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The Access Paradox in Analogical Reasoning and Transfer: Whither Invariance?

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Despite the burgeoning research in recent years on what is called analogical reasoning and transfer, the problem of how similarity or invariant relations are fundamentally accessed is typically either unrecognized, or ignored in componential and computational analyses. The access problematic is not a new one, being outlined by the paradox found in Plato's *Meno*. In order to understand the analogical-access problematic, it is suggested that the concepts of analogical relations including the lexical concept *metaphor*, *isomorphic relation* in mathematics, *homology* in biology, *stimulus generalization* in psychology, *transfer of learning* in education, and *transposition* phenomena in perception, be reconceptualized as subsets of a higher-order domain as all share the problem of how invariance relations are generated and accessed. A solution is suggested based on two specific evolutionary and neurological models, coupled with findings regarding the cognitive importance of knowledge-base. The paper constitutes a reciprocal complementarity analysis of a previous paper on metaphor. A higher-order form of analogical reasoning called analogical progression is introduced. Implications for research are discussed that indicate the need for a paradigm shift. The paper concludes with a four-stage model of analogical access.

Keywords: analogical, invariance, transfer, access problem, metaphor

Analogy, and its sister concept metaphor, has disenjoyed a long and controversial history. Indeed, the history and analysis of analogy and metaphor have been traced by authors in virtually every discipline: for example, in psychology (Haskell, 1987a; Hoffman, 1980; Lakoff and Johnson, 1980; Leary; 1990; Ortony, 1979); in philosophy (Dreistadt, 1968; Hesse, 1963; Ricoeur, 1977);

This article was originally an invited paper to appear in a 2004 special issue on analogical reasoning in *Theoria et Historia Scientarium* (8(1), 159–196), Edited by Tomasz Komendzinski at Nicolas Copernicus University, Turin, Poland; for reasons unknown, despite being in galley proof stage, the issue was never published. This is a slightly modified version. I would like to thank Dr. Ray Russ for further editing. Request for reprints should be sent to Robert E. Haskell, Ph.D., University of New England, Psychology Department, Hills Beach Road, Biddeford, Maine 04005. Email: haskellre@gmail.com or rhaskell@une.edu in anthropology (Fernandez, 1991); and in artificial intelligence (Kling, 1971; Winston 1978). When I first began to be interested in analogy and metaphor as cognitive phenomena (Haskell, 1968a), analogy and metaphor were seen as linguistic literary devises to be avoided by "hard" scientists. There were a few notable exceptions advocating their use; for example in psychology Asch (1955) and Nash (1963); in archaeology Ascher (1961); in paleontology Gould (1977); in biology and general systems theory Bertalanffy (1963); in ethology Lorenz (1974); and in physics Oppenheimer (1956). Research in the humanities already had a massive literature on both analogy and metaphor (e.g., Shibles, 1971). Neither concept, however, was conceptualized as cognitive.

Early on, I considered analogy and metaphorical reasoning to be different surface manifestations of a set of cognitive processes based on analogical relations generated by a more fundamental underlying cognitive invariance process (Haskell, 1968a).[1] Accordingly, in addition to analogy and metaphor, I also considered the concepts of *isomorphic relation* in mathematics, of *homology* in biology, of *stimulus generalization* in psychology, of *transfer of learning* in education, of *transposition* phenomena in perception with all based on an "analogical" process, and that analogical reasoning was fundamental to thinking and reasoning.[2] What I was beginning to conceptualize at that time was that these concepts were subserved by some kind of neurological *invariance* function.

Over the years, I have developed a framework for understanding the underlying process responsible for this array of surface phenomena (Haskell, 1968a, 1978a, 1982, 1987b, 1989, 1991, 2001, 2000, 2001, 2002a, 2002b, 2003a, 2003b,

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[1] This article (Haskell, 1968a), written as an undergraduate, was an awkward and groping first attempt to outline what I saw at that time was the cognitive significance and scope of application of analogical reasoning. I later developed this view into a masters thesis (Haskell, 1968b), and still later into an applied aspect of analogical reasoning (Haskell, 1978b). These early works have served as a blueprint that has set my research agenda ever since.

[2] In the opening of this paper, I indicated the concepts of *metaphor, isomorphic relation, homology, stimulus generalization, transfer of learning,* and *transposition* as variants on a fundamental "analogical" process. There is (at least) one more concept to add to this list: the "*example.*" Examples, are not seen as "analogies" largely because an example is said to belong to the same class, category, or domain of what it is an example of. Some who emphasize the role of *similarity* are more likely to consider the example in their conceptualizaton, though even then it is not seen as an "analogical relation" but as on a similarity continuum. For example, Rumelhart (1989) observes that "It is possible to see a continuum of possible situations for reasoning by similarity involving at one pole what might be called remembering and at the other what might be called analogical reasoning. In between, we have such processes as generalizing, being reminded, and reasoning by example" (p. 301). An example that is seen as crossing a class, category or domain has been considered a "category mistake," to use Ryle's (1953) classic view. However, since nothing is ever absolutely the same as anything else, when we create an example we have already engaged in analogical reasoning with implicit mapping and matching processes.

2004a, including an undergirding algebraic structure; see Haskell and Badalamenti, 2003). The issue this paper will explore involves the fundamental cognitive and neurological process subserving the various surface phenomena indicated above.[3] Accordingly, when referring to analogical reasoning, this paper will, in fact, be referring to a neurological and evolutionary-based invariance function subserving the various surface manifestations (see Figure 1).

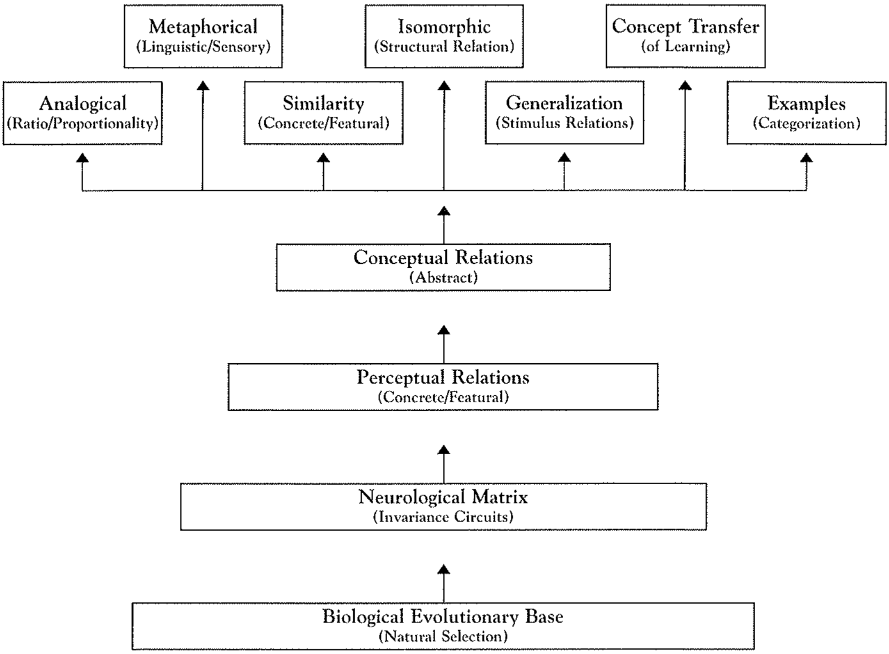

Figure 1. Invariance Relations Scheme. Adapted from Haskell, R.E. (2004b, p. 576). Beginning at the bottom, the scheme shows the origins of the various surface manifestations, indicated at the top, of an invariance operation; each level is subserved by the prior level.

