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THE AGE OF FORM AND THE AGE OF IMAGINATION

> It is far more useful to view computational science as part of the problem, rather than the solution. The problem is understanding how humans can have invented explicit, algorithmically driven machines when our brains do not operate in this way. The solution, if it ever comes, will be found by looking inside ourselves.
>
> —*Merlin Donald*

WE LIVE IN THE age of the triumph of form. In mathematics, physics, music, the arts, and the social sciences, human knowledge and its progress seem to have been reduced in startling and powerful ways to a matter of essential formal structures and their transformations. The magic of computers is the speedy manipulation of 1s and 0s. If they just get faster at it, we hear, they might replace us. . . . Life in all its richness and complexity is said to be fundamentally explainable as combinations and recombinations of a finite genetic code. The axiomatic method rules, not only in mathematics but also in economics, linguistics, sometimes even music. The heroes of this age have been Gottlob Frege, David Hilbert, Werner Heisenberg, John von Neumann, Alan Turing, Noam Chomsky, Norbert Wiener, Jacques Monod, Igor Stravinsky, Claude Lévi-Strauss, Herbert Simon.

The practical products of this triumph are now part of our daily life and culture. We eat genetically engineered corn; we announce births and send wedding congratulations and buy guns on the Internet. We buy groceries by having our credit cards scanned. Our taxes are determined by formulas invented by demographers and economists. We clone sheep. Serialist composers choose their notes according to mathematical principles.

ACHILLES AND HIS ARMOR

All of these wonders come from systematic manipulation of forms. By the magic of such transformations, the picture of your newborn baby becomes a long string of 1s and 0s. They are transmitted electronically over thousands of miles and turned back into the same picture on the other end. The powerful and deeply meaningful image appears therefore to be the same as a bunch of 1s and 0s. Form carries meaning with no loss. A picture is worth a thousand 1s and 0s, and vice versa.

A college student enrolled in economics, once a branch of ethics, will now spend considerable time manipulating formulas. If she studies language, once firmly the province of humanists and philologists, she will learn formal algorithms. If she hopes to become a psychologist, she must become adept at constructing computational models. The manipulation of form is so powerful and useful that school is now often seen as largely a matter of learning how to do such manipulation.

Formal approaches lead us not only to reconceive hard problems but also to ask new questions previously inconceivable or inexpressible. Systematic study by Zelig Harris, Noam Chomsky, and their students revealed that linguistic form is astonishingly complex and difficult to account for, thereby compelling psychologists to abandon simple associative modes of explanation. The Bourbaki group and others, by the same kind of systematic analysis, revealed how shaky the foundations of mathematics had been for centuries. Most impressive, Kurt Gödel, by recasting mathematical questions into purely formal schemes such as Gödel numbering, showed inherent limits on proofs within axiomatic systems, thereby using form to analyze itself.

Claude Lévi-Strauss showed how ostensibly different myths shared meaning in virtue of having a shared structure. Vladimir Propp gave formal structures applicable to all Russian folktales. Roman Jakobson and others used as their primary method of literary analysis the investigation of formal relationships among the sounds, rhythms, and orthography of the work. Abstract expressionism came to see the height of meaning as carried by the intersections and juxtapositions of form. Many of these efforts were controversial, but our century has seen enormous energy devoted to the discovery and manipulation of meaning through systematic analysis of form.

These approaches could lead us to think that scientific knowledge is only a matter of finding deep hidden forms behind ostensible forms. On the other hand, common sense tells us that form is not substance: The blueprint is not the house, the recipe is not the dish, the computer simulation of weather does not rain on us. When Patroclos donned the armor of Achilles to battle the Trojans, what the Trojans first saw was the spectacular armor, and they naturally assumed it was Achilles, and were terrified, and so the armor by itself looked as if it was turning the battle. But it didn't take long for the Trojans to discover that it was just Achilles's armor, not Achilles himself, and then they had no pity. In our century, we often look at form the way the Trojans looked at the armor, and indeed, the armor is indispensable—without it even Achilles would fail. The gods

may put considerable effort into making superior armor for the mortals, but they take the power of the warrior for granted. Clearly the miracles accomplished by the armor depend on the invisible warrior inside.

