arise from the two metaphorical mappings of space onto time. To claim, as does the thematic relations hypothesis, that the spatial and temporal domains have thematic parallels simply cannot account for the specific meanings of temporal expressions (ibid.).

This discussion does not mean that time is never understood in its own right apart from metaphor. It may be possible to define time in a nonmetaphorical way that is neutral between the two special cases of metaphor described above. But it is not clear that a nonmetaphorical understanding of time can explain the specific meanings of different expressions English speakers use in talking about time.

I have taken this brief detour to consider the thematic relations hypothesis as an alternative proposal to explain the relationship between thought and language because it is one of the few attempts to argue specifically against metaphor's role in everyday thought (see also Ortony, 1988). Cognitive scientists, to the extent that they disagree with the claims about metaphor's pervasive role in human cognition, must provide specific detailed evidence that metaphor does not have a role in motivating many abstract concepts and the language we use to express these thoughts.

METAPHOR IN SCIENCE

It is commonly thought that science and metaphor mix about as well as oil and water. Because reality is thought to have a preferred description, scientific research seeks to uncover this description through objective empirical means and to present these "truths" in a language that best reflects them. Literal language is commonly seen as the language of science precisely because it presumably matches or reflects objective reality.

The standard view of science and language draws a principled and rigid distinction between literal and metaphorical meanings. Literal meanings are proper; metaphorical meanings are distorted and deviant. This distinction has its roots in Aristotle, even though many writers, including many of the ancient Greeks, saw the deviant metaphorical use of language as being of some value, with special power in poetry and rhetoric. The standard view of metaphor in science, in fact, represents a decisive break of philosophy and science from rhetoric. This separation and consequent identification of science with the literal, or the nonmetaphorical, gained much momentum from the theories of language championed by empiricist philosophers in the 17th century, such as Hobbes and Locke.

Metaphor, according to the standard view, contaminates the precise and stable meanings science attempts to discover behind the terms it uses. This metaphoric contamination compromises scientific inquiry and the integrity of the deductive reasoning so often used in scientific theories and explanations. Although metaphor may play a heuristic role in early scientific discovery, mature sciences should avoid metaphor at all costs. When metaphor is found lurking within some theory, it must be eliminated or reduced to some stable literal set of propositions. For instances, as Hobbes noted, when we say *Man is a wolf* we indirectly present some literal meaning, such as "Man is fierce, avid, cruel, and deceitful." Science must work toward eliminating metaphor to identify the literal set of similarities suggested by these tropes. For this reason, metaphor should be used only for rhetorical purposes and is denied any autonomous cognitive content.

Modern positivists do not radically alter the standard view of metaphor in science. The distinction between the cognitive and emotive aspects of language, along with the belief that scientific knowledge can be reduced to a system of literal sentences, implies that metaphor has no cognitive import. For the positivist, the language of science refers. In the case of observational terms, language refers directly, whereas the reference of general and theoretical terms, such as *electron* and *equilibrium*, must be fixed by explicit conventional definition. Because metaphor says one thing and means something else, it can have no literal meaning and cannot refer to anything.

According to the standard view, metaphor is appropriate to the prescientific stage of a field. For example, early economic theory describes the relations among production, circulation, and distribution of goods in terms of relations among human body parts (Bicchieri, 1988). Economic society was seen as a social body from which the division of labor and specialization of the parts naturally followed. The "social body" metaphor mirrors the organization of economic activities, with the separate body parts working together for the benefit of the whole society. In the early stages of a discipline, metaphors like the "social body" trope are thought to provide a new vocabulary and a general model for how a field should proceed. As a discipline develops over time, metaphor should be replaced by a more rigorous, self-contained vocabulary.

However, a closer look at scientific language provides good evidence of metaphor even in mature disciplines. A paradigmatic example has been found in contemporary physics. The mechanical models of 19th-century physics described gases as collections of moving particles obeying Newtonian laws and atoms as miniature solar systems. The conventional wisdom in the philosophy of science held that these metaphoric descriptions would give way to more direct, complete, literal descriptions of the primary system. In fact, many 19th-century models have been replaced in modern physics, but not so their underlying metaphorical processes (Kuhn, 1979). When Bohr's model replaced the solar system model, the new model was not intended to be taken literally: Electrons and nuclei were not seen as being exactly the same as small billiard or Ping-Pong balls.

Models, and the metaphorical processes underlying them, are an integral part of science. They organize the primary system, provide scientists with a new vocabulary, and introduce new predicates in the domain of the primary system, allowing new predictions to be made. Some metaphors may eventually come to be rejected. Yet unsuccessful metaphors fail precisely because they have cognitive content and are not merely rhetorical devices.