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[3] For some years now I have been developing an applied linguistic and cognitive framework with a logico-mathematic and structural methodology for analyzing verbal narratives that are generated by the analogical/invariance relations described in this paper (Haskell, 1978a, 1982, 1989, 2002a, 2002b, 2003a, 2003b, 2004a). For purposes here, suffice it to say that in my small group dynamics laboratory, where there is a one-way vison mirror, or tape recorder, I have found that discussants will select into conversation stories about the CIA or FBI, secrets, and wiretapping. While these stories are otherwise "literal," they isomorphically map onto the group situation, where stories about X have what I have termed sub-literal meaning X'. Discussants, however, have no recognition of why these stories were selected-into the conversations. Such "analogical narratives" call into question the very definition of what constitutes literal v. metaphoric, analogical, or figurative language.

As with my article on a neurofunctional shift underlying the origin of lexical metaphor (Haskell, 2002a), this paper suggests an integrative cross disciplinary approach. Together these two papers constitute reciprocal complementarity theories on the neurological origins and a reconceptualization of what are commonly called analogical and metaphorical reasoning. More specifically, the paper will address the fundamental problem of how this invariance function is cognitively initiated; this is known as the access problem.[4] It has yet to be solved.

Overview

In the past few decades, the concepts of analogy and metaphor have come to be accepted as reflecting not just logical and linguistic properties but deeper cognitive processes (e.g., MacCormac, 1985; Tourangeau, 1982) and that somehow involve similarity relations (see Rips, 1989; Vosniadou and Ortony, 1989). Analogy and metaphor are increasingly seen as fundamental to thinking and reasoning (e.g., Holyoak and Thagard, 1995; Hummel and Holyoak, 1997). During this time, a voluminous literature in psychology and cognitive science, including artificial intelligence and other fields, has accumulated with most of the cognitive research and theory being domain-centered (i.e., either on analogy, or metaphor, or similarity, etc.). In addition, historically — and even now — research in each domain area has remained relatively isolated from the others, e.g., research on analogical reasoning has seldom been cited by metaphor researchers, and vice versa. Because each concept has been defined by its surface structure, it has been seen as "different" from the others (research on similarity being somewhat an exception).

Moreover, cognitive research on analogical reasoning has been largely conducted with componential, computational, and experimental frameworks. The most well-known perhaps being the work of Gentner (1983) on analogical reasoning and Sternberg's (Sternberg and Rifkin, 1979) work in analogical reasoning and metaphor (Sternberg, Tourangeau, and Nigro, 1979). The research of both Gentner and Sternberg is concerned with the analysis of *retrieving*, *accessing*, *mapping* and *matching*, and, more recently, *alignment* processes (Markman and Gentner, 1993), and can be seen as paradigmatic of componential and computational type approaches to understanding analogical reasoning. Despite this, componential approaches to analogical reasoning have led to a virtual paradigm shift in the way thought is thought about, indeed, to a new Weltanschauung: thinking and reasoning are now nearly equated with analogical reasoning.

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[4] For purposes of this paper, I will not distinguish between "access" and "retrieval" processes as is often done in the literature.

Perhaps the most important aspect of the voluminous research on analogical and metaphorical reasoning has been the wide-spread recognition and analysis of its role in everyday reasoning (Holyoak and Thagard, 1995; Read, 1983); in legal reasoning (Levi, 1949; Marchant, Robinson, Anderson, and Schadewald, 1991; Sunstein, 1993); in organizational research (Tsoukas, 1993); and in governmental policy making (Spellman and Holyoak, 1992). In their work on analogical reasoning, Hummel and Holyoak (1997) noted that their " aim is to lay the groundwork for a more general theory of human thinking" (p. 427). Thus the field has progressed from seeing analogy, metaphor, and similarity relations as linguistic literary devices to being fundamental to human thinking and reasoning. In this respect, cognitive science seems to be finally catching up to Plato and Aristotle.

Following his mentor, Socrates, Plato says about reasoning with similarity: "*I am myself a great lover of these processes of division and generalization; they help me to speak and to think. And if I find any man who is able to see 'a One and Many' in nature, him I follow, and walk in his footsteps as if he were a god*" (Rouse, 1956, p. 55, italics added). Later, Aristotle (see Cooper, 1960) similarly suggests: "*The greatest thing by far is to be a master of metaphor. It is the one thing that cannot be learned from others. It is the mark of genius*" (p. 101, italics added). Indeed, in one form or another, the ability to reason analogically, cum ability at transfer of learning, has historically been linked to intelligence. For example, Holyoak, Junn, and Billman (1984) note that "Analogical thinking is widely, albeit arguably, recognized as a hallmark of human intelligence, and as such the course of its development is a topic of clear importance" (p. 2042). McKeachie (1987), in commenting on papers about transfer of learning research, says, "As I read these papers, I could not help thinking of discussions of the 'g' factor in intelligence which is characterized by flexibility. Very likely the skills described by 'g' include those we have discussed here under the rubric 'transfer' " (p. 711).

The Access Problem

Given the pervasiveness of so-called analogical and similar processes, along with their role in thinking, reasoning, and intelligence, it becomes important to understand how these processes are recognized and accessed. Despite the voluminous research we still do not know how we know that something is the *same as* something else. Intuitively, it seems simple: we perceive "similarities" between two or more ideas, events, objects. But counterintuitively, research suggests that featural "similarity" is not the fundamental explanation (e.g., Rips, 1989).

Recognition of the Access Problem

From the vast literatures, a few researchers have recognized this fundamental problem of access: how the recognition of "sameness" is apprehended. Mostly the problem is either not recognized or is simply ignored. The problem is this: even given that similarity relations — however defined — subserve the array of seemingly different phenomena like analogy and metaphor, how is the similarity relation identified? Eskridge (1994) recognized that, "Retrieval of a source is arguably the most complicated issue currently facing researchers in analogical reasoning" (p. 210). And Keane (1988) notes that "One of the most important and least understood questions in analogical problem solving research is "Where do analogies come from?" or, more precisely, "How are base analogues retrieved? . . . Explanations of the source of such analogues have been found wanting and in the absence of a better explanation seem largely serendipitous" (p. 53). Holyoak and Koh (1987) also point out that "If two situations drawn from disparate domains have never previously been associated, there can be no direct retrieval pathway linking the two. How, then, might the target activate the source?" (p. 333).

Spencer and Weisberg (1986), too, point out that, "Creative discovery is often promoted by noticing an analogy in a remote domain. However, even if one assumes that this view is correct, the question of how these creative discoverers initially noticed their analogies remains open" (p. 448). In reviewing the research on stimulus equivalence, Clayton and Hayes (1999) lament, "We are told that stimulus functions of B are transformed consistent with its mutual relation to A, but we are no closer to an understanding of transformation itself. . . . [A] satisfactory description of the process of transfer or transformation is absent" (p. 152). Continuing, they conclude that "If indeed equivalence gives rise to rules, then for a rule to specify a contingency may simply mean that the rule and the contingency are members of the same equivalence class" (p. 149). So this does not solve the problem of access either. Others deal with the problem by considering *stimulus equivalence* to be an unanalyzable primitive (Sidman, 1990).

For Johnson–Laird (1989), "The processes underlying the discovery of profound analogies are much harder to elucidate than is generally realized" (p. 313); that analogies "cannot be guaranteed by any computationally tractable algorithm" (p. 313). Again, Holyoak and Koh (1987) maintain that "particularly in the case of analogies between problems drawn from disparate domains, it is unclear how a problem solver can retrieve a potentially useful source analogue from a large knowledge-base. *Computational models* of analogy have typically evaded this issue, either by explicitly directing the program to compare particular situations . . . or by implementing a psychologically implausible exhaustive search mechanism" (p. 332, italics added). deJong (1989), too, asks, "How can a system retrieve a relevant source if it does not already know the 'correct' analogy mapping?" (p. 351).

Finally, in asking how someone recognizes a similarity, Green (1979) confesses "I still do not know how they 'get it' . . . how anyone gets the metaphor. But neither can I explain how anyone 'gets the joke,' or 'gets the parable,' or 'gets the premise' needed to escape the clutches of paradox" (p. 473). The solution to the access problem is neither simple, nor obvious. It is, however, an old and venerable one that precedes cognitive science. The access problem has been grappled with for over two thousand years in Western philosophy: specifically in Plato's paradox in the *Meno*.