Like the Trojans, we in the twenty-first century have come to realize that the miracles of form harness the unconscious and usually invisible powers of human beings to construct meaning. Form is the armor, but meaning is the Achilles that makes the armor so formidable. Form does not present meaning but instead picks out regularities that run throughout meanings. Form prompts meaning and must be suited to its task, just as the armor of Achilles had to be made to his size and abilities. But having the armor is never having Achilles; having the form—and indeed even the intricate transformations of forms (all those 1s and 0s)—is never having the meaning to which the form has been suited.

The famous computer program "Eliza" cleverly delivers canned responses on the basis of superficial word matches to questions and statements made by a real human being. For example, "Tell me more" is a catch-all production of the machine that easily fits into almost any real conversation. People who encounter Eliza are amazed to find that they cannot help feeling they are taking part in a rich human conversation. Even when they know the program's tricks, they cannot suppress the urge to feel that Eliza is manipulating meanings and that the meanings are causing the expressions it produces. Even when they know that Eliza is an empty suit of armor, they cannot help feeling that they are standing before the flesh-and-blood Achilles.

When we see a picture of the newborn baby, we cannot suppress our feeling that we are seeing a baby. In fact, the two-dimensional arrangement of colors in the photograph has almost nothing in common with a baby, and it takes a brain evolved over three billion years and trained through several months of early life to construct the identity between the picture and the baby. Because the brain does this instantly and unconsciously, we take the construction of meaning for granted. Or rather, we tend to take the meaning as emanating from its formal representation, the picture, when in fact it is being actively constructed by staggeringly complex mental operations in the brain of the viewer.

The illusion that meaning is transmitted when we send the digitized picture over the Internet is possible only because there is a brain on each end to handle the construction of meaning. This illusion takes nothing away from the technological feat of transmitting the picture—just as the Trojans took nothing away from the divine technological feat of constructing Achilles' armor—but the picture still needs the human brain just as the armor still needs the human warrior.

Achilles got the best armor, made by Hephaestos, because he was the best warrior, and to be useful at all, the armor must be suited to the warrior. Just so, as we argue in this book, human beings have the most elaborate forms (language, math, music, art) because they have the most effective abilities for the construction of meaning. The forms are especially impressive because they have been suited to the meanings they prompt, but on their own the forms are hollow. In particular, meaning is not another kind of form. Inside the armor is not more armor.

What is in the armor is not a thing at all but a potential force that, no matter the circumstances, can be unleashed dynamically and imaginatively upon the Trojans to lethal effect. Just so, what is behind form is not a thing at all but rather the human power to construct meanings. It, too, no matter the circumstances, can be unleashed dynamically and imaginatively to make sense.

The theme of this book is what the form approaches have assumed as given: the operations of identity, integration, and imagination. These operations—basic, mysterious, powerful, complex, and mostly unconscious—are at the heart of even the simplest possible meaning. We will show that they are the key to the invention of meaning and that the value of even the simplest forms lies in the complex emergent dynamics they trigger in the imaginative mind. We will argue that these basic operations are more generally the key to both everyday meaning and exceptional human creativity. Surprisingly—but, as it turns out, crucially—even the most basic forms, the chestnuts of the form approaches, are prompts for massive imaginative integration.

In investigating identity, integration, and imagination, we will return repeatedly to certain themes:

- *Identity.* The recognition of identity, sameness, equivalence, A = A, which is taken for granted in form approaches, is in fact a spectacular product of complex, imaginative, unconscious work. Identity and opposition, sameness and difference, are apprehensible in consciousness and so have provided a natural beginning place for form approaches. But identity and opposition are finished products provided to consciousness after elaborate work; they are not primitive starting points, cognitively, neurobiologically, or evolutionarily.
- *Integration.* Finding identities and oppositions is part of a much more complicated process of conceptual integration, which has elaborate structural and dynamic properties and operational constraints, but which typically goes entirely unnoticed since it works fast in the backstage of cognition.
- *Imagination.* Identity and integration cannot account for meaning and its development without the third *I* of the human mind—imagination. Even in the absence of external stimulus, the brain can run imaginative simulations. Some of these are obvious: fictional stories, what-if scenarios, dreams, erotic fantasies. But the imaginative processes we detect in these seemingly exceptional cases are in fact always at work in even the simplest construction of meaning. The products of conceptual blending are always imaginative and creative.