Many 20th-century philosophers now contend that metaphors are in many respects constitutive elements of scientific theory rather than mere ornaments or dangerously misleading figures of speech. These revisionist theorists argue that metaphors play a significant role in science, even in highly specialized technical, mature sciences. Metaphor is closely linked to arguments about whether or not language is constitutive of science itself, of what scientists do, and of the theories they construct. Since the early 1960s many theorists have been arguing for the constitutive nature of metaphor in virtually every natural and social science discipline (Arbib & Hesse, 1986; Bono, 1990; Boyd, 1979; R. H. Brown, 1976, 1987; Bruner & Feldman, 1990; Carroll & Mack, 1985; Gentner & Grudin, 1985; Gordon, 1978; Gould, 1977a, 1977b, 1983; Gruber, 1974; Harre, 1970; Hesse, 1966; Hoffman, 1980; Jones, 1982; Kuhn, 1979; Leary, 1990; Letherdale, 1974; MacCormac, 1976, 1985; Rogers, 1978; Sarbin, 1990; Turbayne, 1962). These references represent just a small portion of the work that has begun to study the ways in which metaphorical thinking has helped to constitute, and not merely reflect, scientific theory and practice.

Contemporary philosophers distinguish between "pedagogical" metaphors and "theory constitutive" metaphors in scientific language and reasoning. Pedagogical metaphors are considered to encourage memorability of information to generate a better, more insightful, and more personal understanding. They play a role in the teaching or in the explanation of theories that can already be formulated completely, or almost completely, in a nonmetaphorical way. Theory constitutive metaphors function, on the other hand, as indispensable parts of a scientific theory. They cannot be reformulated in literal terms. Whereas pedagogical metaphors invite the reader to view the new subject matter in light of a known subject matter, theory constitutive metaphors go further by exploring the similarities and analogies between the two subject matters (including aspects of the new subject matter that have not yet been discovered or fully understood).

Metaphorical claims in science function like any other hypotheses. They are articulated, clarified, disambiguated, and extended by diverse members of the scientific community. Such metaphors do not reside in a single work, nor are they the property of a single author. Like literal hypotheses, metaphorical ideas will be incorporated into a scientific theory if they prove fruitful, explanatory, and at least approximately true. Some scholars suggest that scientific metaphors differ from literary metaphors precisely because scientific metaphors become the property of the entire scientific community, whereas literary metaphors are the creation and property of individual authors (Bicchieri, 1988; Boyd, 1979). For this reason, theory constitutive metaphors in science may, and perhaps should, be capable of being fully explicated, because they are not subjective but are the products of the scientific community's collective insight.

Scientific metaphors differ from literary metaphors in how they are used and explicated. If scientific metaphors were only literary devices or embellishments imposed on other basic, literal language, we might be justified in treating them as we often do poetic metaphors. Most literary metaphors grow stale when overused. But scientific metaphors are made to be overused. As they undergo further analysis and examination, more similarities and dissimilarities are noticed between the two domains being contrasted and compared. How do gas particles behave like small elastic spheres? In what ways is the human mind like a computer? Scientific metaphors invite us to publicly, collectively probe their entailments. Successful scientific metaphors become dead when they become a well-established part of our knowledge.

There seem, then, to be few differences in the cognitive roles of literal and metaphorical claims in science. Both are open to intersubjective scrutiny. Both can be contested, confirmed, or disconfirmed by evidence, accepted and incorporated into science, or rejected as false or as trivial, or as lacking in explanatory power. It is difficult to maintain that metaphors do not have cognitive value or are dispensable in light of the ways metaphors function in science.

It is important and interesting to note that not only are scientific theories metaphorical, but so is the concept "theory." A popular conceptualization of "theory" is to see theories as buildings (G. Lakoff & Johnson, 1980). There are various literal expressions that are systematically motivated by the THEORIES ARE BUILDINGS conceptual metaphor. These include:

> Is that the foundation for your theory?
> The theory needs more support.
> The theory is shaky.
> We need to buttress the theory with solid arguments.

The theory will stand or fall on the strength of the data.
The theory collapsed.
The new data exploded his latest theory.
I haven't figured out the form of his theory.
We have to put together the framework of the theory.

Other expressions extend regularly used parts of the THEORIES ARE BUILDINGS metaphor. For instance, *These facts are the bricks and mortar of my theory* refers to the outer shell of the building, whereas the conceptual metaphor THEORIES ARE BUILDINGS does not specify the materials used to construct the building (i.e., the theory).

Various other expressions specify mostly unused parts of the conceptual metaphor. For instance, *His theory has thousands of little rooms and long, winding corridors* and *Complex theories usually have problems with the plumbing* specify aspects of how the interior structure of the building is laid out. It should again be clear that what appear at first to be random metaphorical examples are not at all random. Instead, these different expressions used to talk about theories work together in a consistent manner to show the complex way in which we metaphorically conceptualize theories. These metaphors arise from our concrete experiences that we then use to partly structure highly abstract and elaborate concepts, such as those pertaining to theories.

