

Chapter 2

Simulation and Cognition

Music is a horizontal force that unfolds in time.

Leon Fleisher (American pianist and conductor)

2.1 Mental Models

What if mental simulation is not just a way to discuss and to solve problems, but also an essential aspect of brain functioning? Indeed, what if this process lies at the very foundation of our ability to understand other peoples' intentions and emotions, to remember past events, to create new ideas, and to imagine the future? A growing body of cognitive science literature on human "mental simulation" capacity points to the cogency of this view. The present chapter begins by examining a particular kind of model, i.e. "mental models", to more closely investigate the relation between simulation and cognition.

Mental models are internal representations people commonly use to comprehend, reason about, and predict events in the world. In his 1894 work "Principles of Mechanics", Heinrich Rudolf Hertz clearly expressed the idea that our thought processes are based on internal representations that allow us to simulate the external world: "We make for ourselves internal images or symbols of external objects, and we make them in such a way that the consequences of the images that are necessary in thought are always images of the consequences of the depicted objects that are necessary in nature... Once we have succeeded in deriving from accumulated previous experience images with the required property, we can quickly develop from them, as if from models, the consequences that in the external world will occur only over an extended period or as a result of our own intervention" (in Niehans 1990).

As early as 1943, the English psychologist Kenneth Craik laid the foundations for more recent mental models theories (in his book entitled "The Nature of Explanation") by stating that the mind develops "small-scale models of reality" on the basis of experience and uses these models to think, to predict future events, and to provide explanations: "If the organism carries a 'small-scale' model of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, and in every way to react in a much fuller, safer, and more competent manner to the emergencies which face it" (Craik 1943, p. 61).

Interestingly, he prophetically viewed this predictive power as not pertaining exclusively to the human mind. The word “simulation” never actually appears in Craik’s book, given that the computer, as we know it, had not yet been invented. He did use, however, the example of Kelvin’s tide predictor—a mechanical calculator that is also an analog computer. Moreover, by stating that a thought process can be divided in three steps: (1) representation by symbols, (2) calculation, and (3) retranslation into events, he was implicitly referring to a form of mental simulation.

Craik’s ideas subsequently lay fallow for many decades, one of the causes being the growing behavioral psychology movement’s rejection of all forms of “mentalism”. Yet, later on, during the 1970s, in the newly consolidated field of cognitive psychology, Shepard and Metzler’s experiments on the mental rotation of images brought researchers’ attention back to the subject of mental representation (Shepard and Metzler 1971). Shortly thereafter, Kosslyn and his collaborators found interesting experimental evidence for the mental scanning of images (Kosslyn 1973, 1980). In Shepard and Kosslyn’s “pictorialist” approach, thought was considered to operate through some process of visual imagery and therefore, to be capable of representing information analogically, i.e., by maintaining the visuospatial features of visual perception. Pylyshin’s (1973) “computational” approach conversely considered mental images to be akin every other kind of thought, and therefore based on linguistic representations, with none of the visuospatial features of images. An analogy can be made with the images on a computer screen, which are actually based on a binary language decoded by the software. In any event, regardless of whether images are analogical or propositional in nature, these experiments demonstrated that they can be analyzed, rotated, and/or scanned, as occurs with perceptual images and that they “behave” like the physical objects they represent.¹

The concept of mental models came to the forefront in 1983, when two books with the same title “Mental Models” (but representing two different approaches) were respectively published by Gentner and Stevens (1983) and by Johnson-Laird (1983). The first approach originated in the field of Artificial Intelligence and conceived mental models as being knowledge structures people use to understand specific knowledge domains (Gentner and Stevens 1983). The domains analyzed were simple physical systems or artificial devices, and participants tended to rely on “naïve theories” to describe and explain them. These theories are similar to scientific ones, as they have axioms and rules, but are “naïve” because they are not formalized and are occasionally wrong. The knowledge representation formalisms used in this approach were those of Artificial Intelligence. The second approach focused on mental models viewed as a special kind of mental representation supporting speech comprehension and logical reasoning (Johnson-Laird 1983).

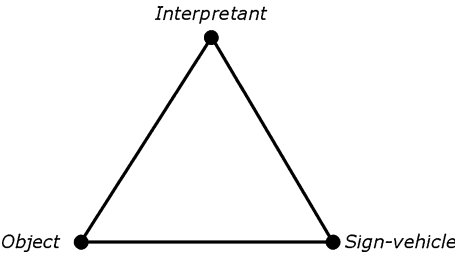
¹ Auditory, olfactory, and tactile mental models have also been studied. In particular, Halpern (1988) used experiments similar to those of Kosslyn to investigate the mental scanning of auditory images produced by familiar songs. Visual mental models, however, have been the most widely studied.