Identity, integration, and imagination—the mind's three *I*'s—are the subject of this book.

CHINKS IN THE ARMOR

The spectacular success of form approaches in many domains, combined with the Eliza effect, which leads us to see forms as carrying far more meaning than they actually do, naturally encouraged people to develop these approaches as far as they would go in fields like artificial intelligence, linguistics, cybernetics, and psychology. Yet, invariably, form ran up against the mysteries of meaning. What looked simplest—seeing a line, picking up a cup, telling the difference between *in* and *out*, combining a noun and an adjective, making the analogy between your mommy and your mommy's mommy—turned out to be diabolically hard to model. Learning and development had looked like unfortunate primitive aspects of evolutionary systems, which the more powerful and precise instruments of formal manipulation would simply leap over. But evolution turned out to be far more powerful than the logicians could conceive. Human babies, who looked incompetent and bumbling, doomed to long and tedious processes of learning even that a shoe is a shoe, turned out to be incomparably more capable than anything form approaches could offer, on paper or silicon. It was natural to think that if form approaches could handle apparently hard things like chess and the Goldbach conjecture, it would be child's play for them to account for much more rudimentary things like child speech or navigating a new room or seeing a simple analogy. But not so.

As more and more effort and money were devoted to solving these problems, researchers developed not the expected solutions but a deep respect for their intractability. Problems that were supposed to take a few years at most—machine translation, machine vision, machine locomotion—became entire fields. Although brute-force statistics has often provided improved performance, many take the view that in such cases the form approaches have not improved our understanding of the conceptual processes at work.

In fact, the situation is graver than this. Phenomena that were once not even perceived as problems at all have come to be regarded as central, extremely difficult questions in cognitive neuroscience. What could be simpler than recognizing that a tree is a tree? Yet when we look at works in cognitive neuroscience, we find this recognition problem listed under "conceptual categorization," already regarded as a higher-order problem, beyond the already difficult feat of "perceptual categorization." Apparently simpler still would be the simple recognition of a single entity, as when we look at a cup of coffee and perceive the cup of coffee. As neuroscience has shown, the many aspects of the cup of coffee—the color of the cup, the shape of the opening, the topology of the handle, the smell of the coffee, the texture of the surface of the cup, the dividing line between the coffee and the cup, the taste of the coffee, the heavy feel of the cup in the hand, the reaching for the cup, and so on and on—are apprehended and processed differently in anatomically different locations, and there is no single site in the brain where these various apprehensions are brought together. How can the coffee cup, so obviously a single thing for us at the conscious level, be so many different things and operations for the neuroscientist looking at the unconscious level? Somehow, the combination of three billion years of evolution and several months of early training have resulted in the apprehension of unities in consciousness, but neuroscience does not know the details of that unification. How we apprehend one thing *as one thing* has come to be regarded as a central problem of cognitive neuroscience, called the "binding problem." We do not ask ourselves how we can see one thing *as one thing* because we assume that the unity comes from the thing itself, not from our mental work, just as we assume that the meaning of the picture is in the picture rather than in our interpretation of its form. The generalized Eliza effect leads us to think the form is causing our perception of unity, but it is not. We see the coffee cup as one thing because our brains and bodies work to give it that status. We divide the world up into entities at human scale so that we can manipulate them in human lives, and this division of the world is an imaginative achievement. Frogs and bats, for example, divide the world up in ways quite different from our own.