One discipline where constitutive metaphors have been examined closely is experimental psychology. Metaphors abound in experimental psychology in theories about most aspects of human experience (cf. Sternberg, 1990). For instance, the concept of memory is described as a *wax tablet*, a *dictionary*, an *encyclopedia*, a *muscle*, a *telephone switchboard*, a *conveyor belt*, a *storehouse for ideas*, a *computer*, and a *hologram*. Descartes referred to memory as being like a *riverbed* through which sensory impressions *flow*. Freud talked of memory as a *house full of rooms*. Most modern theories of memory are variations of a metaphor theme of mental space with recall as a search through the contents of this space (Hoffman, Cochran, & Nead, 1990; Roediger, 1980). Mental images are viewed as *drawings*, *working spaces*, *blackboards*, *scratch pads*, and *cathode ray tubes* (Roediger, 1980).

Information processing psychology sees the mind as consisting of a set of cognitive *demons*, each of which is responsible for some small bit of knowledge (Lindsay & Norman, 1977; Selfridge, 1966). In visual perception, for example, there are individual demons for particular visual features, such as lines or angles. The demons are said to *look* for inputs that match their patterns and to *loudly shout* if there is some degree of match between the input and the demon. The *decision demon* responds to the loudest demon, labeling the input pattern with the category of that loudest demon. This metaphorical view of mind supposes that homunculi (the individual demons) recognize, compute, decide, and shout. At a theoretical level, the demons' activities correspond to hypothetical neural processes, supposedly making the model more literally real. However, the metaphors in theories of memory, mental images, and information processing, to take just three cases, cannot be discounted as merely illustrative or decorative, for psychologists currently have few ways of marking such distinctions other than through metaphor.

An examination of the metaphors employed in psychological texts shows that the domains from which metaphors are chosen are often related to new technology (Van Besien, 1989). An analysis of a corpus of reports on psychological research shows that the computer metaphor is the most important theory constitutive metaphor in contemporary psychology. The computer metaphor, with its talk of inputs, accessing, retrieval systems, and the like, facilitates communication and verbal reasoning concerning human cognitive processes. The metaphor then organizes the phenomena for investigation and provides a vocabulary with which to carry out that investigation. It is implausible, at best, to claim that a metaphor that plays these roles is not functioning cognitively.

How did psychologists conceive of the mind before the rise of computer technology? One study reviewed the evolution of mental metaphors in a corpus of articles published in *Psychological Review* between 1894 and 1975 (Gentner & Grudin, 1985). During this time period, four main categories of mental metaphors were employed: animate being metaphors, neural metaphors, spatial metaphors, and systems metaphors.

In *animate being metaphors*, ideas or certain aspects of the human mind are compared with animate beings. For example:

Through lying, the mind grows wary or strong from swimming against the stream. (Dewey, 1984: 110)

Reaction arcs block each other, varying in tension, until one waxes strong enough. (Dashiell, 1925: 59)

... super discriminating preperceiver who selectively prevents recognition (Minard, 1965: 76)

In *neural metaphors*, the physical system is taken as a domain. For example:

Wider ideas shortcircuit smaller ideas. (James, 1905: 17)

Thinking is neural impulses shifting along associative fibers from one area to another. (Dashiell, 1925: 20)

... loudness perhaps proportionate to the number of mental impulses (Zwicker & Scharf, 1965: 24)

Spatial metaphors are derived from the position or movements of an object in space. For example:

Anything hidden in the background is not mental activity. (James, 1905: 7)

... habitual connections between ideas (Peterson, 1935: 8)

... reservoir model for fixed action patterns (Moltz, 1965: 43)

System metaphors compare certain mental phenomena with a system of lawfully constrained interactions between elements. For example:

A body moves in empty space by its own momentum as when our thoughts at their own sweet will (James, 1905: 6)

The nervous system is like a switchboard mechanism. (Gray, 1935: 111)

... serial, iterative operations (Carpenter & Just, 1975: 47)

Besides these four main categories, a large number (71 of a total of 265 metaphors) of *conventional metaphors* were found. These expressions have some kind of metaphorical basis but supposedly have lost their metaphorical associations, as in "mental health," "intellectual growth," "mental state," and so on. Of course, even conventional phrases, such as "intellectual growth," may reflect the strong tendency of psychologists to conceive of the mind in metaphorical terms.

