- Models, which are extended metaphors, give rise to metaphorical entailments, which influence the ways in which the model is understood and applied. Models commonly form the basis for theory formation.

In the chapters ahead we will build on these themes to show that metaphor is a key to understanding the most important aspects of scientific activity. We will see that metaphors serve social roles in science, such as promoting a particular idea or staking a priority claim. We turn in the next chapter to a brief look at the theory of conceptual metaphor, which provides valuable tools for detailed examination of important metaphors in the chapters that follow.

3

THE THEORY OF CONCEPTUAL METAPHOR

In the long history of writings on metaphor, beginning with Plato and Aristotle and extending through Richards and Black, metaphor has been identified as the use of words and expressions outside their normal, conventional meanings. We saw in chapter 2 examples of metaphor in literary contexts, in everyday figurative language, and in scientific communication. But we saw also that metaphor encompasses more than just linguistic devices; physical models and drawings may also be metaphorical.

Within the domain of verbal metaphors, the distinctions between so-called literal and metaphorical uses of language have always been uncertain. Theories of metaphor have come and gone without shedding much light on their roles in reasoning and communication. Recently, the study of metaphor has moved from primarily literary and philosophical territory to the realms of psychology, linguistics, and other cognitive sciences. As cognitive scientists have learned more about human conceptual systems, the essential roles played by metaphorical thought have become more evident. Many of the entities that we want to think about and talk about, such as love, time, or the meanings of scientific observations, are abstract concepts. To convey ideas about these abstract entities, we call upon language and conceptions that we normally use in speaking and thinking about more concrete experiences. David Rummelhart points by way of example to our conceptualizations of mind:

> Nearly always, when we talk about abstract concepts, we choose language drawn from one or another concrete domain. A good example of this is our talk about the mind. Here we use the spatial

> model to talk about things that are clearly nonspatial in character. We have things "in" our minds, "on" our minds, "in the back corners of" our minds. We "put things out" of our minds, things "pass through" our minds, we "call things to mind," and so on. It is quite possible that our primary method of understanding nonsensory concepts is through analogy with concrete experiential situations.[1]

That is, we understand abstract concepts by metaphorical mappings from source domains based on direct physical and social experiences. In this chapter we examine the basis of such metaphorical mappings.

Conceptual Metaphors

The spatial metaphor for mind is but one example of the general observation that we talk about abstract concepts by using language drawn from concrete domains. Such use of language is metaphorical, but not in the sense used in classical theories of language, which concerned themselves with novel constructions, in which words are not used in their ordinary senses. The new view of metaphor asserts that our everyday language is replete with metaphors that we use without being conscious of their metaphorical character. These are called *conventional metaphors* or, preferably, *conceptual metaphors*, to distinguish them from the novel constructions found in fiction, poetry, and scientific theories. George Lakoff asserts that conceptual metaphors are not simply matters of language: "The locus of metaphor is not in language at all, but in the way we conceptualize one mental domain in terms of another. The general theory of metaphor is given by characterizing such cross-domain mappings. And in the process, everyday abstract concepts like time, states, change, causation, and purpose also turn out to be metaphorical."[2] Note that Lakoff here refers to metaphor as a conceptualization process. The linguistic expression that may result from this cross-domain mapping is a surface manifestation of a more fundamental and deeper matter of thought.

In 1980 George Lakoff and Mark Johnson published the book *Metaphors We Live By*, in which they described the theory of conceptual metaphor, citing a host of examples drawn from a wide range of human experience.[3] These authors have further developed their theory of metaphor in more recent books.[4] Although the literature of the field has grown enormously since its appearance, *Metaphors We Live By* remains a widely read and quoted statement of conceptual metaphor theory. In what follows I will attempt to extract the most important aspects of their ideas for our purposes in understanding the roles of metaphor in science.[5]

We carry around in our heads a large array of concepts that govern our thought processes and everyday functioning. They determine how we perceive

the world, even what we perceive, how we navigate through our daily lives, and how we relate to others. Many of the most important entities for which we must have conceptual representations, such as time, love, and inflation, are abstract. To conceptualize such abstract domains of thought we relate them to more concrete concepts with which we have direct experience. We do this by mapping across domains, making connections between the elements of the more abstract conceptual domain and corresponding elements of the more concrete one. We saw a few simple examples of mappings of this kind in chapter 2. In those cases, we readily identified the mapping as metaphorical. But cross-domain mappings show up in our language use as what are often called conventional metaphors. Lakoff and Johnson provide evidence that these metaphors are based on underlying conceptual structures that derive from our embodied experiences with the world. It is for this reason that they are properly called conceptual metaphors.

To illustrate how this works, let's consider the metaphor "An argument is a construction." *Argument* is used in the sense of reason or reasons offered in support of a proposition or theory. (Most commonly, the metaphor notation is a shorthand of the form "Target domain is source domain." The notation "An argument is a construction" denotes a set of correspondences between our understanding of certain properties of arguments and our understanding of analogous properties of constructed objects. It is the set of correspondences that makes up the mapping from the source to target domain.) Here are several sentences that illustrate this general metaphor, the first two from Lakoff and Johnson:[6]

> He is trying to *buttress* his argument with a lot of irrelevant facts, but it is still so *shaky* that it will easily *fall apart* under criticism.
>
> With the *groundwork* you've got, you can *construct* a pretty *strong* argument.
>
> If his key assumption is disproved, his argument will *collapse.*
>
> Smith's argument is *built on* two key sets of experimental results.
>
> These latest results *undermine* most of his argument.