These chinks in the armor of form show us that elements of mental life that look like primitives for formal analysis turn out to be higher-order products of imaginative work. The next step in the study of mind is the scientific study of the nature and mechanisms of the imagination. Having investigated form with an array of instruments, we are now turning to the investigation of the fundamental nature of meaning on which form relies. Our own research, developed in this book, will focus on a wide array of ostensibly quite different phenomena in the construction of meaning, in a number of different fields—art, mathematics, grammar, literature, counterfactuals, cartoons, and so on. Like the neuroscientist considering the perception of the coffee cup, we will show that these apparently simple mental events are the outcome of great imaginative work at the cognitive level.

BACK TO ARISTOTLE

The view we take here—that form approaches are a special kind of capacity, as useful to the imaginative human being as armor is to the great warrior—has a long and honorable tradition. Aristotle, for example, in surveying the scope of human knowledge, including botany, the generation of species, and ethics, gave a sharp and influential analysis of special areas of human knowledge in which precise formal operations can be of some help. In particular, he noticed that there are certain patterns of language that preserve or change meanings in

systematic ways that depend on parts of speech but not on the specific nouns or adjectives we pick. These language patterns are of course the famous syllogisms of the type:

- All men are mortal.
- Socrates is a man.
- Therefore, Socrates is mortal.

Here, nothing depends on *Socrates* or *man* or *mortal*. Aristotle's syllogism is a formal, truth-preserving manipulation of meaning that we could also code as "All As are B, C is an A, therefore C is B." Aristotle's observation and systematization are the seed for all the approaches that we have been referring to as "form approaches." Their power lies in the reliability of symbolic or mechanical manipulations that preserve truth no matter how involved the manipulation. Neither Aristotle nor any of his successors in the analysis of form considered this a general solution to the problem of knowledge. Clearly, however, scientific and mathematical progress was accompanied by ever more formal sophistication. With the explosive development of the form approaches at the beginning of the twentieth century, advanced by thinkers like Bertrand Russell and David Hilbert, the prevailing view is still that correlation of meaning and form is highly desirable but not found in so-called messy, soft, fuzzy, everyday, nontechnical natural systems like language. For example, Russell, a man known for expressing what he confidently viewed as truths about nearly every human sphere, including sex, war, and religion, nonetheless had a stark view of formal mathematics: "Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we say is true." One fundamental goal of these approaches, then, is to construct artificial languages that have rigorous and reliable form-meaning correlations. The pursuit of this goal brought great success in mathematics as well as physics, chemistry, logic, and, later, computer science.

The same goal became important in philosophy and the social sciences, but the successes were not as clear. In these fields, pursuit of the goal again brought out great and often unperceived complexity of problems, but not effective solutions. For example, Rudolph Carnap's herculean efforts to develop inductive logic were remarkably helpful in highlighting unexpected complexities of reasoning, but they did not lead to an all-unifying logic.

The development of formal systems to leverage human invention and insight has been a painful, centuries-long process. Some forms assist meaning construction much more effectively than others. As Morris Kline writes, "The advance in algebra that proved far more significant for its development and for analysis than the technical progress of the sixteenth century was the introduction of better symbolism. Indeed, this step made possible a science of algebra." It is a commonplace that no one who wants to learn differential and integral calculus will try to learn it through Newton's nearly impenetrable notation; the notation developed by Leibniz is incomparably more perspicuous. Once the appropriate forms are invented, they are easily learnable. Schoolchildren everywhere have little trouble learning to manipulate simple equations like $x + 7 = 15$ or $x = 15 - 7$ or $x = 8$ or $8 = x$, but developing this notation took the efforts of many mathematicians over centuries in many different cultures—Greek, Roman, Hindu, Arabic, and others. In the twelfth century, the Hindu mathematician Bhaskara said, "The root of the root of the quotient of the greater irrational divided by the lesser one being increased by one; the sum being squared and multiplied by the smaller irrational quantity is the sum of the two surd roots." This we would now express in the form of an equation, using the much more systematically manageable set of formal symbols shown below. This equation by itself looks no less opaque than Bhaskara's description, but the notation immediately connects it to a large system of such equations in ways that make it easy to manipulate.

$$\sqrt{\left(\sqrt{\frac{n}{k}}+1\right)^2 k}\;\dot{=}\;\sqrt{\dot{k}}+\sqrt{\dot{n}}$$