The Access Problem and Plato's Paradox of the Meno

In a critique of behaviorist learning theories, Weimer (1973) — in what should be considered a classic article in cognitive science — recognized the access problem in one of Plato's famous paradoxes. He framed the problem of recognizing stimulus similarity most succinctly: "How can an organism recognize all the potential instances, on the basis of no prior exposure to them, as instances of the *same* concept?" (p. 29, italics added).

In his *Meno*, Plato has Socrates argue "That man cannot inquire either about that which he knows, or about that which he does not know; for if he knows, he has no need to inquire; and if not, he cannot; for he does not know the very subject about which he is to inquire." This is the problem of accessing an analogy in Platonic terms. How is it possible that X is recognized as *like* Y, or X *like* X'. The Socratic "solution" to this paradox is that all so-called new learning is actually *remembering something that we already know*. This is known as the doctrine of anamnesis or recollection. Since Plato, philosophers, theologians, psychologists, physical scientists, and poets at one time or another, or in one form or another, have grappled with this paradox. Indeed as Pylyshyn (1979) noted some time ago, "almost every major cognitive theoretician . . . has had a crack at it" (p. 421). No solution, however, has been generally accepted for Plato's "access" problem. It is, therefore, crucial to understand this paradox in relation to analogical reasoning.

Although Weimer, like some others (Balaban, 1994; Shanon, 1984), questions whether the paradox of the *Meno*, as worded, is a true logical paradox, he recognized that the problem it poses is, nevertheless, a real problem for both philosophy and psychology that must be dealt with if progress is to be made in understanding analogical reasoning.[5] While this paper will not presume to have logically solved the paradox, it will have a crack at a resolution, suggesting (1) a possible evolutionary basis, (2) a neurological substrate and (3) how, on these biological bases, access can be better understood and therefore initiated.

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[5] For a more extended treatment of Plato's paradox in relation to this issue, see Haskell (2000).

Transfer of Learning and the Access Problem

Like analogical reasoning, the instructional concept of transfer of learning is emblematic of the problem of access. Transfer of learning is the use of past learning in learning something *new* and the application of that learning to both *similar* and *new* situations (see, Haskell, 2001). Like analogical reasoning and its other equivalent terms, transfer of learning, too, has had a long history regarding the access problem.

Thorndike and Woodworth (1901) explained transfer of learning on the basis of identical elements theory. This theory maintained that transfer of learning only occurs when two situations have identical elements (read: highly similar) in common. If identical elements are not present, then, no transfer of learning will take place (except by sheer contiguity). Thorndike's view of transfer has held sway in educational theory ever since. Modern cognitive research on analogical reasoning and artificial intelligence is also based on Thorndike's identical elements view. As Singley and Anderson (1989), in their seminal theory of how we acquire skills, make clear:

> The essence of this book is that Thorndike's identical elements theory is alive and well in a new body. We have resurrected Thorndike's theory by redefining his identical elements as the units of declarative and procedural knowledge in the ACT* theory . . . . The key difference between his proposal and ours is that, whereas Thorndike's elements referred only to external behaviors, ours include purely cognitive operations that reference abstract mental objects. (p. 248)

The authors have not in fact resurrected Thorndike's theory — since it never died — but have recast it in modern language. In much of cognitive science, the view of how general concepts are constructed has not changed since the time of Aristotle. Following Aristotle, Singley and Anderson, in explaining how generalization works in their system, maintain that it "is done by *abstracting common features* of the source and target of the analogy" (p. 31, italics added). Aristotle's attempt to solve Plato's notion of universal concepts by positing abstract categories based on "*common*" features merely eliminates the problem of access by defining it away, since claiming common features already assumes accessing similarity relations. Further, Singley and Anderson (1989) clearly state,

> Conspicuous by its absence in this discussion is any mention of the . . . mechanisms of *generalization* and discrimination which create new productions by inductive, syntactic transformations . . . processes of generalization and discrimination do not figure in our analysis of skill acquisition . . . . *We have nothing new to say about this type of transfer* in this book. (p. 50, italics added)

These two major figures reflect the current state of affairs in cognitive science regarding both similarity as an explanatory concept ignoring the fundamental problem of access.

With some exceptions, then, nearly the entire history of research on metaphorical and analogical reasoning in the humanities, philosophy, and in psychology has been dominated by the idea that analogies and metaphors are accessed by similarity relations of some kind (concrete, abstract, sensory, etc.) despite the concept of similarity itself being historically known to be problematic both logically (see Goodman, 1952; Quine, 1953) and cognitively (Rips, 1989; Shanon. 1988). Medin and Ortony (1989) "agree with Rips that, unless one can specify how similarity is determined, the resemblance approach to similarity is vacuous" (p. 188). At this point it is necessary to look in more detail at the current state of cognitive science with respect to the problem of analogical access. To reiterate: while the look of similarity has changed from referring to (a) concrete features, (b) to abstract conceptual relations and (c) to procedural or production sequences, similarity — in one form or another — remains the primary explanation for how an analogue is accessed. From Aristotle, to Thorndike's influential identical elements theory of transfer, up through the contemporary cognitive science and information processing literatures on analogical transfer, similarity remains the default position for explaining analogical transfer and, by implication for explaining Plato's paradox.

A related question remains: How are categories constructed? Again, the classic answer has been Aristotle's: by abstracting out the common features from an array of stimuli, despite long-standing research to the contrary on categorization processes (e.g., Rosch and Mervis, 1975). According to this abstraction view, categories are constructed by the increasing predominance of the similarities among stimuli, over their differences. The process of abstraction subtracts from an array of the relevant attributes, which are defined in terms of similarity. Thus the theory presupposes in its explanation what it proposes to explain (Plato's paradox, once more). As I have noted elsewhere (see Haskell, 1997), "Though there is a great deal of research on cues, systematicity, and other apparent routes into 'recognizing' similarity, what computational models, in fact, actually do is to tell us how we process a similarity relation after we have already recognized or accessed it" (p. 92).

Componential and Computational Approaches to Analogical Reasoning

Componential and artificial intelligence research on analogical reasoning and transfer holds that accessing an analogy is largely based on scanning and finding a similarity and then *mapping* and *matching* between the two parts of the analogy. The conventional approach to how an analogy is initially recognized is that the brain scans its memory stores in search of a similarity and finds a "match."

One influential componential model of analogical reasoning is Gentner's (1982, 1983, 1988, 1989) analysis of the well-known analogy between the solar system and the atom. The research by Gentner purports to explain analogical transfer, but being based on similarity relations — whether concrete or abstract — does not address the paradox. Markman and Gentner (1993), however, propose an interesting perspective on the concept of recognizing similarity. Instead of dealing with individual featural similarities, Markman and Gentner assume similarity resides in a set of systematic alignments of all features between an analogy. Accordingly, similarity resides in an isomorphic matrix (my term, not theirs) alignment, or structure mapping, between source and target, X and X'. For example, given source characteristics X, target characteristics must have the same alignments, e.g., $X'_{1\,4\,3\,7\ldots}$; they can not be $X'_{1\,7\,4\,3\ldots}$. While this is an interesting advancement to matching, it merely adds another step in explaining how similarity is originally accessed. Their view does not change the problem of access as it, too, assumes what it later purports to show — similarity; it merely switches the burden from *individual features* to *systems alignment*. Though the concept alignment is itself important (see Haskell, 1968b), this view of similarity compounds the problem.

A variant to a strict componential approach is the work of Holyoak (1985; Holyoak and Koh, 1987) who emphasizes plans, goals, and other cognitive constraints in accessing analogues. This view is not so much interested in the mechanisms underlying analogical reasoning as it is the multiple constraints imposed on the reasoning process, i.e., its use: for example, problem space constraints, purpose or plans of use, etc. While quite aware of the access problem, Holyoak does not solve it. In addition to the historical and voluminous research on the function of similarity relations in accessing analogical transfer, other techniques such as giving hints (e.g., Gick and Holyoak, 1980, 1987), cues (Gick, 1985), and use of metacognitive strategies (Gray, 1991; Nickerson, Perkins, and Smith, 1985) — while useful in other respects — do not address the problem of access.

