) location of an overlapping category (instantiation followed by abstraction).

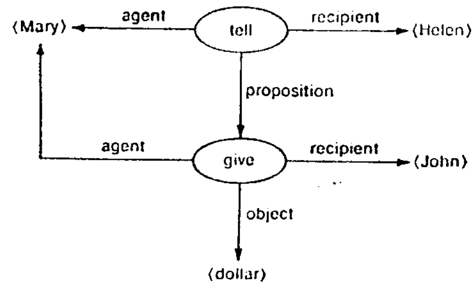
Proposition level. The most familiar operations that can be applied to propositions are grammatical transformations of tense, mood, and voice. These emergent properties, and the structures required to support them, may be partly appreciated by analogy to familiar operations on function-plus-argument structures in mathematics -- the integration and differentiation transformations of the calculus. It is plausible that cognition of temporal relations depends on

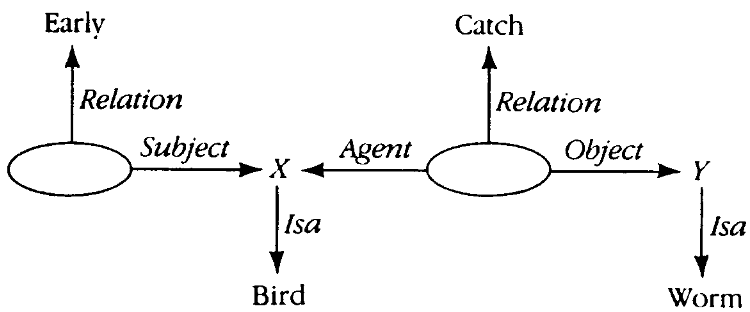
The meaning propositions underlying language are called conceptualizations. A conceptualization can be active or stative.

An active conceptualization has the form:
Actor Action Object Direction (Instrument)

A stative conceptualization has the form:
Object (is in) State (with Value)







1. (BECAUSE, α, β)
2. (FELL DOWN, CLEOPATRA) = α
3. (TRUST, CLEOPATRA, FIGURES) = β
4. (FOOLISH, TRUST)
5. (FICKLE, FIGURES)
6. (POLITICAL, FIGURES)
7. (PART OF, FIGURES, WORLD)
8. (ROMAN, WORLD)

→r means an **ACT** results in a **STATE**.

→E means a **STATE** enables an **ACT**.

→I means a **STATE** or **ACT** initiates a mental **STATE**.

→R means a mental **ACT** is the reason for a physical **ACT**.

→dE means a **STATE** disables an **ACT**.

John gave Bill an orange for his cold.

John **ATRANS** orange **to** Bill

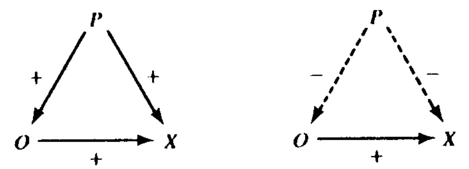
→rE

Bill **INGEST** orange **to INSIDE**(Bill)

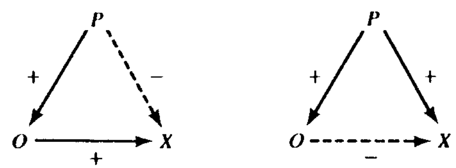
→r

Bill **HEALTH**(POS change)

Balanced States



Unbalanced States



Name	Figure	Major premise	Minor premise	Conclusion
Barbara	first	A	A	A
Baroco	second	A	O	O
Bocardo	third	O	A	O
Bramantip	fourth	A	A	I
Camenes	fourth	A	E	E
Camestres	second	A	E	E
Celarent	first	E	A	E
Cesare	second	E	A	E
Darapti	third	A	A	I
Darii	first	A	I	I
Datisi	third	A	I	I
Dimaris	fourth	I	A	I
Disamis	third	I	A	I
Felapton	third	E	A	O
Ferio	first	E	I	O
Ferison	third	E	I	O
Fesapo	fourth	E	A	O
Festino	second	E	I	O
Fresison	fourth	E	I	O

propositional structures. It may be apparent that existing structural portrayals of propositions (see Figure 8) provide little suggestion as to how the emergent properties of propositional representation, such as agency, instrumentality, and temporality, are computed.

Schema level. The use of schema structures to produce propositions, as in the derivation of theorems from axioms or conclusions from premises, corresponds to one of the uses of productions in some treatments of artificial intelligence (e.g., Anderson, 1982; Newell, 1973). The schema structure also must compute whether or not a configuration of propositions is consistent with the schema rule. The representational constructions that philosophers of mind refer to as propositional attitudes (e.g., the belief in the truth of a proposition, or the desire that a proposition be true) may also be conceived as products of schema-level operations. Schema-level processes are also importantly involved in ordinary comprehension of language; the meaning of a sentence may often depend more on its role in a familiar schema structure than on its proposition-level interpretation. (See Figure 10, which reinterprets a proposition from Figure 8 by assimilating it to a schema structure.)

Figure 10. An illustration of LOR_{h5}'s levels applied to interpretation of The early bird catches the worm. The components of this sentence can be related to representational entities at lower (feature, object, and category) levels. However, the commonly understood meaning is a causal schema consisting of four propositions. In abstract form, the four propositions (and their causal links) are: Agent A performs some action (which results in) A is early (which enables) A performs some [second] action (which results in) A attains some desired goal. By virtue of this schema structure, the meaning is more similar to A stitch in time saves nine than to (say) The best time for worm-hunting is in the morning.