The italicized words in each case reveal the metaphorical conception of an argument as a construction.

There are other commonly used metaphors for argument, such as "An argument is a journey":

> Let's see how *far* this line of argument can *carry* us.
>
> We've *come to* an important *point* in the overall argument.
>
> I think she's correct, but her argument is pretty *roundabout.*

As we *move* a little further *along* in the argument, you'll see what I mean.

Look, here's where his argument *goes* completely *off the track*!

These examples show how we understand the making and presenting of arguments in terms of a construction or a journey. Constructions and journeys are familiar aspects of our lives. Of course, arguments are not physical objects or journeys, but some of the properties of arguments map onto corresponding properties of constructions or journeys. If we can conceive of arguments as metaphorically related to constructions or journeys, then the activity of making an argument can be conveyed metaphorically, and we can talk about arguments in terms of the metaphorical relationships to constructions or journeys. Notice that we have not specified what sort of construction is involved or by what means of transport the journey is undertaken. "Construction" and "journey" are called superordinate categories; "construction" includes any number of more basic-level terms for buildings, such as "house," "church," and "office building"; a "journey" might be undertaken by any vehicular means, such as car, train, or airplane. In some cases the metaphor may be sharpened by a choice of one particular basic-level term, but more commonly the more general superordinate level of reference is used.[7]

* * *

We can see from these examples that words used to characterize constructions or journeys are regularly used to talk about arguments. Words such as "build," "buttress," and "undermine" reveal how we conceptualize arguments as structures. Similarly, such phrases as "come to," "move along," and "goes off the track" demonstrate our conceptualization of argument as a journey. In both instances these metaphors are systematic; the general metaphor carries with it a host of potential entailments that could follow from the core metaphor. These conceptualizations affect the ways in which we form arguments and understand them. In "formulating," "assembling," and "constructing" an argument or thesis, we proceed as though we were putting together a construction. Alternatively we might use the "journey" metaphor, thinking of where we need to get to, the stages along the way, what it will take to get us to each stage, and so on. Beyond this, we might use novel metaphors based on these conventional metaphors to make a point more dramatically, convey irony, or address some other aspect of the general theme. For example,

Smith's argument is basically an attempt to shore up a decrepit structure.

I followed his argument to the end, but the trip wasn't worth it.

This theory is OK, but it's one of the wings, not the whole cathedral.

Ontological Metaphors

The metaphor "An argument is a construction" is an example of what Lakoff and Johnson call an *ontological* metaphor, in which abstract concepts, such as ideas, events, and activities, are thought of as entities and substances. The abstract notion of argument is understood and talked about in terms of physical construction. Ontological metaphors abound in our thinking and use of language. Here are several examples:

Pornography makes me sick.

The Federal Reserve is always wary of high inflation.

My mind just isn't operating at full capacity today.

In dealing with these people, weigh carefully everything they say.

In these examples, four abstract concepts are spoken of as though they had the properties of tangible things. Pornography is seen metaphorically as a poison, inflation as a potential adversary to be carefully watched, the mind as a kind of machine, and statements as objects with weight.

Time

An important example of ontological metaphors is the way in which we talk about the abstract idea of time. Because it is so central to our lives, no one metaphorical representation of time suffices to express the many ways in which it must be conceptualized. Among the many metaphorical mappings for time, one of the most general is "Time is a resource." A subset of this is "Time is money." Here, from Lakoff and Johnson, are some of the manifestations of this conventional metaphor in contemporary English:

You're wasting my time.

This gadget will save you hours.

I don't have the time to give you.

How do you spend your time these days?

That flat tire cost me an hour.

I've invested a lot of time in her.

You're running out of time.

He's living on borrowed time.

I lost a lot of time when I got sick.

Thank you for your time.[8]

We don't need to look far for the origins of this conventional metaphor in our social experience. Workers' pay is expressed as so much per hour; we rent things by the month or week and pay for services on the basis of so much per unit of time. We have annual budgets, quarterly earning reports, daily hotel room rates, and so on. The metaphor "Time is money" is part of the larger metaphor "Time is a resource," something that can be spent, saved, wasted, sold, or squandered. The major point for the present is that the abstract quantity, time, is conceptualized in terms of entities that we deal with in everyday life. Metaphorically speaking, time is an entity, a "thing."

The *passage* of time is conveyed using metaphors related to flow or movement. So we say, "time flies" or "with the passage of time." These concepts of time imply a spatial representation of some kind. Frederick Waismann, one of the early-twentieth-century Vienna Circle (logical positivist) philosophers, had these wry comments to offer on the perplexities of the quest for an understanding of time:

> "Time flows" we say—a natural and innocent expression, and yet one pregnant with danger. It flows "equably," in Newton's phrase, at an even rate. What can this mean? When something moves, it moves with a definite speed (and speed means: rate of change in time). To ask with what speed time moves, i.e., to ask how quickly time changes in time, is to ask the unaskable. It also flows, again in Newton's phrase, "without relation to anything external." How are we to figure that? Would it flow on irrespective of what happens in the world?[9]

Time often is conceived of as a river, with the future flowing toward the observer and the past receding in the opposite direction. The general spatial metaphor for time is exemplified in many everyday expressions, such as

I'll see you *at* four this afternoon.