We can see the struggle involved in developing this formalism by looking at moments of partial progress. For example, Kline says of Hindu notation:

> There was no symbol for addition; a dot over the subtrahend indicated subtraction; other operations were called for by key words or abbreviations; thus *ka* from the word *karana* called for the square root of what followed. For the unknowns, when more than one was involved, they had words that denoted colors. The first one was called the unknown and the remaining ones black, blue, yellow, and so forth. The initial letter of each word was also used as a symbol. This symbolism, though not extensive, was enough to classify Hindu algebra as almost symbolic and certainly more so than Diophantus' syncopated algebra. Problems and solutions were written in this quasi-symbolic style.

Similarly,

> Cardan . . . wrote $x^2 = 4x + 32$ as *qdratu aeqtur* 4 *rebus p*:32.

Historically, the development of armor was a long and effortful process, involving the discovery of metals, the invention of mining and refining, and the evolution of all of the techniques and tools of the smith. Just so, the development of formal systems is an admirable tradition in the expansion of human knowledge, and one that cultures do not get for free.

In the evolutionary descent of our species, in the history of a science, and in the developmental history of an individual person, systems of form and systems of meaning construction intertwine, so that it is not possible to view them as separable. As Kline points out, the advance in algebra in the sixteenth century was simultaneously conceptual and formal, each aspect being necessary for the other. Formal systems are not the same kind of thing as meaning systems, nor are they small translation modules that sit on top of meaning systems to encode and decode work that is done independently by the meaning systems. Like the warrior and the armor, meaning systems and formal systems are inseparable. They co-evolve in the species, the culture, and the individual.

Just as we have emphasized that the Eliza phenomenon involves seeing more in form than is there, so we emphasize that form is not an ancillary or illusory aspect of the human mind. Much of our effort in this book will go toward unraveling the complex ways in which forms prompt largely unconscious and unnoticed constructions of the imagination.

THE MIND'S THREE *I*'S—IDENTITY, INTEGRATION, IMAGINATION

As we noted earlier, the binding problem—the problem of how we can perceptually apprehend *one integrated thing*—has its counterpart in neurally inspired computational modeling. Psychologists and cognitive scientists at the University of California–San Diego in the early 1980s developed the theory and implementations of parallel distributed processing (PDP), a remarkably successful approach to modeling cognitive phenomena. PDP was widely acclaimed as a major advance in the understanding of cognition, and its merits were contrasted with shortcomings of the traditional symbolic approach, which used logic-like computer programming languages to try to represent cognitive phenomena. But, startlingly for anyone who thinks identity is simple or primitive, the major challenge for this new kind of modeling turned out to be capturing identities and linking roles to values. For example, Zeus as a bull and Zeus as a god and Zeus as a swan are the same, and in turn, the Cloud-Gatherer (a role) is the "same" as Zeus (its value). But the sameness of the god, the bull, and the swan is not a matter of resemblance and shared features. Even now this problem is by no means resolved, and the exceptionally complex and technical solutions that have been proposed for it look nothing like an intuitive representation of identity. Paul Smolensky's approach uses tensor products, and Lokendra Shastri's depends on temporal synchrony. In short, connectionist modeling, like neuroscience, has come to recognize that identity, sameness, and difference, far from being easy primitives, are the major and perhaps least tractable problems involved in modeling the mind.

A related area of research that has undergone tremendous development is the study of analogy. Here, too, what initially seemed easy and primitive, the explicit characterization of sameness, turned out to be extraordinarily complex. Matching and aligning the elements of two domains, finding the common schematic structure that motivates an analogy between them, are now recognized as formidable feats of imaginative work to which the current state of computational modeling cannot do justice. Yet the ability to perceive everyday analogies, like the ability to perceive everyday identities, is completely taken for granted by human beings at the conscious level. It seems like no work at all. In the common view, taking cube roots is hard but finding the door out of a room is no work at all. In fact, extracting cube roots is extremely easy to model computationally, but present-day robots waste a lot of time trying to get out of rooms, and often fail. Understanding the room you are in by comparing it with rooms you already know is an everyday analogy. We find such an analogy trivial because the complex cognitive processes that provide the solution run outside of consciousness (and because "everybody can do it!"). Only the "obvious" solution to this analogy comes into consciousness, and quietly at that. Because we have no awareness of the imaginative work we have done, we hardly even recognize that there was a problem to be solved.