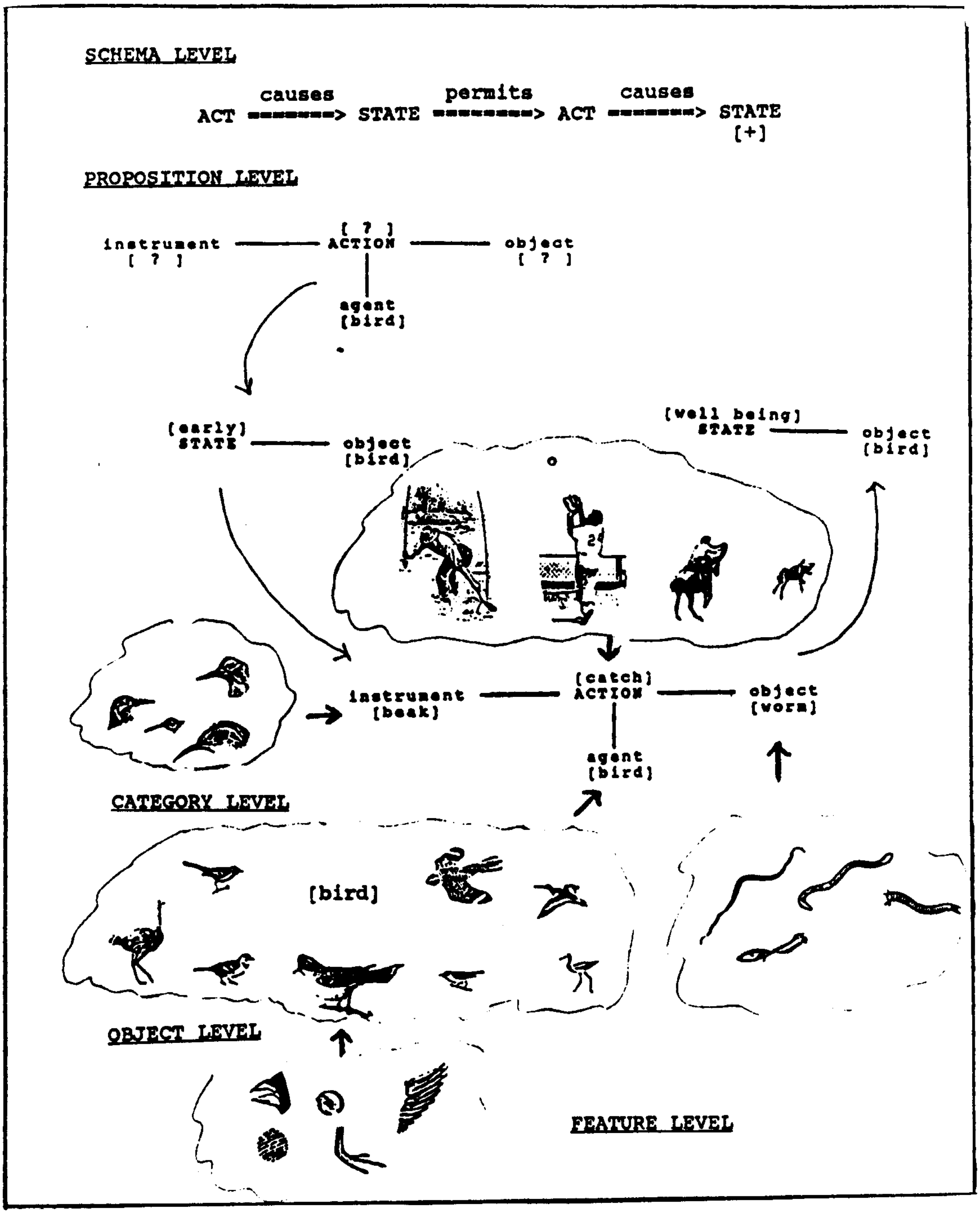
Some Comments on LOR_{h5}

Incompleteness of the description. Full description of a set of levels of representation should include detailed computational specification of the operations or relations that compose and transform the representational units at each level. The possibility that a system like LOR_{h5} can be computationally specified, even though the effort of doing so is certainly massive, is suggested by the success of computer programs that model substantial portions of multi-level representational systems (e.g., Marr, 1982; Schank & Abelson, 1977; Winograd, 1972).

Relation to LOR_{c4}. It is not accidental that the first four levels of LOR_{h5} closely parallel the four levels of LOR_{c4}. The parallel may be extended by supposing a fifth level added to LOR_{c4}, to accommodate such computer capabilities as error-identifying program compilation and comprehension of natural language.

Qualitative distinctness of levels. In measurement theory, qualitative differences in representations (for example, the differences among nominal, ordinal, and interval scales) result from differences in the relational structures that underly these representations (Krantz et al., 1971; Roberts, 1979). Similarly, qualitative distinctness of LOR levels depends on differences in underlying relational structures. LOR_{h5}'s relational structures, which are approximated by the diagrams in Figures 6 through 9, are more complex than those that underlie measurement representations. Correspondingly, the qualitative distinctness of LOR_{h5}'s levels can not yet be characterized other than in the informal terms used above in describing levels and operations.

The qualitative distinctness of LOR_{h5}'s levels provides a novel perspective on a type of definitional problem in which cognitive theorists occasionally become entangled. The problem is that of attempting to define a representational concept at one level in terms of relations that are more appropriate for some other level. For example, a few decades ago much effort was


SCHEMA LEVEL
causes
ACT ========> STATE
permits
=========> ACT
causes
========> STATE [+]
PROPOSITION LEVEL
instrument [?]
[?] ACTION
object [?]
agent [bird]
[early] STATE
object [bird]
[well being] STATE
object [bird]
instrument [beak]
[catch] ACTION
object [worm]
agent [bird]
CATEGORY LEVEL
[bird]
OBJECT LEVEL
FEATURE LEVEL

spent on producing sets of grammatical rules that could generate or (in reverse) parse all utterances of a natural language. In the LOR_{h5} framework, this effort is prejudged as inappropriate, because it attempts to use schema-level relations (e.g., an axiom-based set of grammatical rules) to describe units of another (proposition) level that are not expected to be so describable. Similarly, attempts to define categories in terms of rule-specified criteria for membership, or in terms of the multidimensional locus of feature combinations, are inappropriate in the LOR context (cf. Smith & Medin, 1981, for a review of the conceptual and empirical difficulties of such category definitions).

Possibility of additional levels. One can conceive of additional levels within the span of LOR_{h5}'s five levels. For example, LOR_{v4} can plausibly amplify the transition between LOR_{h5}'s adjacent feature and object levels. Likewise, the levels of LOR_{v4} could be further elaborated by embedding within it levels such as those described by Hubel and Wiesel (1963). Abelson (1973) suggested a set of six levels that span the present bridge between proposition and schema levels. Consequently, it appears that the number of levels used in a theoretical analysis of representation is optional, constrained chiefly by one's taste for detail.