Still another approach in artificial intelligence is the use of abstract plans and other conceptual features to *index* the source of analogy. But as de Jong (1989) concludes "Any example of the source would be stored under these conceptual indexes"(p. 351) and therefore, the theory assumes what it later purports to explain: similarity relations are built into the indexing.

Brief Critique of the Componential Approach to the Access Problem

Neither componential, nor artificial intelligence, approaches in cognitive science add anything of significance to explaining the analogical access problem. In fact, it could be said that other than as a systematic heuristic, the analysis of mapping, matching, and alignment of analogical components has yielded little of consequence that has not been known previously by philosophers, those in the humanities, and by other non computational and non componential researchers analyzing and applying analogical reasoning.

Componential approaches have essentially contributed only a set of abstracted steps for processing analogical reasoning; for example, accessing, retrieving, mapping, matching, and alignment, by which to analyze how subjects' reason about and "retrieve" an analogy *after the fact.* Just as Weimer recognized that these kinds of approaches do not solve Plato's learning paradox, so, too, Arthur Koestler (1967) understood that in learning theory explanations, there is a "ghost in the machine."

This brief critique of the componential and computational approaches to analogical reasoning and access is not meant as a broad sweeping indictment. Certainly, for heuristic and pragmatic purposes, componential listings of presumed systematic steps involved in analogical reasoning have been useful, just as a listing of algorithmic-like problem solving procedures in medical emergency manuals are useful.

Finally, almost by definition, virtually all computational approaches to analogical reasoning — connectionist models not withstanding — are based on the assumption that the brain functions like a computer. Thus, all such artificial intelligence-like computational programs and systems for analogical reasoning operate on programs that already have built into them "recognition" algorithms for accessing the analogy or similarity relation. Perhaps what Fodor (1980a) concludes about computational and artificial intelligence approaches is appropriate here. Says Fodor, "people who do machine simulation, in particular, very often advertise themselves as working on the question of how thought (or language) is related to the world. My present point is that, whatever else they're doing, they certainly aren't doing that" (p. 65). In short, as Hofstadter (1995) points out, AI approaches have "cooked the books." I point this out, in part, to support the fact that cognitive science research on analogical reasoning and transfer has remained provincially cloistered from the vast philosophical and other non computational and componential literature.

Quite frankly, much of the research has become repetitive, uninteresting, and firmly engaged in what Kuhn (1970) has called "normal science," where, after a paradigm shift, the drudge work on details is conducted. Accordingly, the normal science approach in analogical reasoning has been merely the tweaking of minor issues. The problem is that there was never a prior paradigm shift, or revolution, from what basically has been, and largely remains, a "folk" conceptualization of analogical reasoning.

I point all this out also in hope of generating integrative research and theory based on a more fundamental paradigm leading to a broader spectrum of what is typically conceptualized as analogical processes. Just as juxtaposing two metaphors — Black's (1962) interactive view of metaphor — often leads to new insights bringing together the different concepts of analogy, metaphor, isomorphism, transfer, etc., and to new hypotheses to be investigated by both experimental and non experimental methods. For example, see my concept below of *analogic progression* — a higher-order continuous form of what is currently called analogical reasoning.

Agenda

Analogical Reasoning Research and Literacy

A final concern examined in my article (Haskell, 2002a) on the neuro functional shift underlying the origin of lexical metaphor remains. That article argued that the prevailing view of lexical metaphor as a figure of speech is the consequence of an inappropriate cognitive turn that resulted in a superimposition or back scanning of a modern alphabetic/literacy-based epistemology on to a linguistic phenomenon originating in a preliterate or oral culture. I suggested (as have a few others) that lexical metaphor was originally not a linguistic figure-of-speech derived from literal language but only later came to be so conceptualized as the consequence of a neurofunctional shift in hemispheric laterality, a shift precipitated by the invention and adoption of the Greek vocalic alphabet.

It is generally accepted that most of the cognitive science program can be directly traced to Greek philosophy (Gardner, 1985). More specifically, Le Doux (1996) notes, "cognitive science resurrected the Greek idea of mind . . . as a carefully engineered machine [which] seemed more appealing than the idea of the mind as a biological organ with an evolutionary history" (p. 39). A modern variant on Aristotlean logic — which was developed as a philosophy hundreds of years after the adoption of the Greek vocalic alphabet had become interiorized (see de Kerckhove, 1986; Havelock, 1963, 1983; Skoyles, 1984) — it follows that the model of mind inherited from Aristotle's literacy-derived epistemology has distorted the investigation and understanding of analogical reasoning and its attendant problem of access. In short, it is being suggested here that much of what is known about analogical reasoning and access is an artefact of this literacy-based epistemological cognitive turn.

In this regard, Luria (1976) found that populations lacking in literacy engaged in a different form of thinking from populations who were literate. More recently, Chernigovskaya (1994) has suggested a cerebral laterality difference between literate and non literate subjects as well. Accordingly, not only are computational and Aristotlean approaches to research on analogical reasoning not compatible with evolutionary and neurological data, but may only be congruent with literate populations. If so, then as argued earlier, a broader and interdisciplinary formulation may be required, a paradigm shift away from the current "folk" conception of analogical reasoning and access.

Resolutions of the Access Paradox

Over the years Plato's paradox has been recognized, in one form or another by major researchers in cognitive science (Shanon, 1984; Simon, 1976; Weimer, 1973), in developmental psychology (Boom, 1991), and in philosophy and other fields (Balaban, 1994; Calvert, 1974; Moline, 1969; Rohatyn, 1974). A number of solutions have been advanced, none of which has solved the problem (for a more extended description, see Haskell, 2000).

Conscious versus Unconscious

One obvious solution to Plato's paradox is to divide knowledge into conscious and unconscious knowing. Though we may not know something consciously, we may know it unconsciously. Plato, of course, did not have our modern concepts of conscious and unconscious. Polanyi (1967) implies that the paradox can be resolved by resorting to unconscious knowledge which he calls "tacit" knowledge. Similarly, Haslerud (1972) considered the discovery of a post hoc reaction when an individual intuitively feels that something is familiar or similar but which may not reach a level permitting conscious recognition of it. Schon (1963) recognized that "people have been trying to explain the emergence of new concepts for over two thousand years" (p. 3). He advances a similar unconscious explanation for how we can inquire about something that we do not know about. He says that we intuitively feel an "intimation" of a similarity relation based on our store of knowledge. While having unconscious knowledge allows us to know more than we can consciously know, this solution — as the unconscious is commonly understood — only postpones Plato's paradox; it merely pushes the paradox back a step.

Johnson–Laird (1983) maintains that his theory of mental models solves the paradox. His attempt to solve it by claiming that the paradox rests on false assumptions does not solve it but arbitrarily eliminates the paradox. More importantly, however, he claims that reasoning with mental models relieves the dilemma. In fact, reasoning with mental models itself is based upon the a priori apprehension of similarity between the model and what the model is a model of. More systematic resolutions to the access paradox have been suggested.

The Philosophical Nativist Resolution

As might be expected, philosophers have applied their skill to cognitive science and have entered the instructional arena as well. The history of Western philosophy might well be characterized as the hunt for the origin of the link between the abstract or universal concept, and the particular instance, and thus essentially the resolution of the paradox of the *Meno*. The psychologist and philosopher Harald Hoffding (1893, 1905a, 1905b) wrote extensively on this problem, though he did not specifically mention the *Meno*. He says,

> There are typical or general ideas, only in the sense that we can make a concrete individual idea serve as an example or representative of a whole series of individual ideas. The generality of an idea will, then, mean nothing more than its fitness to be employed as example or representative. But it still remains to be asked, *what is the psychological process by which an idea comes thus to be set up as representative?* (1905a, p. 166, italics added)

The unexplained psychological process (or missing step) by which an idea comes to be set up as representative (read: similar to) has become known as the *Hoffding step*; it is a contemporary analogue of the paradox of Plato's *Meno*. The Hoffding step leads Weimer (1973) to maintain that "in so far as we are 'directly' aware of anything, it is universals rather than particulars" (p. 30). In this view, it is the universal — i.e., representativeness or similarity-ness — that enables the perception of particulars, not the other way around. But where does this abstract representativeness come from? Plato's question remains extant.