I'll see you *in* three days.

Meteor showers occur at several times *throughout* the year.

In the first of these examples, a specific time is a location. In the other two, it is conceptualized as a container.

Several interesting entailments follow from the general conceptualization of time in terms of space.[10] The mapping from the source domain of space to the target domain in this case means, as we have just seen, that specific times are entities. Future times are in front of the observer, past times are behind the observer, and the passage of time is continuous and one-dimensional. The metaphor "Time passing is motion" has two special cases. In one, the observer is fixed, and times are entities moving with respect to the observer. Time has a velocity relative to the observer. On the other hand, times may be imagined as fixed locations, and the observer moves with respect to them.

These ways of conceptualizing time show up in everyday language when we say, for example,

In the coming months . . .

I'm looking ahead to summer vacation.

The time has long since passed when . . .

She's facing the future with optimism.

I can't believe how quickly the time has passed!

In science the conceptualization of time as a spatial entity is reflected in the general mapping "Time is length." For example, data may be collected at specific time intervals over a period of time and the results displayed as a two-dimensional graph in which the measured quantities are displayed along one axis and time along the other. The length of the time axis represents the time elapsed from some reference starting time.

In Newtonian mechanics, time is a separate dimension, independent of the three dimensions of free space. Newton conceived of time as flowing continuously and endlessly, independent of occurrences in the spatial world. In his special theory of relativity Einstein introduced a new way of thinking about the temporal domain. He asked what is meant by the statement that two events are simultaneous. In addressing this question, the special theory of relativity postulates that space and time are not separate, independent entities but form a four-dimensional continuum called space-time. In relativity theory, "Time is length" is present as an explicit feature.

Evidently, we find it necessary to use various metaphors to reason and communicate about time, and some of them may be mutually exclusive. A given conceptual metaphor may be applicable in one situation but not in another. Time is conceptualized as an entity, but what kind of entity? Clearly, it is conceptualized as different things in these five examples:

No matter how much time passes, we will remember this day.

I don't want to spend my time that way.

Time is on our side in this affair.

Hurry, we're running out of time!

That was the longest afternoon of my life.

The fact that an abstract entity such as time is conceptualized in many different ways is consistent with the theory of conceptual metaphor. Because we have many different experiences of time, we need differing metaphorical concepts to structure those experiences.

Orientational Metaphors

A major tenet of the theory of conceptual metaphor is that we understand abstract concepts in terms of concrete experiences and feelings. Most powerful in this regard are our direct physical experiences of living on Earth. Beginning at some early stage in development, we begin to experience the world outside our bodies. We learn to distinguish this outside world from the one within ourselves. We learn about the force of gravity and other forces, distances, depths, balance, and symmetries. We learn that when an opaque object is placed between us and another object, it obstructs our view of the farther object. All the lessons learned in development become part of the way we conceptualize the physical world.[11] We acquire what Mark Johnson calls image schemata.[12] Image schemata are not pictures, ready for calling up when we need to understand a particular abstract concept. Rather, they are structures based on bodily experience that organize the conceptual system at a more general, abstract level than any particular image. We rely on image schemata when we attempt to conceptualize more abstract ideas. This process is at work in our use of orientational metaphors, based largely on spatial orientations such as up-down, in-out, front-back, on-off, and deep-shallow.

Use of the vertical dimension in orientational metaphors is especially prevalent. The many examples of this conventional metaphor type are based on fundamental physical experiences with verticality, which arise because we and the objects with which we deal in our lives are subject to the force of gravity. The metaphor "More is up" is one of the most prevalent examples of an orientational metaphor:

> Sales of handheld computers keep going up.
>
> His temperature was high when he had the flu.
>
> Underage drinking is a problem in this town.
>
> Neurons that are not being stimulated fire at a low rep rate.
>
> Inflation dropped to a new low last quarter.
>
> Enrollments are down for the third year in a row.

The experiential basis for this metaphor is easy to discern. When we pour liquid into a glass, the level of fluid rises; as we shovel dirt on a pile, it grows taller, and so on.

We also apply the up-down orientation to abstract entities that don't involve quantity. For example, in the social domain, "High status is up; low status is down":

> He'll rise to the top of the organization.

> Women's careers in corporations are impeded by the glass ceiling.
>
> He's at the peak of his career.
>
> Everyone in this neighborhood is upwardly mobile.

The grounding of such metaphors is not the same sort of direct physical experience as "More is up." Rather, there is a general understanding that in the social domain "Better is up." Where does such an understanding arise? There are plenty of historical origins, but by way of contemporary example we need only ask where the rich and famous live. Which pieces of residential real estate in San Francisco are the priciest? Those on the hills, with the best views, of course. And where do the privileged live in cities such as New York? On the top floors of the tallest residential buildings, of course. Orientational metaphors that are strongly cultural in content form an internally consistent set with those that emerge most directly from our physical experience. The up-down orientational metaphor can apply to situations that contain both physical and cultural elements, such as

> He's at the peak of health.
>
> She came down with pneumonia.