Testability of LOR formulations. The LOR conception is a theoretical schema -- a set of rules for describing theories of mental representation rather than a specific, testable theory. Any specific version of the LOR schema (such as LOR_{c4}, LOR_{v4}, or LOR_{h5}) is testable, in the sense that, when accompanied by operational definitions of units and relations, it can be examined for agreement with empirical observations. The next section provides further specification of LOR_{h5}, increasing its testability as a theory of mental representation. However, this article aims less to assert the empirical validity of LOR_{h5} than to establish the usefulness of the LOR framework as a theoretical schema for psychology.

IV. Applications of the LOR Framework

How is a theory in the LOR form potentially more useful than one in nonhierarchical form? What justification is there for the specific identities of the five levels in LOR_{h5}? The range of the following applications indicates both that (a) a theory in the hierarchical LOR form has the potential to offer a unified theoretical treatment of phenomena that are not clearly related in other representation-theory formats, and (b) the five levels of LOR_{h5} can be associated with empirical phenomena in a broad range of domains.

Memory

A striking development in recent cognitive psychological research has been the steady expansion of procedures used to measure the dependent variable in studies of human memory. Using an extension of Tulving and Thomson's (1973) encoding specificity principle, LOR_{h5} can be used to propose an organization of this growing set of memory measures. According to the encoding specificity principle, the memory trace of an item's occurrence includes a representation of the context in which the item was previously encountered. Memory performance is then facilitated by the success of a test situation in re-evoking the acquisition context. The application of LOR_{h5} assumes additionally that memory traces capture the level(s) of representation used in encoding and, consequently, that memory is facilitated to the extent that a test situation prompts use of the representational system(s) with which the item was encoded.

Levels of Representation and Orienting Task Effects

In studies of incidental learning, the subject encounters a series of items (usually words) without being led to expect a later memory test. Typically, the subject is distracted from deliberately studying the items by being given a task (an orienting task) to perform in relation to the items. Craik and Lockhart's (1972) levels-of-processing theory credited orienting tasks with an important role in accounting for variations in the effectiveness of incidental learning (see also Hyde & Jenkins, 1969). Orienting tasks that have been used frequently in levels-of-processing research include judging whether or not a target word is (a) printed in capital letters (a feature-level judgment), (b) a synonym of another word (a category-level judgment), (c) an acceptable completion of a sentence that contains a blank space in place of a word (a proposition-level judgment), or (d) descriptive of oneself (a schema-level judgment). These orienting tasks should influence the level of representation applied to the target word. In LOR_{h5}'s terms this set of orienting tasks noticeably lacks one that requires an object-level judgment. The lexical decision task -- judging whether or not a letter string constitutes a word -- might serve as an object-level judgment task.

Results from levels-of-processing experiments show that memory is better the higher the level of representation required by the orienting task. Craik and Lockhart (1972) have interpreted these findings as indicating that higher levels of processing (or greater depth of processing) establish stronger memory traces. The extended encoding specificity principle suggests a different, but related, interpretation. The recognition and recall measures typically used in depth-of-processing experiments are assumed to require schema-level representations (cf. Tulving, 1972; 1983). Because they favor different levels of representation, orienting tasks differ in their effectiveness in establishing a trace at the schema level. It is a corollary of this interpretation that measures that tap traces at lower levels of representation (see next subsection) should eliminate, and possibly reverse, the usually observed effects of orienting task variations. Consistent with this interpretation, Bransford (1979), Jacoby (1983), and others have demonstrated that nonstandard memory tests can reverse the usual levels-of-processing effects.

Levels of Representation and Memory Measures

Recent studies of memory-impaired patients provide a basis for associating levels of representation with the dependent variables of memory experiments. Korsakoff-syndrome amnesics, who typically fail at tests of recall or recognition, nevertheless display substantial memory on measures that (a) do not require the subject's awareness of previous exposure to the item, and (b) presumably reflect relatively low levels of representation. These include measures of perceptual and motor skill (Cohen & Squire, 1980), spelling (Jacoby & Witherspoon, 1982), and word fragment completion (Graf, Squire, & Mandler, 1984). In a related finding, Jacoby (1983) showed that, with normal subjects, a measure of perceptual fluency -- identification of very briefly presented words -- detects memory traces that are not revealed by recall or recognition measures. Subsequent studies have amply confirmed these empirical phenomena (see the review by Roediger & Blaxton, 1987).

Table 1 proposes associations of memory measures with levels of representation. Only the measures associated with the schema level in Table 1 rely on a subject's reportable knowledge (i.e., conscious awareness) of the trace-establishing event. For measures at all other levels, the trace of an initial event is assessed by observing the subject's response to a subsequent event. If the response to the second event is facilitated or impaired (and the first event doesn't plausibly have any general performance enhancement or interference effect) then it is inferred that the first event established a trace. These trace-inferring procedures are referred to as priming, savings, or transfer measures. Characteristics of the trace are inferred from the characteristics of events that result in facilitation or interference. This analysis predicts that each of the measures in Table 1 should be most strongly affected by orienting tasks that invoke representations at the level tapped by the measure.

Table 1. Association of Memory Measures with Levels of Representation

Level	Measures used in published studies	References
feature	retrieval from iconic storage Stroop interference repetition priming	Sperling (1960) Dyer (1973) Kornblum (1973)
object	perceptual fluency word fragment completion picture fragment completion	Jacoby (1983) Graf et al. (1984) Tulving (1985)
category	classification latency naming latency category priming	Sternberg (1967) Collins & Quillian (1969) Posner (1978)
proposition	priming among proposition components	Ratcliff & McKoon (1978)
schema	free recall recognition fact verification	Tulving (1983) Jacoby (1983) Anderson (1982)

Performance Control

In biology, "homomorphism" designates the occurrence, in evolutionarily distant species, of organs that are superficially similar, such as the wing of a bat and the wing of a bird. A corresponding concept of homomorphism might be adopted in psychology, to label the occurrence of superficially similar actions that have representationally unrelated control processes -- for example, running in fear and running in order to lose weight. Theoretical controversies that mark several traditional problems can be clarified by recognizing that similar performances -- not just by different organisms, but also by the same organism at different times -- can be controlled at different representational levels.