Like Plato's resolution of innate memory and recollection, Fodor (1980b) maintains that humans are born with knowledge that allows them to "re-cognize" novel events. Fodor does not deny the reality of everyday learning, however. Concerned with the issues surrounding "new" concept (and cognitive stage) learning which he believes to be a confused notion, his claim is that all learning theories are based on flawed premises and that there can be no such thing as "new" concept learning. Fodor agrees that complex concepts might be learned because they can be initially represented by other more primitive concepts, maintaining that initial mental structures are powerful enough to generate apparently new concepts only to the extent that they do not exceed their own conceptual boundaries — in which case, they have not created anything "new." Further Fodor (1980b) says that a theory of learning "must be a theory of how the environment selects among the innately specified concepts. It is not a theory of how you acquire concepts, *but a theory of how the environment determines which parts of the conceptual mechanism in principle available to you are in fact exploited*" (p. 151, italics added).

In Platonic terms, the structure for learning language is *recollected*, i.e., retrieved from "memory," as it were. This epistemological view is known as nativism, which holds that all fundamental knowledge inherently resides within the individual. Fodor (1980b) further says,

> It seems to me that there is a sense in which there isn't any theory of learning . . . [and] that in a certain sense there certainly couldn't be; the very idea of concept learning is,

> I think, confused. [He goes on to say] Anybody who has ever given a theory of learning in terms of mental processes (anybody who has ever said anything about what the information flow [read: computational] in learning is like) has said, in effect, that learning is a matter of inductive extrapolation, that is, of some form of nondemonstrative *inference*. (pp. 144–145, italics added)

As Gardner (1985) comments, Fodor's radical claims are deadly earnest; and even though his claims have failed to persuade most of his cognitive science colleagues, they have proved difficult to undermine. At their fundamental level, learning theories, then, are based on *transferring* what we already know. So the learning paradox of the *Meno* — and therefore the accessing of analogical transfer — remains intractable after more than two thousand years.

The Biological Nativist Resolution

If there exists innate learning structures, as Fodor suggests, then they must have evolved through millions of years. Enter evolutionary approaches to the paradox of the *Meno* — and to the problem of analogical access. Despite recent abuses, evolutionary psychology has valid roots (see Campbell's 1960 classic article that Popper [1987] has said is "A treatise of prodigious historical learning: there is scarcely anything in the whole of modern epistemology to compare with it" p. 115). Popper and Campbell are both known for spearheading what is called evolutionary epistemology which holds that, "the main task of the theory of human knowledge is to understand it as continuous with animal knowledge; and to understand also its discontinuity — if any — from animal knowledge" (p. 115). More recent work is exemplified by Plotkin (1998) and Cummins and Allen (1998). Computational approaches tend to be divorced from any biological base (see below).

Now, if cognitive science is stuck with Plato's paradox, then it is likely we are stuck with Plato's anamnesis or recollection resolution, or some variant form. For most scientists — cognitive or otherwise — Plato's doctrine of anamnesis appears to be an absurd doctrine. But is it possible to resuscitate the doctrine of anamnesis in modern form? Weimer (1973) believes the answer is "yes," the doctrine of anamnesis can be resurrected if we understand what the doctrine requires, and what it was designed to accomplish. Weimer suggests that the Plato's doctrine "requires . . . a priori knowledge that transcends any given individual's lifetime and experience" (p. 28). To reinstate the doctrine of recollection, we need an a priori mechanism (in the sense of innate) of knowledge acquisition in the sense of capacity, rather than specific content. If such did exist, it would have to have biologically evolved.

Weimer pointed to a neglected book by a Nobel Laureate economist turned psychologist, Friedrich Hayek (1952). Hayek was concerned with perception, and the physiological correlates of our psychological abilities. Briefly, his thesis is that no sensory input is "perceived" unless it is perceived as *one of the kinds of inputs already accepted* by the nervous system, that is, analogous or isomorphic. Says Hayek, "An event of an entirely new kind, which has never occurred before, and which sets up impulses which arrive in the brain for the first time, could not be perceived at all" (p. 142). Put another way, unless inputs are "isomorphically" accepted as a match to something already in our nervous system that has been acquired in the course of the development of the species, we don't perceive it: for example, it is clear that we don't have the necessary biological apparatus to perceive X-rays and most other electro magnetic wave lengths. In Hayek's words, "We do not have sensations which are then preserved by *memory*, but it is as a result of *physiological memory* that the physiological impulses are converted into sensations" (italics added, p. 53). Nothing comes into our mind unless it matches what we already have in our mind. Hayek sees transfer as being hardwired into our neurological system.

Under a heading entitled "The Nervous System as an Instrument of Classification," Hayek says, "A wide range of mental phenomena, such as discrimination, equivalence of stimuli, generalization, transfer, abstraction and conceptual thought may all be interpreted as different forms of the same process of classification which is operative in creating the sensory order" (p. 16). As Weimer insightfully recognized, Hayek's psychological thesis is *literally* Plato's doctrine of anamnesis in modern evolutionary and neurological dress. Is there any empirical evidence suggesting that this rather strange and ancient doctrine of Plato's might exist in some modern form, and thus address the analogical access problem?

The Biological Evolution of Selection Schemas

While for certain purposes cognitive science has achieved considerable success in understanding the mind as an abstract information processing and computational system; because it has been abstract and formal, these explanation lack actual nervous system instantiation. As Chiarello (1991) has observed, "Because our brain is the result of evolutionary pressures that select for biological fitness and reproductive success we can expect that the human mind will have some design features that may not be predictable from an information engineering standpoint" (p. 251). Concluding, she says, "The most elegant model of some cognitive process, even if it predicts a range of behavioral data, may not be the right model unless it is also neurologically plausible" (p. 251). In agreement with Chiarello, Kosslyn, and Koenig (1995) have called for a "wet mind" approach instead of a "dry" computational one.

If it is the case that evolution has hardwired an invariance function into the brain that subserves analogical access, then what is needed to explain how a hardwired invariance module or set of circuits might work is not current computational "software" but what Kosslyn and Koenig (1995) have called a "wetware" approach to understanding how the brain works. For analogical transfer in its many manifestations to be so fundamental and pervasive, it must have evolved a neurological substrate through natural selection (see below). What most language theories and computational approaches to analogical transfer lack is a compatibility with evolutionary principles and neurological findings.

Since the brain has not essentially changed for a hundred thousand years — long before most theorists believe complex language came into being — any neurological substrate would not be language specific, but rather for language as a bi-product of some other adaptation (see Chomsky, 1972; Gould and Lewontin, 1979). Though not all theorists are in complete agreement (see Pinker and Bloom, 1990), it has been increasingly suggested (Chiarello, 1991; Edelman, 1987; Kimura and Archibald, 1974; Kosslyn and Koenig, 1995; Springer and Deutsch 1981; see Haskell, 2002a) that the left hemisphere capacity for language did not evolve for language per se (à la syntax), but is an adaptation on an already existing complex set of motor sequencing functions.

Edelman's Immunological "Analogy"

Perhaps the most fascinating evidence for a nativistic view of how new knowledge is acquired comes from the work of two Nobel Laureates in immunology (see Jerne, 1985; Edelman, 1987, 1992). Niels Jerne and Gerald Edelman believe that the immune system is a kind of sealed system that contains all of the possible responses to the external antigen world. The immune system does not directly learn from the external world but instead "recognizes" the vast array of possible antigens. Even "more astonishing," says Edelman (1992), "is the fact that a specific recognition event occurs even for new molecules synthesized by organic chemists, molecules that never existed before either in the responding species or in the history of the earth for that matter" (p. 75). Here is a kind of modern Platonic doctrine of immunological anamnesis.