Here good health is associated with "up," in part because of the general metaphor that "Better is up" and perhaps also because when we are well we are on our feet, and when we are ill we are more likely to be lying down.

Other orientational metaphors are obviously cultural in origin:

> He's one of the higher-ranking officials in the agency.
>
> These people have very high standards.
>
> I tried to raise the level of the discussion.

Whether the experience on which an orientational metaphor is based is directly emergent physical experience or one drawn from the social domain, the core metaphorical framework is the same in all of them. There is only one verticality concept "up." We apply it differently, depending on the kind of experience on which we base the metaphor.

Container Metaphors

Aside from the up-down orientational metaphor, one of the most pervasive metaphors involves the in-out orientation. Our direct experience with containers begins with our awareness of our own bodies as having a discrete boundary. We take things into our bodies, and things come out of them. We also learn about containers of various kinds and learn that we can put things into and take things

out of them. But much of what we encounter in the physical world does not have obvious boundaries. For example, a clearing in the woods, a mountain range, or a subdivision may not have sharply delineated boundaries. It is helpful in talking about such entities to treat them as though they were containers, with discrete boundaries. Thus we have expressions such as

> I picked these flowers *in* the field back of the barn
>
> She lives *in* southwest Chicago.
>
> Kemper Creek has its origin *in* the Pine Barrens.

In these examples of orientational metaphors, land areas are conceptualized as containers. More abstract entities such as thoughts, feelings, events, actions, activities, and states are conceptualized as objects. For example, an event is conceptualized as an object that may have the properties of a container. Lakoff and Johnson give these examples to illustrate:

> Are you going to the race on Sunday? (race as OBJECT)
>
> Are you running in the race on Sunday? (race as CONTAINER OBJECT)
>
> Did you see the race last Sunday? (race as OBJECT)
>
> Halfway into the race I ran out of energy. (race as CONTAINER OBJECT)
>
> He's out of the race now. (race as CONTAINER OBJECT)[13]

Ontological and orientational metaphors can be quite complex; they allow us to elaborate our ideas about nonphysical entities. To illustrate, aspects of society can be expressed via the metaphor "Society is a container":

> There is *room* for every point of view *in* this society.
>
> Many of the poor have basically *dropped out of* society.
>
> We believe in an *open* society.

The Grounding of Metaphors

Lakoff and Johnson claim that most of our normal conceptual system is metaphorically structured. Most of the concepts to which we have frequent and varied reference are at least partially understood in terms of metaphorical reference to other, more concrete concepts. This means in turn that our conceptual system must be grounded in a core set of direct experiences that are not themselves dependent on a metaphorical relationship. The core concepts must be those that arise from our most ubiquitous physical experiences, such as verticality, space, and vision. Such concepts are called directly emergent. They are grounded in our daily activities, in continually performed motor functions and regularly perceived events.

Some of the broadest and most provocative conclusions drawn by Lakoff and Johnson arise from their assertion that no experience is purely physical in character:

> What we call "direct physical experience" is never merely a matter of having a body of a certain sort; rather, every experience takes place within a vast background of cultural presuppositions. It can be misleading, therefore, to speak of direct physical experience as though there were some core of immediate experience which we then "interpret" in terms of our conceptual system. Cultural assumptions, values, and attitudes are not a conceptual overlay which we may or may not place upon experience as we choose. It would be more correct to say that all experience is cultural through and through, that we experience our "world" in such a way that our culture is already present in the very experience itself.[14]

Physical experiences, such as sitting, are to be distinguished from more cultural experiences, such as participating in a graduation ceremony. An important aspect of the issue of grounding is that physical experience is not somehow more basic than emotional, intellectual, cultural, or other kinds of experience. However, it is more clearly delineated because it follows directly from the workings of our sensory system. Experiences in less clearly delineated domains may be as powerfully felt as any physical experiences, but we express them in terms of the more clearly delineated physical domain. Consider the following related examples:

> Sally is in the shower. (shower as container)
>
> Sally is in New Orleans. (city as container)
>
> Sally is in the Friday discussion group. (social group as container)
>
> Sally is in a bad mood. (emotional state as container)

These four cases refer to equally valid and basic kinds of experiences. It is tempting to think of each sentence as a literal statement. But Sally has a different kind of experience in each case: simple physical location, location in a complex physical and cultural milieu, membership in a social organization, and being in a particular emotional state. The statements thus range from literal to metaphorical applications of the container concept.

Experiential Gestalts

As we have seen, the theory of conceptual metaphor is based on the idea that our thinking, language, and actions are based in large measure on a metaphorically structured conceptual system. We conceptualize and talk about abstract ideas in terms of more concrete ones. This is possible because we are able to map (i.e., identify a correspondence between) the elements of a concretely

based concept and those of a more abstract one. We map the elements of the more concretely based concept (which forms the source domain) onto corresponding elements of the more abstract concept (which forms the target domain). But what are these elements for which correspondences are made? In some cases the concept is very simple, grounded in everyday physical experience (e.g., an orientational concept such as verticality). On the other hand, when the source domain involves activities and relationships, a complex set of related elements is involved.