At the lowest level of LOR_{h5} action is governed by conditioned and unconditioned reflexes, the theorized mechanism of receptor-effector linkage at the lowest level of nervous system organization. Higher levels of representation may be involved in the control of action in two ways: (a) selection of action may depend on analysis of sensory input at a higher level, and (b) actions may be organized into increasingly abstract units analogous to the organization of sensory experience into objects, categories, propositions, and schemata. The present discussion considers the first of these possibilities. A levels-based analysis of performance control is given here for a domain that has been the subject of much controversy concerning the nature of its control processes, aggressive behavior.

Aggressive Behavior

Theorists in social, personality, developmental, and comparative psychology have long recognized the difficulty of producing a single, generally acceptable definition of aggression. Proposed definitions range from minimally theoretical ones, such as that aggression is the delivery of noxious stimuli (Buss, 1961) or the initiation of attack (Scott, 1958), to highly theoretical ones, such as that aggression is the characteristic response to frustration (Dollard, Doob, Miller, Mowrer, & Sears, 1939) or the expression of an intention to injure (Baron, 1977; Berkowitz, 1962; Zillmann, 1979). Corresponding to this breadth of definitions is the variety of hypotheses about aggression's control processes. The major hypotheses are that aggressive actions are under the control of (a) genetically transmitted neural or physiological mechanisms (e.g., Lorenz, 1966), (b) motivational states activated by external stimuli, such as frustration (e.g., Dollard et al., 1939), or (c) socially acquired norms (e.g., Bandura, 1973).

Some writers have suggested that aggression should be classified into distinct types such as territorial aggression, predatory aggression, angry aggression, and instrumental aggression. Application of the LOR conception elaborates this multi-type approach by supposing that there are (at least) as many types of aggression as there are levels of representation from which aggression (construed broadly as harming) can be controlled. Table 2 categorizes examples of aggressive behavior in terms of control processes that are associated with each of the levels of LOR_{h5}. These examples were assigned to levels by judging, for each, what level of analysis of the stimulus situation should be required for the action's occurrence.

Table 2. Harming (Aggressive) Behavior Controlled at Five Levels of Representation

Level	Illustrations
feature	slapping on feeling a mosquito bite soldier firing at 'anything that moves'
object	swatting a fly firing at an attacking soldier
category	voting against opposition-party political candidates firing at men, but not women or children
proposition	football player executing a blocking assignment obeying an order to fire at enemy soldiers
schema	using corporal punishment as a disciplinary technique deciding whether or not to obey an order to fire at the enemy

Table 2's analysis of aggressive behavior has potentially useful applications, such as in understanding the effects on aggressive behavior of viewing violence in the mass media. Many discussions of this problem have implicitly assumed single-process mediators of the effect of viewing violence. For example, the observational learning analysis predicts that observing unpunished aggression by an attractive actor should lead to an <u>increase</u> in aggression by the viewer, mediated by vicarious reinforcement (Bandura & Walters, 1963). On the other hand, a psychodynamic analysis predicts that the same experience should <u>reduce</u> the viewer's tendency to be aggressive, mediated by the process of catharsis. In the LOR context, the search for a single theoretical description of the behavioral effect of witnessing aggression is too limited. Instead, it is assumed that witnessing an episode of violence can produce various effects depending on the level of representation at which the witnessed episode is analyzed. For example, witnessing an aggressive act may have effects that depend on a schema-level judgment by the viewer, as to whether or not the viewed action was justified. This, in turn, must depend on (among other factors) whether or not the viewer is capable of schema-level representation.

<u>Application to other significant performance domains</u>. The analysis just outlined for aggression can be used for other significant classes of behavior -- for example, helping, eating, exercise, drug use, and job performance. Behavior in each of these domains is potentially

controlled from multiple levels. The multiplicity of controls has important implications for treating problem instances of the behavior, because the success of any treatment should depend on the match between the behavior's representational level of control and that at which the therapy is targeted. The possibility that different problem behaviors in these domains have different representational levels of control makes it unlikely that a single form of therapeutic strategy can be generally successful.

Practice and the Regression of Control Levels

Actions that have been performed many times -- for example, dressing, washing, eating, typing, and automobile driving -- are said to be habitual. The process of an action's becoming habitual was characterized by Anderson (1982) as a progression from declarative to procedural representation of the action. Declarative representations of action are (in LOR_{h5}'s terms) propositional. A declarative/propositional representation of action might originate in a teacher's instruction, from observation of another's actions, or from a reasoned decision. The transition to procedural representation through repeated practice results in the action being controlled by a representation at a lower level.

Anderson's analysis appeals to only two levels in performance control -- declarative and procedural. In a prior analysis, Fitts (1964) had distinguished three levels in the improvement of a skill -- an initial cognitive phase, an intermediate associative phase, and a final automonomous phase. The first and third of Fitts's stages resemble Anderson's declarative and procedural control levels. A still more elaborate hypothesis, based on the LOR_{h5} model, is that the course of a skill's development consists of a transition from an initial high (schema or proposition) level downward through all of the lower control levels in succession.

As an example, consider the athletic skill of responding to a rapidly moving ball, as in hitting a baseball pitch or returning a tennis serve. One could start the acquisition of this skill (as some instructors do) with a schema-level analysis of the "theory" of the baseball swing or the tennis return of serve. This can be distilled to a set of proposition-level instructions, such as "Watch the ball" or "Use a short backswing." Further practice may lead to the identification of action categories, such as (in tennis) the full swing, blocked forehand, or backhand chip, which depend on a corresponding category-level analysis of the stimulus situation, such as flat, twist, and spin serves. As skill progresses further, the relevant actions may depend on attention to the critical objects in the situation, especially the opposing pitcher or server and the ball. Finally, playing habits may become conditioned to the component stimulus features of the critical objects, such as features of the pitcher's or server's or the ball's movements that are associated with variations in the ball's spin or speed. Throughout this process of acquiring skill, the performer has the difficult problem of maintaining consistency between lower-level controls and the earlier schematic or propositional representation of the action. A related, although opposite, problem is dealing with a faulty schematic analysis -- that is, a theory of the performance that doesn't translate into effective lower-level controls.