Why didn't the form approaches run up earlier against these extremely difficult problems of identity, sameness, and difference? The quick answer is that human beings who ran the procedures handled the problems unconsciously, so that no one noticed the difficulty. Consider, for example, a logical formula like $\forall x, p(x) => q(x)$. This logical form sets up a schema, according to which anything with property p has property q. A human being who understands the formula can then use it to discover particular truths by instantiating the properties p and q for a specific thing or individual. How does the human being know that the same individual who has property p also has property q? He knows it because the identical letter x has been used in the formula. But that formal identity itself is not itself a binding; it is only a prompt for real binding to occur in the mind of the interpreter of the form. What the real binding allows a real brain to do is to apply the general schema behind the logical formula to particular things and individuals and to keep track of when they count as the same and when they count as different. "Choose a point in the plane such that $x = 1$" asks us to lump together, for the purpose of the direction, an entire set of points as equivalent. By binding all these points, we create an integrated object: the line. "Choose a point in the plane such that $x = -1$" asks us to do the same, and although it uses the same x, it's a different line. The lumping together of points as the "same" is a mental achievement that creates an integrated object.

Formal approaches, in prompting these integrations, take their cue from human perceptual and conceptual systems. We are disposed to construct objects and preserve identities, so that although we hold and move and see and feel "the wine bottle" in many different situations, we effortlessly and unconsciously bind together all these events as involving a single wine bottle. Conversely, we are equally able to use the very same perceptual evidence to distinguish "two" "wine bottles," to all appearances identical and yet not the "same" object.

"I was born in 1954" prompts us to bind an infant in 1954 with an adult living many decades later as the "same," despite the manifest and pervasive differences. "Chaucer's London bore no resemblance to the London of today" allows us to construct and keep separate two cities that we know to be the "same" from another perspective. And "If I were you, I would wear a black dress" prompts us to bind the "I" and the "you" with respect to some aspects but not others. This marvelous capacity for binding turns out to depend on very sophisticated cognitive and neurobiological processes.

In form approaches, identity is taken for granted; analogy, by contrast, is typically not even recognized. How can this be? The answer is that analogy is smuggled in as part of the formal system through a number of back doors. As an instance of the smuggling in of analogy, consider the relationship between "Paul loves Mary" and "John kicks Joe." They share not a single word, so at least at the most obvious level, they have no identical parts. Yet we recognize instantly that they are similar in *form*. In production system approaches such as generative grammar, this similarity falls out not from an explicit analogical mapping between the two specific sentences but from their sharing a common part of a syntactic derivation. In such theories, there are typically hidden layers of structure, so that what looks like an analogy at one level is treated as a superficial by-product of structural identity at a deeper level. Analogical mapping *per se* is not part of the theoretical apparatus; nor is it viewed as part of the child's learning apparatus. So, paradoxically, although the child may be equipped with vast analogical capacities in all kinds of domains, the view of formal linguistics has been that the learning of grammar does not involve analogical mapping. Rather, to learn the grammar is to induce a production system (the formal grammar) on the basis of innate *a priori* constraints (the universal grammar). Perceived analogy will be a by-product of that system, not one of its theoretical concepts nor, surprisingly, a means for the child to apprehend that system.

In form approaches, as we noted, analogies are replaced by structural identities at hidden levels. But because the form approaches take identities for granted, the apprehension of the structural identities is not seen as posing any problem. Analogy thus seems to be dispensable. In fact, the form approaches have been forced to smuggle in some analogy, even if unwittingly, in the guise of formal manipulation, but have suffered from not being able to bring in yet more analogy.