To illustrate, consider the metaphor discussed earlier, "An argument is a journey." The source domain in this case is the concept "journey." In using this metaphor to think and talk about an argument or theory, we call on our experiences with journeys, which are complex activities. Based on experiences with journeys of various kinds, we conceptualize a prototypical journey as having several elements, including the following:

> Journeys are undertaken by people.
>
> Each journey has a starting point and destination.
>
> A successful journey may require advance planning.
>
> Each journey follows a route taking us from our starting point to the destination.
>
> Some means of conveyance (walking, car, rail, aircraft) takes us on our journey.
>
> Some parts of the journey may be more difficult than others.
>
> We might lose our way and go in a direction that will not lead us to our destination.

These elements, and others that one might think of, together constitute our concept of a journey. It is not a single idea but a collection of related ideas, forming a structured, multidimensional whole. Lakoff and Johnson call this collection an experiential gestalt[15] or image schema. The various dimensions that make up the whole are categories that emerge naturally from our experiences. In the metaphor "An argument is a journey," the elements of the gestalt or image schema for journey are mapped onto elements of the process of formulating and presenting an argument or theory. Here, for example, are statements about arguments and theories that more or less map onto the ones listed earlier for journeys:

> An argument is formulated by someone and followed by others.
>
> An argument has a starting point and an intended point of completion.
>
> To successfully formulate an argument may entail research into background materials and methods.

> A complex argument or theory involves a progression from one step to another, in an ordered sequence.
>
> There may be choices of theoretical methods or background materials to use in formulating and advancing the argument.
>
> Certain steps in an argument or theory may be difficult to understand or prove.
>
> It is possible that, by proceeding along a certain direction in terms of the model used or theoretical tools chosen, the argument will come to a logical cul de sac.

Many "literal" expressions we use in talking about arguments and theories involve imagery associated with journeys:

> The first steps in the proof . . .
>
> At this stage in the argument . . .
>
> When I use renormalization methods here I come up against a dead end . . .

This is no mere happenstance; our understanding of argument or theory is structured metaphorically, partially in terms of the metaphor "An argument is a journey." This particular metaphorical mapping is grounded in our experience and finds its expression in common phrasings such as those illustrated earlier. We regard these expressions as literal language in the sense that our use of them is conventional and we are largely unconscious of any metaphorical character. Nevertheless, our concept of argument is shaped by one conceptual metaphor or another, such as "An argument is a journey" or "An argument is a construction." In this way, these metaphorical mappings determine how we think about arguments and theories and how we act in formulating or evaluating them.

It is worth repeating a point made earlier: Although we might attempt to represent any given gestalt or image schema as a list of propositional phrases, such as those given above for "journey," it does not exist simply as such. Rather, it corresponds to something much richer and more complex. Johnson calls them "structures of embodied understanding." He takes "understanding" to involve "*our whole being*—our bodily capacities and skills, our values, our moods and attitudes, our entire cultural tradition, the way in which we are bound up with a linguistic community, our aesthetic sensibilities, and so forth. In short, our understanding *is* our mode of 'being in the world.'"[16] This view of cognitive functioning and the relation of language to thought contrasts with what Lakoff and Johnson call an "objectivist" view: that meaning is representable solely in terms of propositional statements. The objectivist assumes that we have

access to objective, mind-independent knowledge of the world. These conflicting points of view are in evidence when we consider how we understand change.

Change and Causation

Humans are part of an ever-changing world. Early in life each of us learns to function optimally in the world by responding appropriately to changes as they occur and by imposing changes on the environment to suit our needs and desires. From infancy on we build complex, largely unconscious cognitive understandings of what causes things to happen, of change, actions, states, and purposes. As with all of our human conceptual structure, these understandings are the product of our interactions with the world. Because those interactions are many and varied, we have multiple ideas based on our embodied experience of each concept (e.g., of causation).

When we lift a book from a table we have a direct experience of force against which we operate to lift the book. When we exert force against an open door, we cause it to close. Direct experiences of manipulating objects by exerting a force, the use of our bodily capacities to effect change, provide our most fundamental concepts of causation. Most typically, the application of force causes a change in location of the object acted upon, as when the book is lifted or the door is closed. These direct experiences form the basis of our metaphorical concepts of change and causation.

In one of the most fundamental metaphors for our understanding of events and causes, change is conceptualized as physical movement between one state and another. In this complex metaphor the source domain is motion in space. The metaphor rests on our varied and intimate knowledge of motion that derives from our actions on objects. The target domain is the domain of events as we perceive them. The "state" to which the metaphor applies may be the physical state of an observed entity or something more abstract, such as an emotional state. A state or set of conditions is metaphorically conceptualized as a bounded space, such as a container:

> The house is *in* good condition.
>
> She is *in* a terribly depressed state.
>
> At room temperature, water is *in* the liquid state.
>
> The molecule is *in* an excited state.
>
> A short pulse of radiation at the resonant frequency *puts* the electron *in* the excited state.