Motivation

A partial listing of psychology's established motivational concepts includes (alphabetically) affect, attitude, drive, emotion, incentive, need, secondary reinforcement, and value. Psychological theory of motivation has rarely dealt with more than pairwise relationships among such motivational concepts. The LOR framework offers the possibility of integrating this diverse set of motivational constructs by associating them with levels of representation.

Evaluative variations are identifiable at each of LOR_{h5}'s levels. Sensory features such as warmth, brightness, hardness, and loudness vary in pleasantness. Objects such as a piece of candy or a piece of garbage vary in their attractiveness, as do categories such as automobiles, music styles, insects, or weapons. Propositions can represent beliefs or states of affairs that vary in desirability. At the schema level, stories, persuasive arguments, and political or religious belief systems can be evaluated positively or negatively, for example as moral or immoral.

In Table 3, motivational constructs are linked with the representational units at each of LOR_{h5}'s levels. (This analysis is amplified in Greenwald, 1988b, with particular focus on the place of attitude within the larger set of motivational consructs.) The terms assigned to the feature level in Table 3 are treated as human motivational primitives, and each higher-level motivational construct is placed at the lowest level that can be justified by established usages. However, some of Table 3's terms -- especially attitude and emotion -- have additional usages that belong at higher levels than those indicated in the table. (For example, Shaver et al., 1987, present an analysis of emotion that focuses on the schema level.) Thus, attitude, incentive, and emotion imply the involvement of an object (or higher) representation; whereas belief, intention, and opinion require representations at least at the proposition level. By including motivational primitives (e.g., affect, appetite, drive) that are on a par with cognitive primitives, this analysis does not assume cognition to be more fundamental than motivation (or vice versa).

Table 3. Relationships Between Motivational and Representational Constructs

Levels	Motivational terms
feature	affect, appetite, drive, feeling
object	attitude, emotion, incentive
category	value
proposition	belief, intention, opinion
schema	ideology, justification (moral reasoning), motive, script

The linkages proposed in Table 3 permit psychology's diverse array of motivational constructs to be interpreted as parts of an interrelated multilevel system. There is some precedent for theoretical description of interrelations between levels of motivation, as in analyses of the relation between evaluation of subject-verb-object propositions and evaluations of their category-level components (e.g., Gollob, 1974; Osgood & Tannenbaum, 1955) or in analyses of the relation between primary and secondary reinforcement (e.g., Miller, 1951). However, rarely have such analyses encompassed more than two of Table 3's five levels. (An exception is the 3-level analysis of motivation by Staats, 1968.) Most often, motivational terms such as attitude, motive, and intention have appeared to be either theoretically unrelated competitors or unacknowledged synonyms, rather than concepts with distinct, but interrelated, interpretations.

Table 3's analysis can be applied in interpreting motivational differences that relate to differences in representational capabilities (for example, motivational differences as a function of age, education, or mental ability), and in clarifying relations between the major motivational constructs of traditional experimental psychology (especially drive and reinforcement) and social psychology (attitude). In regard to the latter, previous accounts had followed Doob's (1942) lead in reducing the construct of attitude to the behaviorist primitives of drive, reinforcement, and habit. In contrast, in the multilevel account of Table 3, the construct of attitude has no place at the level of analysis that contains the behaviorists' primitives. Rather, attitude captures the theoretical idea that motivational significance inheres in objects, over and above the features (behaviorists' physical stimuli) of which those objects are composed. Analysis of the motivational significance of objects is therefore appropriately conducted without reduction to concepts more primitive than attitude.

Application to the Analysis of Unconscious Process

Among the most intriguing recent findings of psychological research are some discoveries of memory and performance influences that occur independently of the subject's ability to report them. A series of experiments by Marcel (1983a) has provided particularly intriguing evidence for unconscious representational processes (but see the skeptical interpretation of these findings by Holender, 1986). Marcel (1983b) has interpreted his and related findings in the following strong terms.

> All sensory data impinging however briefly upon receptors sensitive to them [are] analyzed, transformed, and redescribed, automatically and quite independently of consciousness, from [their] source form into every other representational form that the organism is capable of representing, whether by nature or acquisition. This process of description will proceed to the highest and most abstract levels within the organism. (p. 244, emphasis added)

This statement asserts that unconscious and conscious systems employ the same types of representations and are capable of the same types of mental operations. A drastically different alternative view is that unconscious processes perform only crude analyses, using representational systems greatly inferior to those available to consciousness. These contrasting conceptions of unconscious process as deep or shallow can be characterized, in LOR_{h5} terms, as coordinate and subordinate unconscious systems, respectively (Greenwald, 1988a).

In the simplest LOR_{h5} version of the subordinate (shallow) unconscious view, unconscious analysis is identified with just the lowest (feature) level of representation. In this view, stimulus analysis at the feature level occurs without awareness of the analysis. However, upon detection of novel or significant features, the feature-level analysis activates higher-level (conscious) representational systems. Some of the important early contributions of cognitive psychology to the analysis of attentional phenomena (cf. Broadbent, 1958; Deutsch & Deutsch, 1963; Norman, 1968) employed versions of this subordinate-unconscious view.

In contrast, the coordinate (deep) unconscious position has an LOR_{h5} description as two parallel 5-level systems, one of which operates outside of subjective awareness. The psychoanalytic conception of unconscious processes is of the coordinate variety, as are the recent cognitive psychological positions presented by Marcel (1983b, quoted above) and Erdelyi (1985).

The distinction between subordinate and coordinate views of unconscious process is critical in regard to many areas of psychological application. For example, in clinical applications the coordinate unconscious conception justifies so-called depth therapies, which seek to uncover unconscious schematic processes (complexes) that govern symptomatic behavior. In contrast, the subordinate unconscious conception justifies therapies that seek to modify faulty habitual action patterns by focusing on hypothesized low-level control processes. Similarly, in the domain of consumer beavior, a marketer's preference for the coordinate versus subordinate view of unconscious process would dictate very different designs of an advertising campaign that seeks to increase the attractiveness of a product or a political candidate.