Based on this framework, Edelman (1992), like Fodor, radically critiques cognitive science. He says,

> the cognitive science view of the mind based on computational or algorithmic representations is ill-founded. Mental representations that are supposedly syntactically organized (in a "language of thought") and then mapped onto a vaguely specified semantic model or onto an overly constrained objectivist one are incompatible with the facts of evolution. (p. 152)

Edelman bases his critique of the cognitive science model of learning on his immunological research.

Now, what is significant here for a nativist view of learning and knowledge acquisition — and by adaptation, for a resolution of the access problem — is that both Jerne and Edelman have suggested that the human brain works like the immune system; that so-called learning by instruction is really "recognition." By recognition, Edelman means "the continual adaptive matching or fitting of elements in one physical domain to novelty occurring in elements of another, more or less independent physical domain, a matching that occurs without prior instruction" (p. 74).

The question is whether there is any evidence that this parallel between the immune system and the brain is more than a simple analogue. What makes Edelman's hypothesis that the brain works like the immune system more than just an analogue is the following startling discovery: in terms of embryological development, says Edelman, "My colleagues and I were excited to discover that neural cell adhesion molecules or 'brain glue' are the evolutionary precursors of the whole immune system" (p. 79). It appears that our brain and our immune system are evolutionarily and embryonically connected.

Edelman goes on to say, "In considering brain science as a science of recognition I am implying that recognition is not an instructive process. No direct information transfer occurs, just as none occurs in evolutionary or immune processes. Instead recognition is selective" (p. 81). Just as in evolution and in the immune system model, information is selected — not learned or acquired through instruction. It should be noted that Edelman's selectionist view of "new" ideas is also compatible with Campbell's (1960) classic evolutionary theory of creative thought.

In agreement with Edelman, Gazzaniga (1992) rightly concludes that "If, indeed, selection theory does operate at the higher level of "whole-brain" processes, we must seriously rethink our current conception about the nature of psychological processes" (p. 5). It would seem that the philosophical rationalism and nativism view of mind and Plato's learning paradox has a scientific base. But while Plato may have scientifically come of age, has cognitive science learned anything new that Plato didn't already know? Weimer concludes that

> In 20-odd centuries we have managed to learn nothing at all "new" about the nature of knowledge and learning. And that does not augur well for the future of psychology. Perhaps we are doomed to have a (tolerably efficient) technology of behavior modification, but no science of knowledge and learning at all. (p. 32)

This is not to say, however, that heuristically useful everyday knowledge of how learning has not been acquired. Indeed, the componential and computational findings of cognitive science have been useful in helping to understand the mental technology involved in some aspects of thinking, and learning processes — but, again, only once the "new" has already been discovered. While Plato's paradox and Edelmans's immunological and selectionist view of learning are fascinating, it must be asked if there is additional neurological evidence that might explain Plato's paradox and how analogues are accessed?

The Evolution of the Neurological Architecture of Invariance

Is there further evidence suggesting a neurological substrate for invariance relations? The work of Happel and Murre (1994) can be applied to the problem of "similarity" relations and to analogical access. On the basis of their simulation of neural networks, they suggest that the hardwired architecture of the brain is the result of a long evolutionary process during which a large set of specialized subsystems evolved interactively to carry out the tasks necessary for survival, suggesting

> that the evolutionary directives encoded in the structure of the brain may extend beyond merely an increased ability to learn stimuli necessary for survival. We propose that the initial architecture is not only important for rapid learning, but that it also induces the system to generalize its learned behaviour to instances not previously encountered. Generalization of learning may well be a principal function of much of the initial structure of the brain. (p. 1000)

Generalization of learning is, of course, just another way of describing a kind of (micro) analogical transfer. These findings, too, can be seen as suggesting that the foundation for analogical transfer has apparently been selected by evolution and is directed at increasing the chances of survival for all species.

It appears that these neurological structures have evolved on the basis of several principles. Happel and Murre claim that in addition to hierarchical and global organizational systems, there are highly regular structures at a more microscopic level in the form of neural modules containing as little as one hundred cells, known as mini columns. Mini columns have been proposed as the basic functional units of the cerebral cortex, the part of the brain largely responsible for reasoning. Happel and Murre (1994) note that the structure of these pathways is *similar* (i.e., analogous) to the broad division of the primate visual system into two principal pathways: one pathway processes visual input in a coarse manner and has a fast response time, the other pathway carries out a much more detailed analysis and is much slower at processing input (p. 1000). This two-stage process will become important in a moment. Happel and Murre further suggest that learning from examples can be viewed as a method to reduce the intrinsic entropy in the system by excluding non relevant connections that are incompatible with a learning set.

Effective extraction of rules from examples must be directed at locating mappings in the network that are compatible with the entire task domain rather than just with the encountered examples. Such mappings are said to *generalize* well from the learning situation to the task situation. In general, then, the extraction of effective rules is likely to occur if the summed probability of all internal network configuration connections is high. Thus, Happel and Murre state:

> If the architecture prohibits the formation of undesired mappings, learning is greatly facilitated and the network will generalize well . . . . This would explain why for many vital learning tasks only a minimal exposure to relevant stimuli is necessary. Evolution coarsely programs the brain to function in specific task domains. Learning completes these neural programs by fine-tuning the connections and dynamics. The combination of an initial architecture produced by evolution and experience-based additional fine-tuning prepares the organism to function in an entire domain, rather than just the limited part of the environment to which it was exposed. (pp. 987, 1000)

Happel and Murre go on to conclude that if the above is an important underlying principle of learning, then it must be concluded

> that the hidden structure of the brain may capture many more regularities of the world around us than we have expected so far . . . . The main conclusion that can be drawn from the above two experiments is that *an initial modular architecture can induce a system to better generalize its learned behaviour to instances never encountered before.* (p. 1000, italics added)

It appears, then, that the brain may have evolved to function largely on the basis of innate invariance — *or generalization* — relations, with innate modules designed for quick recognition of surface similarities which are then later processed by specific learning. Why this mechanism evolved may be due to its survival characteristics.

There seems to be a positive correlation between surface similarity and deep important underlying structural similarity. That is, surface similarity is sometimes a good indicator of deeper kinds of transfer. First-glance similarities are fast evaluations that are often needed to avoid danger. In evolutionary terms, if it looks like a hungry tiger, prowls like a hungry tiger, and growls like a hungry tiger, not only is it probably a tiger, but in terms of the probabilities, we damn well better assume it is a hungry tiger. Evolutionarily speaking, the consequences of an invalid surface similarity is likely not as serious as ignoring a valid one. In short, it may have more survival value to assume that a surface similarity is meaningful than to assume it is not. On the other hand a reason for us to be oblivious to many similarities is perhaps understandable given the large size of our everyday knowledge-base.

For an animal having a large knowledge-base, the cost of attending to all similarity would be cognitively prohibitive. Thus a conservative approach to seeing similarity may be reasonable. As we have seen above based on the work of Happel and Murre (1994), the hidden structures of our brain may recognize many more regularities in the world around us than we have expected. To compensate for a massive recognition of similarity, through evolution the brain has evolved two different basic modes of responding to the world. The first is a pathway for *rapid* analysis of stimuli, the second a pathway for conducting a slower and more considered (learned) analysis.

A Functional Architecture of Invariance

Further supporting the hypothesis of a neurologically based invariance function subserving "analogical" access comes from adapting the work of Pribram (1986, 1988; Pribram et al., 1974). Invariance relations are fundamental to Pribram's theory. He maintains that on a basic cellular level the brain functions as a spectral frequency analyzer and that individual cells and ensembles of cells fundamentally conform to certain mathematical functions called Fourier and Gabor transforms. Pertinent to transfer, these mathematical functions involve the application of *constants*, *identities*, *equalities*, and *associations*, not discrete on/off functions found in many artificial intelligence programs.