Change is expressed metaphorically as movement from one location (state) to another:

> His condition *has gone from* bad *to* worse.
>
> The weather *went from* sunny *to* stormy in just an hour.
>
> We had little success in preventing *progression* of the disease.
>
> The transition *from* the ground *to* the excited state is symmetry-forbidden.
>
> Amphiphilic block copolymers can self-assemble *into* ordered mesophases.

Because a change from one state to another is conceptualized as change in location, the rapidity with which a change occurs is expressed metaphorically as a rate of motion, that is, speed:

> Folding can be a *fast* or *slow* process, depending on the protein.
>
> A catalyst serves to *speed up* the rate of a chemical reaction.

Changes sometimes are seen as proceeding through distinct intermediate stages. Consistent with the concept of change as change in location, we speak of such overall processes as proceeding in "steps":

> She *took steps* to reorganize the office.
>
> The overall mechanism of the reaction is a *multi-step* process. The second *step* is rate-determining.
>
> We can visualize transcription as a *three-step* process.
>
> At this *stage* of the overall rearrangement process, the molecule is at the highest energy point.

An entailment of this metaphor for change, commonly found in scientific accounts, is that impediments to change are conceptualized as "barriers." Systems that do not change are conceptualized as "isolated" from factors that could produce change. Here are some examples taken from recent scientific literature (italics mine):

> The clusters are formed in the high-density, relatively hot region of the expansion, where there is still sufficient energy to *surmount* any *barriers* on the potential energy surface to reach the global minimum.[17]
>
> The *generation* of T cells capable of transferring diabetes *is blocked* in the absence of GAD expression in the beta cells.[18]
>
> In addition, the qubits must be sufficiently *isolated* from the outside world so that interaction with such reservoirs does not disturb. . . .[19]

We regularly use words such as "speed," "rate," "fast," "slow," and "multistep" in their conventional, literal senses to talk about motion in space. Similarly, the words "barrier," "block," and "isolated" are used literally to denote impediments to movement or change. Yet the same words are used in the preceding examples to talk about changes in which physical movement, if any, is incidental. Notice the systematic character of these appearances. Entire families of words that apply to motion in space in the literal, macroscopic world in which we go about our lives are applied to another domain. This systematic character, and coherence in mappings such as those just cited, is evidence for a general mapping from the physical domain of motion in space to the more abstract idea of change in state.

We also find that many words from the domain of social interactions, such as "mediate," "facilitate," "co-opt," and "regulate" are used to characterize features of processes at the microscopic level, as in this example from the literature (italics mine): "This is attributable to the *co-opting* of existing brain blood vessels by the implanted tumor cells."[20] The role of an agent involved in a change is conceptualized in terms of a familiar role played by humans in the social domain.

The conceptual metaphors that underlie all the examples given are the products of unconscious cognition, grounded in our everyday experiences and observations. The systematic character of multiple uses of words, as in the examples just cited, tells us that these are not just cases of using words arbitrarily for multiple meanings. Rather, they result from mapping of the concrete domain of force producing movement onto more abstract domains of change.

* * *

The foregoing metaphor may be the most commonly used metaphor for change, but it is not the only one. In an alternative way of conceptualizing change, the focus is on attributes.[21] The metaphor has these elements:

Attributes are possessions.

Changes are movements of possessions (acquisition or loss).

Causation is transfer of possessions (giving or taking).

Purposes are desired objects.

Here are some examples:

He *lost* his patience.

Somehow she *acquired* the courage to make changes in her life.

Folding *gives* the protein a more compact structure.

In a single mutation the organism *acquires* immunity.

The goal is to find a superconductor that *loses* resistance to the flow of electricity at a temperature above room temperature.

The two basic metaphors for change are related in this sense: In what we will call the location metaphor, the entity undergoing the change is conceptualized as moving from a location identified by one set of properties to another with different properties ("The oxide went from normal to superconducting at a pretty high temperature"). In the alternative metaphor, the entity undergoing the change is conceptualized as remaining in place and receiving or losing properties of interest ("The oxide gains entropy as its temperature increases"). The main point to note is that the two metaphorical forms are based on closely similar reasoning patterns. Both are based on the concept of motion in space. Both are consistent with the idea that our reasoning about the important concept of change is embodied.

Causation

Because we have needs and desires, and we act to satisfy them, the idea of causation as purposeful action is fundamental to our understanding of the world. In Western philosophy, causation is thought of mainly in terms of what Aristotle called "efficient causation": Change is attributed to the application of a force or the existence of a prior necessary condition. There is a literal connection between the causative agent and its effect. The connection often is not clearly evident from the observational data at hand. For example, does the daily consumption of yogurt lead to a longer life? Such questions can be addressed through mathematical analyses of what constitutes legitimate cause-effect relationships.[22] However, such analyses are not concerned with the ways in which the causal relationship is conceptualized.

In the theory of conceptual metaphor, much of our understanding of causation is seen to be metaphorical, not literal. Of course, there is direct, literal causation and change, as in "The golf ball hit the window and broke it." But when we are reasoning about change and causation in more abstract domains, we use conceptual metaphors.