Despite the skepticism of many academic psychologists (e.g., Eriksen, 1958; Holender, 1986; Holmes, 1974; Loftus & Loftus, 1980), the coordinate (deep) unconscious view has long been the dominant one in popular conceptions of psychology. Furthermore, advocacy of the coordinate unconscious among academic psycyhologists is increasing (Erdelyi, 1985; Gur &

Sackeim, 1979; Gazzaniga, 1985; Hilgard, 1977; Marcel, 1983b; Shevrin & Dickman, 1980; Silverman & Weinberger, 1985). This significant controversy persists without resolution in part because the theoretical opponents are unable to agree on research procedures that can provide critical empirical tests.

The LOR_{h5} theory can contribute to resolution of the debate between shallow and deep views of unconscious process not only by providing a theoretical framework in which these contrasting views can be described in comparable terms, but also by suggesting operations that can lead to critical tests. The possibility that key concepts can be operationalized in ways that will be acceptable to adherents of opposing views is suggested by recent tachistoscopic studies of information processing outside of awareness (see reviews by Cheesman & Merikle, 1985; Dixon, 1981; Holender, 1986; Silverman & Weinberger, 1985). In particular, studies that have used dichoptic masking (presentation of stimulus word and pattern mask to separate eyes) appear to have produced replicable semantic priming effects by stimuli of which subjects remain unaware (Balota, 1983; Fowler, Wolford, Slade, & Tassinary, 1981; Greenwald, Klinger, & Liu, in press; Marcel, 1983a); and studies that have used brief binocular presentations (not masked) appear to have produced replicable effects of repeated exposure on liking for nonsense shapes that are unrecognizable as having been previously encountered (Kunst-Wilson & Zajonc, 1980; Seamon, Brody, & Kauff, 1983; but see also Mandler, Nakamura, & Van Zandt, 1987). With further refinement, these procedures may permit the control of stimulus access to conscious and unconscious processes. In combination with dependent measures that tap level-specific memory traces (see Table 1), it may be possible to develop findings that document the analytic capabilities or limitations of unconscious processing.

V. Discussion

Alternative Paradigms

Nonrepresentational Approaches

Two major approaches to psychology avoid representational concepts entirely. In both the radical behaviorism of B. F. Skinner and the ecological psychology of J. J. Gibson, structure is presumed to reside outside the organism. Gibson (1979) declared that "efforts made by philosophers and psychologists to clarify what is meant by a representation have failed ... because the concept is wrong" (p. 289). Skinner's similarly anticognitive position is captured in statements such as the following one (from Skinner, 1978):

> If we have eaten lemons, we may taste lemon upon seeing a lemon or see a lemon upon tasting lemon juice, but we do not do this because we associate the flavor with the appearance. They are associated in the lemon. (pp. 97-98)

In criticizing Skinner's (1957) radical behaviorist explanation of language, Chomsky (1959) observed that Skinner used the terms stimulus and response in quite wide-ranging fashion. That criticism can be elaborated in the LOR context by observing that Skinner often used "stimulus" to indicate object, category, or proposition-like entities, rather than confining them to some designated set of primitive units. Instances of such liberal usage can be seen in the above quotation's references to "lemon" and "lemon juice" as behaviorist stimulus terms. From the LOR perspective, these terms designate, not primitive (feature-like) stimulus units, but rather higher-level units such as objects (e.g., lemon) and categories (e.g., juice).

Gibson's approach employs projective geometric analysis to identify optic-array properties that correspond to adaptively significant environmental structures. In principle, Gibson's approach should be able to account for any degree of stimulus analysis that can be managed by an LOR system, and might do so by describing hierarchical levels of structural complexity in the environment, rather than in the organism. In an otherwise sympathetic analysis, Shepard

(1984) observed that Gibson's approach is nevertheless difficult to reconcile with cognitive phenomena that occur independently of external stimuli, such as dreams, imagery, and apparent motion. A plausible alternative conception (Shepard, 1979) is that representational (internal) structures have evolved to be complementary to environmental (external) structures.

Monotypic Systems

A frequent aim of monotypic systems, which use just a single form of representation, is reduction -- explaining complex abilities in terms of the one type of representation. Perhaps the best known monotypic system is S-R behaviorism, which provides notable examples of reduction -- for example Osgood's (1957) explanation of word meaning and Dollard and Miller's (1950) analysis of psychoanalytic mechanisms, both using the representational construct of habit.

As a consequence of the LOR system's linking of representational elements at any high level with those of the lowest level (by the system's hierarchical series of composition operations), behaviorists' and others' attempts at theoretical reduction are compatible with the LOR perspective. That is, a monotypic reductionist account of any LOR-accountable phenomenon is always possible in principle, just as a computer program that is written in a high-level language such as LISP or FORTRAN can always be translated into (reduced to) a string of binary digit codes in the computer's memory.

Many theorists favor monotypic reductionist accounts because of their assumed veridicality (closeness to an identifiable truth) and parsimony (minimzation of theoretical assumptions). However, these claims can be countered by assertions of equivocality (availability of equivalent alternative reductions) and inefficiency. A reductionist account is equivocal in the sense that there are infinitely many equivalent reductions of any given high-level representation. For example, any FORTRAN or LISP program can be implemented by infinitely many different bit-level codes. The availability (in principle) of theoretically equivalent reductionist accounts undermines the presumption that a reductionist theory is closer than a multilevel one to some identifiable truth. The inefficiency of reductionist accounts is suggested by the observation that producing a reduced theoretical account of complex behavior is equivalent to writing computer programs in bit-level codes (i.e., as lengthy strings of 0s and 1s). Theoretical investigations of the abstract concept of the Turing machine leave no doubt that reductionist approaches are in principle possible. However, their inefficiency is suggested by the clear preference of computer programers for higher-level languages.

Cognitivist, as well as behaviorist, theoretical systems, can be monotypic. One might propose, for example, that all mental representations are data structures in propositional form (e.g., Pylyshyn, 1973). Systems that use a single, complex form of representation have been criticized for being confined to an abstract realm of thought that is divorced from the world of behavior. (This objection may have first surfaced in Guthrie's criticism of Tolman's [1932] "purposive" behaviorism for leaving the rat, upon its encounter with the choice point in a T-maze, "buried in thought" [Guthrie, 1952, p. 143].) As in the case of criticism of monotypic behaviorist systems, however, this criticism indicates only an inconvenience or inefficiency in explaining behavior, not an impossibility of doing so.