A powerful and, at first, highly promising feature of form approaches such as generative grammar was the possibility of postulating successive invisible levels of form (such as deep structure, or logical form) behind the superficial appearances. Mysteries of formal organization at one level would thus be explained in terms of regularities at a higher one. This technique is what we described earlier as looking for more armor inside the armor. In itself it is not as absurd as it sounds—a warrior could have additional protection under his topsuit of armor, and hidden layers of form are a plausible explanatory technique. The absurdity would come from assuming that the *only* thing that can lie behind a form is yet another form.

Analogy has traditionally been viewed as a powerful engine of discovery, for the scientist, the mathematician, the artist, and the child. In the age of form, however, it fell into disrepute. Analogy seemed to have none of the precision found in axiomatic systems, rule-based production systems, or algorithmic systems. When these new and powerful systems came to be viewed as the incarnation of scientific thinking, analogy was contemptuously reduced to the status of fuzzy thinking and mere intuition. The absence of formal mechanisms for analogy was mistakenly equated with a supposed absence of analogy itself as a fundamental cognitive operation. At the high point of the popularity of rule-based systems, analogy had lost status as an important scientific topic and was ridiculed as a method of discovery and explanation. But toward the end of the 1970s, analogy and its disreputable companions—metonymy, mental images, narrative thinking, and, most unpalatable of all to the formally minded, affect and metaphor—made a roaring comeback.

There were many convergent reasons for this comeback. First, analogy came to be seriously studied by psychologists whose methodologies included both clinical experimentation and computer modeling. The results left little doubt that analogy, as a cognitive operation, was intricate, powerful, and fundamental. New modeling techniques, most notably connectionist systems, provided both better and more realistic models of analogical thinking and more precise insights into its real complexities. Analogy became respectable again as a phenomenon, exactly because it could now be modeled along formal lines. But as the limits of the formal line became apparent, it was recognized that analogy posed a formidable challenge to both the modeler and the experimental psychologist. Mental images made a comeback for similar reasons: Researchers like Roger Shepard and Stephen Kosslyn developed clever experimental techniques for investigating visual perception, visual imagination, and their relationship. Mental images were suddenly viewed as respectable scientific phenomena with surprising complexity. The same story began to be repeated: What was easiest for human beings to accomplish with no thought at all turned out to be far harder to model than chess and other seemingly difficult mental tasks.

Linguists and philosophers made a powerful case for the centrality of metaphor in human cognition, and, again, clever methodologies were invented—for investigating metaphoric thought in very young children, for discovering regularities in metaphoric expression across families of languages, for teasing out complexities of metaphoric comprehension by human subjects, and for analyzing the role of metaphor in both sign language and nonverbal communication systems like gesture. Of course, traditional lines of inquiry before this century had often accepted, even gloated over, the powerful role of metaphor in scientific discovery, artistic creativity, and childhood learning, but that acceptance was entirely canceled during the ascendancy of form approaches.

What analytic philosophers gloated over now was the complete exclusion of figurative thought from "core meaning." Core meaning is, as the formally minded philosopher sees it, the part of meaning that can be characterized formally and truth-conditionally. Therefore, goes the logic, it must be the only important and fundamental part of meaning. Inevitably, these analytic approaches were blind to the imaginative operations of meaning construction that work at lightning speed, below the horizon of consciousness, and leave few formal traces of their complex dynamics.

As we continue to see, work in a number of fields is converging toward the rehabilitation of imagination as a fundamental scientific topic, since it is the central engine of meaning behind the most ordinary mental events. The mind is not a Cyclops; it has more than one *I;* it has three—identity, integration, and imagination—and they all work inextricably together. Their complex interaction and their mechanisms are the subject of this book.

We will focus especially on the nature of integration, and we will see it at work as a basic mental operation in language, art, action, planning, reason, choice, judgment, decision, humor, mathematics, science, magic and ritual, and the simplest mental events in everyday life. Because conceptual integration presents so many different appearances in different domains, its unity as a general capacity had been missed. Now, however, the new disposition of cognitive scientists to find connections across fields has revived interest in the basic mental powers underlying dramatically different products in different walks of life.