The evolution of mental metaphors in Gentner and Grudin's review discovered two main tendencies: a shift in the number of metaphors and a change in the kinds of metaphor. An analysis of the metaphors used in three bidecades – an early period (1894–1915), a middle period (1925–45), and a recent period (1955–75) – showed a U-shaped distribution, with many metaphors used in the early and recent periods and far fewer in the middle period. In the early period, spatial metaphors and animate being metaphors dominated. The latter category showed a strong drop in use over the years. Use of spatial metaphors also dropped, though less severely. System metaphors, on the other hand, were an unimportant category in the early period but increased in use over the years. System metaphors were responsible for the overall increase of metaphors in the recent period. The decline of metaphors in the middle period was likely due to the influence of behaviorism: Articles in this period (1925–45) were most often straightforward reports of data without any discussion of the internal functionings of the mind. Mental metaphors and all other forms of mentalistic language were rarely employed. Metaphors that did occur in this period were either mathematical metaphors or neural ones.

This empirical analysis of the metaphors used by experimental psychologists demonstrates just how significant metaphor is in psychological theories of mind. Psychologists, like most scientists, often make the mistake of ignoring the metaphorical character of their own theories. One of the worst criticisms a scientist can make of a theory is that it is "just" metaphorical. Such an accusation is tantamount to saying that the theory is false, unscientific, and of no value. It's interesting, though, that theories substituted for offending metaphorical positions are themselves often constituted by metaphor (Hoffman et al., 1990). Many classic examples of this blindness to one's own metaphors can be found in the scientific literature. One examination of scientific discovery in cognitive psychology claims that scientists' tools shape theories of mind (Gigerenzer, 1991). Tools include both analytical and physical methods of evaluating theories. Analytical tools can be either empirical or nonempirical. Analytic methods of the empirical kind are tools for data processing: statistics, for example. Nonempirical tools include normative criteria for the evaluation of hypotheses. Examples of physical tools of justification are measurement instruments, such as clocks and computers.

The history of science reveals many instances where scientists' tools, both analytical and physical, end up as theories of nature (Hackman, 1979; Lenoir, 1988; Wise, 1988). Experimental psychology also employs a tools-to-theories heuristic whereby theories of mind are discovered through the analogy of various tools. To take one notable example, experimental psychologists view descriptive and inferential statistics as being closely tied to scientific method. Descriptive and inferential statistics, in turn, provide a large part of the new concepts for mental processes that became part of the cognitive revolution in the 1950s and 1960s. Theories of cognition are cleansed of terms like "restructuring" and "insight," and the new mind has come to be portrayed as "drawing random samples from nervous fibers," "computing probabilities," "calculating analyses of variance," and "setting decision criteria." With the institutionalization of inferential statistics in particular, a wide range of cognitive processes, conscious and unconscious, elementary and complex, are reinterpreted as involving "intuitive statistics" (Gigerenzer & Murray, 1987). These new theories exemplified the metaphor MIND AS INTUITIVE STATISTICIAN and were suggested not by new data but by new tools of data analysis.

To take just one example of the tools-to-theories heuristic, the hypothesis-testing view of perception, which reconceptualized Helmholtz's idea of "unconscious inference," accounts for the stability of perceptual forms by suggesting that there is something akin to statistical significance that must be exceeded for a stimulus to be detected and discriminated (ibid.). According to this theory of signal detectability (Tanner & Swets, 1954), the mind calculates two sampling distributions of noise and signal-plus-noise and sets a decision criterion after weighing the cost of two possible detection errors (false alarms and misses). Thus, a sensory input is transduced into a form that allows the observer to calculate its likelihood ratio. The observer will say *Yes, there is a signal* or *No, there is no signal,* depending on whether this ratio is greater than or smaller than the set criterion. This new view provides a different perspective of perception than the one assumed for more than 100 years. The analogy between a statistical technique and the human mind shows how the mind's decision criteria can be manipulated and how two kinds of error (false alarms and misses) can be distinguished. Many other areas of cognitive research propose specific quantitative models based on statistical inference for phenomena ranging from psychophysics to pattern recognition, causal reasoning, and memory (Gigerenzer, 1991).

In general, the tools-to-theories heuristic is a metaphorical process that can account for the discovery and acceptance of cognitive theories, all of which share the view that cognitive processes can be modeled by statistical hypothesis testing. The history of science reveals many other instances where scientists' tools, both analytical and physical, ended up as theories of nature (Hackman, 1979; Lenoir, 1988; Wise, 1988).

METAPHOR IN LAW

Some of the most exciting work on metaphorical thinking is seen in recent discussions of the role of metaphor in legal theory. Just as the change in metaphors accompanies paradigm shifts in science, so too do changes in metaphors result in significant legal precedents. One such precedent that beautifully illustrates how legal reasoning operates metaphorically is the landmark case *National Labor Relations Board* v. *Jones & Laughlin Steel Corp.* (301 U.S. 1, 1937) (Winter, 1989). The National Labor Relations Board (NLRB) found that the steel