Recent developments of connectionist ("parallel distributed processing") models of cognitive process (e.g., Rumelhart et al., 1986) provide the latest development in monotypic approaches. As with other reductionist accounts, the connectionist approach is capable in principle of accounting for anything that can be explained by a multilevel LOR system. It was earlier suggested that the structure employed in connectionist models is particularly useful as a model of the structures that form object representations from feature information.

Modular Systems

An alternative to both multilevel and monotypic systems systems is the approach of partitioning mental activity into coordinately functioning domains (modules or faculties). Perhaps the oldest example of a mental faculty theory is Plato's division of the soul (in The Republic) into rational and irrational domains.

The most prominent descendant of Plato's partition is Immanuel Kant's three-faculty system of affection (feeling, emotion), conation (will, striving), and cognition (knowing, thinking), as presented in his Critique of Judgment. The influence of Kant's scheme is widely apparent in modern psychology, ranging from William James's (1890) division of the functions of the self into affective, conative, and cognitive portions, to the frequent use of the affect-conation-cognition partition in modern investigations of attitudes (e.g., Breckler, 1984; Ostrom, 1969; Smith, Bruner, & White, 1956). Two other influential modern faculty approaches are attributable to Freud. These are the division of the psyche into coordinate conscious, preconscious, and unconscious domains (Freud, 1912) and the identification of id, ego, and superego as complementary mental systems (Freud, 1923/1961). In contemporary psychology, a faculty-like division into domains of perception, memory, motivation, and performance is widely used. (Approximately that same division was used in discussing applications of LOR_{h5} in this article.)

Faculties or modules are interrelated coordinately, in contrast with the hierarchical relationships among levels of representation. Although notions of modularity and hierarchy have sometimes been treated as alternative conceptions of the same phenomena (e.g., Baddeley, 1978) there is no necessary incompatibility between faculty and LOR paradigms. An example of their mutual compatibility can be seen in Fodor's (1983) three-level hierarchy (transducers, input systems, and central processors), which he combines with a modular faculty organization within the lower two of these three levels. Another such example is Konorski's (1967) conception of gnostic fields (modules), within which are embedded hierarchies of gnostic units. Jackendoff (1987) has provided a more recent account in which representational levels are found within modules.

In the present description of LOR_{h5}, the transition from features to objects was conceived in the visual modality. A more complete description of human representations must also include representations based on tactile and auditory features. In audition, the perception of words may be analogous to the perception of visible objects. It is certain that the operations applicable to auditory words bear little resemblance to those applicable to visual or tactile objects. Consequently, it is certain that a modular approach would have to be incorporated into a thorough LOR account of human cognition.

Levels of Analysis

Researchers interested in computer simulation and artificial intelligence have distinguished among the levels of analysis in terms of which their endeavors can be described. In one of the more influential of such treatments, Marr (1982) described three levels: hardware implementation, representation and algorithm, and computational theory. Newell (1982) used six levels, ranging from device level to knowledge level. Pylyshyn (1984) identified three levels, physical, symbolic, and intentional. In recent articles that refer to a wide variety of previous levels-of-analysis formulations, Arbib (1987) described six levels, and Anderson (1987) two. Rather than considering the details of these multilevel accounts, it is more appropriate for present purposes to note the shared properties of levels-of-analysis formulations, and how these relate to properties of LOR formulations.

Most of the levels-of-analysis formulations have a bottom level in computer or neural hardware, and a top level that can be characterized as abstract, conceptual, or mental. This difference represents either an implied or an explicit shift of medium that is an obvious difference from the within-medium property of LOR accounts. The different ways in which the shift from physical to abstract medium is conceived in levels-of-analysis formulations is reminiscent of an earlier era's discussions of mind-body distinctions. By comparison, as a consequence of their being confined to a single medium, LOR formulations avoid mind-body issues. An LOR theory can be conceived equally as an abstract theoretical set of levels, as subdomains within a mental medium, or as structural distinctions in a physical medium. Levels-of-analysis formulations that do not include a shift of medium (e.g., Anderson, 1987) are effectively indistinguishable from LOR formulations.

Summary

The alternative paradigms for representation that have been considered are either subsumed by the LOR approach (monotypic systems) or are noncompetitive with it (modular and levels-of-analysis formulations). Although nonrepresentational approaches (e.g., Gibson's and Skinner's) are explicitly competitive with an LOR approach, it is a simple matter to adapt the LOR machinery to a nonrepresentational form, by interpreting its levels as environment-resident, rather than as representation-medium-resident. Still another alternative is to assume that representational systems have evolved toward structures that match environment structures (e.g., Shepard, 1979). The ability of the LOR framework to accommodate other approaches makes it potentially a general framework for psychological theory.[2] Nevertheless, conclusions about its value must rest on its ability to generate successful applications.

Extensions of LOR Theorization

Possibilities for More Formal Treatment of LOR

The possibility of mathematically formalizing a theory of levels of representation is suggested by parallels between an LOR system and a formal measurement structure (Krantz, Luce, Suppes, & Tversky, 1971; Roberts, 1979). In the theory of fundamental measurement, a system of qualitative relations among elements of an empirical (represented) domain is mapped onto a system of formal relations in an abstract (representing) domain. Once this mapping is established, properties of the representing domain -- for example, arithmetic properties if the representing domain is numerical -- can be used to describe the represented domain. Since those properties are not inherent in the represented domain but, rather, depend on its relation to the representing domain, they are emergent properties of the measurement structure.

An example of such a measurement structure is the interval scaling of weight, for which the empirical domain consists of heaviness comparisons of pairs of objects. When the empirical set of binary relations (i.e., paired heaviness comparisons of objects) is sufficiently orderly (e.g., transitive, see Coombs, Dawes, & Tversky, 1970, Chapter 2) numbers can be assigned to objects such that the numbers are understood as (i.e., represent) weights of the objects. Further, these numbers have an interval scale property, meaning that they can be added to represent the combined weight of two objects, subtracted to represent the weight difference between two objects, or averaged, etc. The interval scale property, and its associated unidimensional construct of weight, are emergent properties of the measurement structure.