According to Pribram, in such a brain, percepts and properties are selected from a primitive matrix in which frequency or spectral conjunctions abound. Everyday categories and objects are constructed by operations performed on this primitive frequency matrix. Largely responsible for the operations that convert the spectral domain to the everyday space–time domain of our experience (read: qualia) are dendritic micro processes (dendrites are like connectors at the end of neurons) which function as cross correlational devises. Cross correlations, explain Pribram et al., (1974) "are a measure of *similarity* of two original images" (p. 429). More importantly Pribram says, "A measure of similarity is precisely what is required for recognition" (p. 429) of the world as we know it. This is probably a good general description of how transfer is created and accessed on a spectral frequency level.

Moreover, Pribram explains that a cell's response is defined by a manifold of frequency averages — not by simple identical features (i.e., surface or featural similarity). The sum of this manifold is constituted by that which remains *invariant* across the various processing stages or levels involved in the processing. The interesting and difficult problem, Pribram points out, is specifying the "transfer functions," that is, the transformation codes involved in *matching* or correlating one code with another, or one level to another. Now, what this likely means is that lexical metaphor and analogical transfer are not fundamentally apprehended by composing or mapping concrete identical features or elements, as most computational research indicates, but rather are generated by a featureless process of cross correlational frequency invariance among or between events. Pribram's account seems compatible with Happel and Murre's (1994) neurological architecture.

Implications of an Evolutionary and Neurological Origin of Invariance Relations

From the above perspectives, the phenomenal or everyday experience of concrete features of similarity and transfer are the end-state or final development or product of a more fundamental evolutionary and neurological process (see Haskell, 1989). Inversely, concrete similarity becomes only an access point, a stimulus activating micro-neurological subprocesses of frequency analysis and cross correlations. In this kind of neurological systems, access would be gained by back propagation to the spectral matrix.

One implication a theory of invariance for analogical transfer is that to improve the ability to access and apprehend *equivalence* or *invariant* transformations is to increase the extent to which the primitive spectral matrix is provided with a wide spectrum knowledge-base (see below). At this point, it should be pointed out that the terms "access," and "representation" are, strictly speaking, metaphorical terms since nothing is actually being "accessed" or "represented."

Analogical Progression

Another implication concerns a "new" and significant area of research which I have termed analogical progression (Haskell, 1968a, 1978a, 2001, 2004b). Though the structure of analogical progression has been implicit in the literature for over two thousand years, perhaps beginning with Aristotle's concept of *continuous analogy*, it has not been recognized by cognitive research. Cognitive science research on analogical reasoning has yet to address this important higher-order aspect of thinking and reasoning.[6] I originally modeled the concept of analogical progression after mathematical progression.

Arithmetically, analogical progression is exemplified as 2 : 4 :: 4 : 8 :: 8 : 16 :: 16 : 32; or 1 : 10 :: 10 : 100 :: 100 : 1,000, where 1 stands in relation to 10 as 10 stands to 100, and 100 to 1,000, etc. Again, in analogical form: the importance of analogical progression is not just in mathematics. Scientists, mathematicians, and other innovative thinkers often reason in progressing analogical forms of thought. Dmitri Mendeleev, the well known Russian chemist who in 1869 discovered the periodic law and constructed the period table of the elements, is one such example.

Mendeleev took the 63 elements that were known at that time, wrote the names and properties of the 63 elements on 63 separate cards, and stuck the cards on the wall of his laboratory. By carefully reexamining the data, sorting out the *similar* elements and pinning their cards next to each other on the wall, a discovery was revealed: he discovered that the properties were periodic functions of their atomic weights that repeated themselves after each seven elements — a kind of analogy to the musical octave (do, re, me, fa, sol, la, ti,

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[6] The similar concept of continuous analogy has a long history in philosophy (Preus, 1970). According to Preus (personal communication, April 8, 2001), the concept is not original with Aristotle but is fundamental in Plato's work. He adopted the concept from the Pythagoreans, who apparently learned of it from the Egyptians.

do). From his "analogical transfer" table or structure, Mendeleev was able by interpolation and extrapolation to then correct previous erroneous atomic weights of some elements. With this structure he was able to successfully predict three new elements from gaps in his octave-like periodic table.

It is also well known that John Newlands, an English chemist, anticipated by about three years Mendeleev's basic idea of the periodic law. The analogy with the musical octave was clear to him. Newlands read a paper at the English Chemical Society in which he compared the arrangement of the elements to the keyboard of a piano with its 88 notes divided into periods or octaves of eight. He said that the elements should be divided into octaves because each eighth element starting from a given one is a kind of repetition of the first, *like* the eighth note of an octave in music. He, in fact, called this the *law of octaves*. At the time, his use of the octave analogy was met with ridicule. The law of octaves was only accepted after Mendeleev completed his work five years later. The perception of musical octaves, where none of the notes is the same, yet the notes are perceived as identical is a form of analogical progression.[7] Similarly, analogical progression can be exemplified by the following progressions.

> *Atom : Molecule :: Molecule : Cell :: Cell : Organ :: Organ : Individual :: Individual : Group; or Species : Genus :: Genus : Family :: Family : Order :: Order : Class, etc.*

Is there a neurological substrate for analogical progression? The answer is "probably." Pribram's work suggests that during frequency analyses and cross correlations, neural cells respond to successive *harmonics* to a given base frequency (what this means is that a sound with a fundamental frequency of, say, 440 Hz [that is, the vibrations of an instrument repeat themselves 440 times each second] is actually a complicated oscillation that also contains a *harmonic* of 880 Hz, another *harmonic* of 1,320 Hz, and so on). This harmonic analysis capacity of cellular functioning, as Pribram — engaging in some analogical reasoning himself — points out, is *isomorphic* (i.e., something being structurally *the same as*) to an abstract transformation group in mathematics. The neurological harmonic form likely reflects the neurological basis of a higher-order analogical reasoning, i.e., analogic progression.

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[7] Recently, research by Bharucha and Menci (1996) on the neurological mechanisms behind the recognition of octaves suggests that though octave equivalence is widely believed to be innate, it may not be octave recognition, *qua octave*, that is innate, but a particular learning mechanism responsible for it and other invariance transformations, suggesting "that the first question can be addressed in terms of the perceptual learning of categories through neural self-organization. A general-purpose perceptual learning mechanism coupled with the acoustic regularities of the environment would not only enable octave equivalence to be learned but would compel such learning" (p. 142). Whether Bharucha and Menci are correct remains to be seen.

Finally, intelligence has historically been related to analogical reasoning and transfer ability. It may be that an important aspect of this involves analogical progression. As Platt (1962) suggested some time ago in another context, "Much, if not all, of what we call intelligence may be the ability to perceive successive analogies at higher and higher levels of abstraction, a multiple repetition of a single basic neural process of organization" (p. 115). Analogical progression, then, is the higher-order form of reasoning with invariant relations. Research needs to be conducted on this form of thought.

A Knowledge-base Resolution to the Access Problem

I will now suggest that what is presented in this paper provides warrant for a resolution to the analogical access problem and, ipso facto, to Plato's paradox. The resolution may be the closest we are likely to come solving the access problem. I suggest that the resolution lies in the quantity and quality of the knowledge-base in the neurocognitive system (Haskell, 2001).

While the importance of a large knowledge-base in thinking and reasoning would seem to be a traditional and commonsense position, only recently has its importance been resurrected. Unlike its original incarnation, cognitive research on knowledge-base now explains *why* and *how* knowledge-base is important in reasoning and problem solving (e.g., Singley and Anderson, 1989). Since the advent of artificial intelligence, emphasis in problem solving and instruction has been on heuristics and strategies. However, there have for some time been findings (especially in relation to expert systems) showing that heuristics and strategies are not sufficent. Still, as Ceci and Ruiz (1993) lamented about their own emphasis on knowledge-base, "This view is likely to displease many of our cognitively oriented colleagues. But it does accord with recent thinking about neural networks" (p. 169).