As we have seen, two basic metaphors dominate in much of our reasoning about change. In the location metaphor, causation is conceptualized as forced movement. The verbs that are appropriate to this metaphor therefore relate to movement. Here are some examples from everyday usages:

The medication eventually *brought her out* of her coma.

His commencement speech *moved me* to tears.

Heating *brings* the liquid *to* a boil.

In these examples a change from one state to another is conceptualized as *movement.* In each case the cause of the movement, the change in state, is an entity—"medication," "commencement speech," or "heating"—that is not literally capable of effecting movement. The following examples, typical of scientific accounts, also describe change as movement. We can readily identify the causal agent and the verb that denotes movement:

> Radiation at the resonant frequency *puts* the electron *into* the excited state.
>
> Neuronal activity can *elevate* serotonin concentrations.
>
> A reduction in food supply could *produce a* major *shift* in marine populations of the deep ocean.

Where change is conceptualized as movement from one location to another, causal agents are many and varied. Change may be facilitated when barriers are reduced or impeded when barriers are formed. Once again, it must be said that we don't ordinarily think of the language used in these examples as metaphorical. Seen from the viewpoint of conceptual metaphor, however, they tell us important things about how we humans reason about change in the world.

Reasons and Purpose in Causation

Humans regularly draw up mental plans to carry out certain purposeful actions. When the plan is carried out, our actions often enough achieve our desired purposes. We therefore develop a conceptual understanding that causation is action taken to achieve a desired purpose. In any given instance the cause of the action is the reason why the action will achieve the intended purpose. In reasoning about change, people often resort to teleology, the idea that there are purposes underlying change. Here are some examples drawn from the scientific literature:

> Knowing how reach plans are represented in the brain can tell us much about the mechanisms and strategies the brain uses to generate reaches.[23]
>
> By forcing the buildup of a protein that prevents NFkB activation, PS-341 seems to starve tumors of their blood supply and growth stimuli, thereby promoting their self-destruction.[24]
>
> These microbes infect cells and enlist several of the components that cells normally use to extend lamellipodia to power the bacteria's own travels within the host's cytoplasm.[25]
>
> Relaxin has diverse actions in the reproductive tract and other tissues during pregnancy. These actions include promotion of growth and dilation of the cervix, growth and quiescence of the uterus, growth and development of the mammary gland and nipple, and regulation of cardiovascular function.[26]

In these examples entities such as body organs, proteins, bacteria, and drugs are understood to be carrying out their characteristic functions as though they were purposeful, self-directed agents. Linguistic use of this kind is common in scientific accounts, although in some quarters it would not be considered good form in formal science communication. Whether frowned upon or not as a stylistic device, teleological metaphors are widely used. They stand as further examples of the many ways in which our conceptualization of the world is founded on metaphorical mappings from other domains of experience. In this case the mapping is from purposeful human actions to the envisioned causative actions of molecular or cellular components of living systems.

Implications of Conceptual Metaphor Theory

The theory of conceptual metaphor casts metaphor in a very different light than approaches based on grammatical or semantic analysis of figurative language. It suggests that metaphor plays an extensive role in the way we interpret individual experiences and relate one kind of experience to another. The metaphorical underpinnings of our conceptual systems are evidenced in our use of language, but according to conceptual metaphor theory, metaphor is much more than a matter of just language. Our experientially grounded metaphorical understanding of abstract concepts influences our thought patterns and actions as well as the ways in which we express ourselves.

The philosophical systems in vogue during much of the twentieth century banished metaphor to a realm outside cognitive significance, granting only that metaphorical constructs might have heuristic or pedagogical value for science. Kittay describes the situation:

> However, it was clear that science made use of "models." These models must be understood as extended metaphors—not literally true, but useful representations of the phenomena which often led to fruitful theoretic conceptions and new empirical discoveries. Examples such as the billiard-ball model of gases or the wave models of sound and light were cited as demonstrating the importance of models in the construction of scientific theories. The positivists' response was to say, in a fashion analogous to granting metaphors an emotive meaning distinct from a cognitive one, that models had a merely heuristic value for science—but then discoveries could be guided by almost anything: dreams, fortuitous findings, a random remark.[27]

Logical empiricism and, more recently, much of analytic philosophy have

given way to empirical evidence from cognitive sciences that shows how humans interact with the world and how they interpret those interactions. The analysis of ordinary language and its uses and acknowledgment of the influences of the social milieu and of an important role for the scientist's intuition and tacit knowledge in scientific discovery have all played a role in ascribing to metaphor a significant place in cognition.