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[2]One approach to representation that cannot be accommodated within an LOR framework deserves mention. This is the proposal that qualitatively different forms of representation are interrelated in a heterarchical, rather than hierarchical, structure. (In a heterarchical structure, nodes do not stand in unambiguous subordinate, coordinate, or superordinate relations to one another.) For some thoughtful examinations of the representational possibilities of heterarchies, see Hofstadter (1979) and Minsky (1985).

Although they are in a sense inherent in the empirical data of heaviness comparisons, the interval scale and the unidimensionality of weight are by no means directly apparent from heaviness comparisons of objects.

Although the theory of fundamental measurement provides a model for formal development of LOR theory, both the multiple levels of an LOR system and the complexity of the empirical relations that it models make formidable the task of formalizing it. The potential payoff is that an axiomatized LOR theory could guide the construction of cognitively powerful artificial systems.

Developmental Applications

Among contemporary psychological theories, Piaget's (e.g., 1954) genetic epistemology is certainly the one that makes fullest use of the idea of hierarchical levels of representation. Piaget's work has influenced the present analysis not only through its general impact on contemporary psychological thought, but also in that the LOR_{h5} theory includes levels that correspond to the second and third of Piaget's three major stages. LOR_{h5}'s proposition level corresponds to Piaget's stage of concrete operations (ages 7-12), and its schema level corresponds to Piaget's stage of formal operations (age 13 and over). Use of Bruner's (1966) subdivision of the preoperational stage (through age 6) into enactive, iconic, and symbolic stages permits a loose mapping of all five of LOR_{h5}'s levels onto the resulting five developmental stages, as follows: (a) enactive (feature representations), (b) iconic (objects), (c) symbolic (categories), (d) concrete operations (propositions), and (e) formal operations (schemata).

The mapping of developmental stages onto levels of representation suggests applications of LOR_{h5} to problems in developmental psychology. Among the possibilities are (a) designing diagnostic tests of mental development in part as tests for ability to use specific levels of representation, (b) interpreting the development of social behaviors (for example, altruism or aggression) in terms of abilities to use increasingly complex levels of representation in the control of performance (cf. Kohlberg, 1981; see also present Table 2), and (c) designing techniques of instruction for children that avoid use of representational systems that have not yet developed. As an example of the last type of application, consider that adults are fond of offering reasons for what they ask a young child to do, even though the child is unlikely to have the schematic representational ability needed to comprehend the adult conception of reasoned justification for action. These child-adult interactions may, of course, help to promote the child's development of schematic representational ability. Nevertheless, the desirability of that eventual impact should not obscure the possibility that effective immediate instruction might be served better by an approach that relied on lower-level representations.

Comparative Applications

The task of characterizing the mental abilities of animal species in comparison with human abilities has been of scientific interest ever since Darwin's theory of evolution provided a rich source of hypotheses about those comparisons. Special interest has focused on the closest evolutionary relatives of humans, the great apes (chimpanzees, orangutans, and gorillas). There have been intense debates about the abilities of great apes (especially chimpanzees, which have been the most frequently studied) to engage in insightful problem solving (Hull, 1935; Kohler, 1925), to represent the self (Epstein & Koerner, 1986; Gallup & Suarez, 1986), and to use language (Gardner & Gardner, 1969; Premack, 1983; Savage-Rumbaugh, Pate, Lawson, Smith, & Rosenbaum, 1983; Terrace, 1985).

The problem of understanding language use by great apes acquires some usefully sharp definition in the context of the LOR_{h5} theory. Three of LOR_{h5}'s representational levels --

categories, propositions, and schemata -- are of obvious relevance to language. The success of researchers in getting chimpanzees to use token symbols (Premack, 1971) or manual signs (Savage-Rumbaugh, Rumbaugh, & Boysen, 1978) as proxies for objects suggests that chimpanzees are capable of category representations. The claims and debates about language use focus most sharply, then, on the question of whether the chimps' responses to (or productions of) strings of tokens or signs can be interpreted as propositional representations. It makes little sense, in the context of LOR_{h5}, to assess great apes' abilities to use language in the highest (schematic) sense before there is definitive support for their ability to use propositions.

As in the case of language use, the analysis of other abilities shown by apes can benefit from empirical research that would establish the type of representation on which those abilities depend. The problem-solving achievements of Kohler's chimps, and the uses of tools observed in groups of chimps in the wild (Goodall, 1970) may require the equivalent of a propositional representation of the solution action or of the tool's instrumentality. The self-recognition achieved by Gallup's (1977) chimps -- a skill that is observed in humans at about age 18 months (Lewis, 1986) -- may require a category-level representation, or perhaps even just an object-level representation, of the self. Other cases of apparent use of representations by various species could similarly benefit from analysis to determine the minimum level of representation that could plausibly support the observed behavior. One intriguing example is Herrnstein, Loveland, and Cable's (1976) report of evidence for apparent use of category representations by pigeons. However, it may be possible that the feats of discrimination performed by their pigeons can be explained by feature-level representations.

Conclusion

This article has sought to describe a form or paradigm of theory -- levels of representation (LOR) -- that substitutes a unified analysis of representation for the present diversity of the major 20th-century psychological schools of thought. In abstract statement, the LOR theory specifies that complex representations are compounds of simpler ones, and have emergent properties that are absent from their simpler constituents. It is difficult to make a compelling case either for or against the LOR approach when it is presented only in this abstract form that does not identify levels in terms of specific units, relations, and emergent properties. Accordingly, this article gave detailed attention to LOR_{h5}, a specific five-level LOR theory, in which the units at successive levels were identified as features, objects, categories, propositions, and schemata.

In the LOR context, behaviorism is interpreted as a preference for stating explanations in reduced form -- either in terms of units at the lowest representational level or, more radically, without representational concepts entirely. By contrast, cognitivists prefer explanations that appeal to one or more higher levels of representation. Providing a third perspective, psychoanalytic theory's division of the psyche into conscious and unconscious systems is interpreted either in terms of a horizontal dissociative barrier between lower and higher levels of representation (the subordinate unconscious view), or a vertical barrier between parallel multilevel systems (the coordinate view). Psychology's three major schools of thought are in this way potentially reconciled by viewing them as alternative strategies for constructing psychological theory on the LOR framework.

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