If the dual model of the brain — one evolutionary-based, hardwired and fast, and the other learning-based and slower — as suggested by both the evolutionary and by neurological findings presented in this paper is correct, the implications seem clear for the importance of an appropriately encoded knowledge-base for accessing analogical/invariant relations. The knowledge-base resolution being presented is also based in part on a modified neural connectionist model (e.g., Eskridge, 1994; Rumelhart, 1989).

According to Happel and Murre (1994), their approach to understanding how the brain works offers advantages that other theories do not. For example, the Parallel Distributed Processing (PDP) approach, involving many of the current connectionist models of how neurological pathways work, relies on very little initial built-in structures. Parallel Distributed Processing systems are large networks of simple processing units, which communicate with each other by passing electrochemical messages back and fourth. In this model, the processing units all work in parallel (or simultaneously) without a specific controlling command structure. In a PDP system, as Rumelhart notes (1989), "Knowledge resides only in its connections, and all learning involves a modification of the connections" (p. 299). In this kind of system, knowledge is not located in any particular place. Instead it is distributed throughout the entire brain. With each input added, i.e., knowledge, the distributed connections are reinforced. Thus the process of *recognition* is the consequence of a statistical process, of assessing probabilities regarding the input as to what it is.

Some of these PDP networks even assume a total interconnectivity between all neural nodes in the network. Others assume a hierarchical, multilayered structure in which each node in a layer is connected to all other nodes in neighboring layers of neurons. The advantage of such fully connected and distributed systems — but low in built-in initial structure — is that they are extremely flexible. Given enough resources e.g., sufficient neural nodes and time, any input and output mappings can theoretically be appropriately encoded and processed. While for many situations having total connections among the nodes is a desirable characteristic, there is a downside: when learning large scale tasks "from scratch," so to speak, such networks may require an incredible amount of time and search resources as the number of iterations necessary for a network to reach convergence increases with the size of the network. Thus, as Happel and Murre note, implementation of such large systems becomes problematic.

A more strategic system must have therefore biologically evolved. Herein lies the difference between Happel and Murre's neural modeling network and most PDP models. There is yet another, more important difference. Typical models of neurological networks, including connectionist models, tend to be based on a learning "metaphor," while Happel and Murre's model is based on biological evolution that works largely by a kind of built-in neural natural *selection*, not *learning*, a kind of neural Darwinism (see Edelman, 1987). Learning in this view is seen as "fine tuning" of the phylogenetically and ontogenetically established neural circuits. I suggest the implications are profound for analogical reasoning and access. Again, as Happel and Murre (1994) note,

> We propose that the initial architecture is not only important for rapid learning, but that it also induces the system to generalize its learned behaviour to instances not previously encountered. Generalization of learning may well be a principal function of much of the initial structure of the brain. (p. 1000)

Happle and Murre conclude that

> The combination of an initial architecture produced by evolution and experience-based additional fine-tuning prepares the organism to function in an entire domain, rather than just the limited part of the environment to which it was exposed. If this is indeed

> an important underlying principle, we must conclude that the hidden structure of the brain may capture many more regularities of the world around us than we have expected so far. (p. 1000)

What the marriage of a hardwired set of fast-acting brain circuits to a connectionist model means is that with the increasing size of a knowledge-base there is an increase in patterns and an increase in the recognition and matching of patterns by the hardwired circuits.

It is this overlap (or "weight" in connectionist terms) that creates mental associations and mappings of similarities of data by the invariance-generating circuits. With continued adding of knowledge, the "summation" strength of the overlaps or weights in the system are increased, thereby increasing cross correlations and the probability that one piece of knowledge will retrieve or be recognized as *like another*. The multiple connections in such a system allow much of the knowledge of the entire system to be applied to any given instance of an event or problem. Since no information resides in a specific place, individual units or brain cells may be destroyed but memories or concepts can continue to exist.

Further, because of the massively distributed character of information in the system, decisions can be arrived at even if the relevant information turns out to be "noisy," incomplete, or approximate. As Gardner observes of connectionist models in general, "These properties seem closer to the kinds of search and decision organisms must carry out in a complex and often chaotic natural world" (1985, p. 133). Applied to analogical reasoning and to the importance of knowledge-base, what this means is that with each added piece of knowledge the entire system is enhanced or made robust. The main implications of a knowledge-base that is fed into such an evolutionarily evolved neurological system, independently described on different levels by Happel and Murre, Edelman, and of Pribram's cross correlations is that as knowledge-base increases, it increases the probability of analogical access and transfer by the evolutionarily hardwired neurological circuits.

Such a process would tend to generate equivalences or invariants that are increasingly complex and which are more sensitive to small but significant nuances, hence, making possible spontaneous access and significant analogical transfer. This is congruent with what is known about experts versus novices, with the primary distinction being that the former's advantage is knowledge-base. Another implication of this two-phase knowledge-base paradigm of analogical transfer is that since the brain is dealing with patterns and probabilities, significant analogues, or — in instructional terms — significant transfer that cannot be acquired by simple heuristics and cookbook type strategies. As Johnson–Laird (1989) has suggested in another context, "There can be no tractable algorithm that is guaranteed to make profound analogies as a matter course" (p. 328). Moreover, a widely recognized failure to demonstrate spontaneous accessing of analogues is ubiquitous in the literature.

The failure of research subjects to access invariance, then, may largely be a lack of an appropriate knowledge-base (again, which must be appropriately encoded). Most of the research on analogues and isomorphisms has been conducted with abstract and unfamiliar examples that have little knowledge-base and thus back propagation to the hardwired innate circuits fails to select or recognize "matching" patterns. Research with more ecologically valid data, like the excellent work by Brown and her colleagues (Brown and Campione, 1984), has shown that the lack of analogical access and transfer by young children is not so much due to their developmental stage as to a lack of an appropriate knowledge-base. Her research clearly demonstrated highly competent analogical reasoning in young children as long as they possess the relevant knowledge-base required for understanding the relations used in an analogy. Brown's research with children can be seen as paradigmatic for the importance of knowledge-base, in general, for accessing analogical relations.

In my reading of these findings, the requirement of a large knowledge-base would increase the ability of a system to more accurately disregard irrelevant information and superficial similarities and/or to cancel them out in an averaging process based on probabilities. It is well accepted that the ability to disregard irrelevance is crucial in recognizing analogues amongst other data (Haskell, 2001; Marr and Sternberg, 1986; Overings and Travers, 1967).

Moreover, an evolutionary and neurological "wetware" view of analogical reasoning is more compatible with recent approaches to thinking; this suggests that reasoning is based on pragmatic-reasoning schemas (see Cheng and Holyoak, 1989; Wason, 1968) and mental models (see Johnson–Laird, 1983, 1989) as opposed to abstract rules and formal logic on which the now generally unsupported formal discipline theory of transfer of learning was originally based.

Finally, given the requirements of the evolutionary and neurological findings here presented, typical research on analogical reasoning looks very much like a Ptolemaic model — useful and reliable for certain navigational purposes, but not a valid model of the way a wet-brain works.

A Four-Stage Model of Analogical Access and Transfer

Based the evolutionary, neurological, and knowledge-base considerations above, a four-stage model for analogical access and transfer suggests itself. *Stage I* involves input of a large (and appropriately encoded) knowledge-base. From the perspective of this paper, this stage is the most crucial because it provides for *Stage II*, which involves evolutionarily established fast hardwired neurological invariance operations. *Stage III* involves implicit or nonconscious slower learning operations that fine tune the original invariance relations established in the previous stages. This stage may also involve non conscious mapping, matching, and alignment processes. Finally, *Stage IV* is where current models of componential-like mapping, matching, and alignment processes are consciously carried out.

This paper suggests a realistic model of how analogical relations, similarity relation or invariants are accessed. A final description would involve a precise empirical delineation of the exact hardwired circuits that generate invariance from the vast array of input patterns.

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