We might well ask whether conceptual metaphor theory carries any special implications for our understanding of how science is done. What light, if any, does it shed on the ways in which scientists model the physical world, design experiments, account for observations, and formulate and test theories? I believe that if we accept the major premises of conceptual metaphor theory, we are forced to recast our picture of how scientists work. The evidence summarized briefly in this chapter points to the following major conclusions:

1. Scientists understand the world largely in terms of metaphorical concepts.
2. In carrying out their activities, scientists use the same conceptual frameworks that they apply to other aspects of everyday life.
3. The most fundamental of those frameworks are based on embodied understandings of how the world works. They derive from the earliest and most pervasive interactions with physical surroundings and involve fundamental notions such as verticality, distance, front-back, and in-out.
4. Many conceptual frameworks used in reasoning about the physical world derive from experiential gestalts, ways of organizing experience into a structured form. These gestalts include those drawn from the scientist's social interactions with individuals, social groups, and society at large.
5. We humans give meaning to our perceptions of the world and interpret data from the world (including extensions of the senses in the form of scientific instruments) largely in terms of metaphorical understandings based on embodied, unconscious reasoning. This contrasts with a hardcore realist position, which would be something to the effect that there is a direct, literal mapping from terms we use to describe the world to things as they are in the world. As a crude illustration, consider the statement that Athens, Greece is hotter than London, England. This seems quite straightforward; the statement is true if Athens is at a given time hotter than London or false if it is colder. In this example, realist thinking would have it that the statement either does or does not correspond to things as they are in the world. But to *what* things as they are in the world? The statement depends for its meaning on what we understand by "hotter." The very concept of hotter or colder, of temperature itself, is the product of human reasoning, grounded in embodied experience. It does not exist independently of human thought. If there were no humans around to decide what is meant by "hotter," there could be no independently existing truths grounded in the concept.

In this way of looking at things, truth is the product of human reasoning. It follows that science does not proceed by discovering preexisting truths about the world. Rather, it consists in observing the world and formulating truths about it. As will become evident in the chapters ahead, much of what we regard as scientific truth is metaphorical representation.

This does not mean that science is capable of yielding only subjective results of uncertain reliability. In development from conception on, all humans undergo largely the same kinds of directly emergent experiences. We therefore possess closely similar conceptual frameworks insofar as embodied understandings are concerned. Because this is so, we are able to communicate with one another about a host of matters and to convey thoughts of great sophistication and subtlety. In the same way, communication between scientists rests on a large body of shared, directly emergent experience with the world. However, although scientists ordinarily have essentially the same directly emergent physical experiences, they may have significantly different social developments and therefore may have different understandings of social values, forces, and interactions. These differences doubtless lead to differing conceptualizations of events in the physical world based on metaphors drawn from the social domain.

6. Given these claims, it follows that modes of reasoning and communicating in science are not fundamentally different from those used in other forms of intellectual endeavor. Scientists apply the same tools of embodied reasoning in carrying out their scientific work that they use in other dimensions of their lives. The systems studied by scientists can often be made simpler (e.g., through the control of variables in experimental work). It is often possible to achieve a high degree of consistency in observations, leading to agreements on standard values for quantities, such as the speed of light in a vacuum.[28] The scientist's ability to control the complexity of the observation system is the basis of the vaunted reproducibility of many scientific results. But independently of the issues of experimental control, accuracy, and precision, scientists' understandings of scientific results, expressed in hypotheses,

> models, and theories, are thoroughly embedded in unconscious cognitive processes and conceptual metaphor. There is no characteristic scientific rationality that stands apart from, let alone is superior to, rational thought applied to other spheres of human experience and knowledge.

If this point of view is correct, metaphorical thought grounded in deeply ingrained physical and social experiences must play essential roles in science. In the chapters ahead we will examine a selection of important metaphors drawn from various areas of science. My purpose is to present descriptive accounts of the ways in which metaphorical reasoning has shaped many important theories and hypotheses. I have not attempted to present exhaustive accounts but instead have selected from the historical record episodes that illustrate the development of individual metaphors as experimental evidence accumulates or that illustrate the ways in which social factors help to determine metaphor choice or interpretation.

We begin by considering atoms. The idea of the atom as the fundamental unit of matter has had a very long run in Western science. Although today it is thought of very differently from its original conception as the fundamental, indivisible particle constituting all matter, the atom remains the fundamental chemical unit. After all these centuries of speculation, search, and scrutiny, what do we know about atoms that is literally true?

4

THE CLASSICAL ATOM

The ancient Ionian Greek cities of Ephesus and Miletus, near the Mediterranean coast in Turkey, are popular tourist attractions. Ephesus, especially, has been uncovered and restored sufficiently to provide a sense of the splendid, prosperous, and energetic place it must have been. The beautiful façade of the library stands as testament to its status during the fifth and sixth centuries B.C.E. as the most extensive collection of materials in the Western world after Alexandria.

Both Ephesus and Miletus are now situated several kilometers from the sea, but for most of the time these cities were in their ascendancy, from the sixth through the first century B.C.E., they were busy seaports and prosperous trading centers. Ships came and went from all parts of the Mediterranean, and commercial traffic moved in and out to civilizations and cultures to the west and south. The more affluent Ionians traveled widely. One of the most famous Miletan explorers, Hecataeus (born about 540 B.C.E.), traveled as far west as Gibraltar and explored the Dardanelles and the coast of the Black Sea. The ideas, attitudes, and technologies that these travelers brought to Ionian city-states made for a lively and stimulating society. It was in this environment that Western science had its beginnings.

The Ionians made a significant departure from previous thinking by attempting to account for the primary causes of what they saw as systematic, reproducible changes in the natural world. The story begins with Thales, a prominent merchant of Miletus, who made many important innovations in early ge-