According to Johnson-Laird, mental models are structural analogues of the world: “they are analogies because structural relations between their elements correspond to the perceptible relations between the elements of the corresponding real-world objects” (1983, p. 147). These kinds of mental models are *iconic representations*; that is, they have a relation of similarity with the corresponding real-world situation, as opposed to *propositional representations*, in which the relation is of a purely conventional nature. This similarity relation has a spatial nature, because the disposition of the elements (“tokens”) in the mental model is isomorphic with that of corresponding real-world elements. Based on the analogical relation between their supposed structure and the situation they represent, Johnson-Laird (2004) compared mental models to architects’ and molecular biologists’ models and to scientific diagrams. Moreover, he formulated the hypothesis that mental models can also contain abstract symbols that allow for the representation of propositional connectives, such as negation and disjunction, used in logical reasoning. According to Johnson-Laird’s “triple code” hypothesis, mental models are a type of representation that differs from both propositional representations and mental images.

Johnson-Laird also saw the most important forerunner of mental model theory in the American philosopher Charles Sanders Peirce, the father of pragmatism. Peirce considered himself mostly a logician and made many important contributions to the domain of logic. In particular, he invented two kinds of logical notation: one symbolic, as currently used in mathematical logic, and the other, graphic—i.e., “existential graphs” or “logical diagrams”. In an existential graph, logical relations are represented by spatial relations among different types of signs, as in Venn diagrams. Existential graphs support a type of reasoning Peirce termed “diagrammatic reasoning”, consisting in the manipulation of relations among the diagram’s signs, by following specific rules to obtain other relations among them. These diagrams therefore constitute a deductive system in which the signs and the rules for manipulating them represent the diagram’s syntactical aspect, and the relations among the signs and objects make up the semantic aspect. With regard to semantics, the problem is to understand how a graphic sign in a diagram can represent something else other than itself. Peirce’s response lay in the triadic model of the sign, which he began to illustrate in 1897, in his work titled “On a New List of Categories” and further developed in his later works. In this model, which is currently used in *semiotics*, a sign is defined by the relation among a *sign-vehicle* (or “representamen”), an *object*, and an *interpretant*, and this relation can be represented as a triangle (Fig. 2.1).

The sign-vehicle is commonly called “sign”, and as Peirce stated, it is “something which stands to somebody for something in some respect or capacity” (1897, p. 228). The object is what the sign refers to—i.e., a real-world thing or another representation. The most difficult concept to grasp, however, is that of the interpretant. It refers to a further kind of a sign, created *in the mind* of a subject *as the effect* of a material sign. In his various works, Peirce specifically addressed the mental nature of the interpretant: “A representation is that character of a thing by virtue of which, for the production of a certain mental effect, it may stand in place

Fig. 2.1 Peirce’s triadic sign theory



of another thing. The thing having this character I term a *representamen*, the mental effect, or thought, its *interpretant*, the thing for which it stands, its *object*.” (1899, p. 1564). “A *Sign* is a Representamen of which some Interpretant is a cognition of a mind” (1903, p. 291). Peirce argued that thoughts are signs, too, and it is this position that reveals a clear analogy between Pierce’s existential graphs and Johnson-Laird’s mental models. Pierce moreover classified signs into the three categories of icons, indexes and symbols (Table 2.1), according to the type of relation that exists between the sign and the corresponding real-world object.

Both the mental models in Johnson-Laird’s theory and Peirce’s existential graphs are *multimodal* or *heterogeneous* information representation systems, because they can contain different types of signs, and specifically iconic elements, spatial elements, and symbols (Shin 2002).

In this parallelism between internal and external representation, some confusion arose as to the different formats Peirce assigned to icons. In fact, at times he compared them to pictures, as in the instance of a portrait or statue of a person, and other times, to diagrams. He actually meant, however, both meanings: In the first case (icons as pictures), the element in common with the object is a visual feature (e.g., a statue partakes its shape with the original), and thus the relation between sign and object is a similarity relation. In the second case (icons as diagrams), sign and object share a spatial feature (e.g., a diagram partakes the spatial structure of an object’s elements), and the sign-object relation is one of analogy. Moreover, although it was not possible for Pierce to foresee it, the difference between these two kinds of iconic representations can also shed some light on the difference between mental images and mental models (Table 2.2).

Table 2.1 Kinds of signs in Peirce’s semiotics

Kind of sign	Relation between sign-vehicle and object	Example of sign-vehicles
Icon	Features partaking	A picture with a cat
	Similarity or analogy	A subway map
Index	Direct connection	The mercury level in a thermometer
		A hand pointing an object
Symbol	Convention or habit	The letters of the alphabet
		A dove as the symbol of peace

Table 2.2 Difference between mental images and mental models

Representation type	Representation relation	Features
Mental images	Similarity	Varyingly vivid visual representations of persons, objects, shapes, and colors (auditory, olfactory, and tactile mental images are also possible)
Mental models	Isomorphism	Spatial representation, of an abstract and schematic nature

It is important to note that the above-mentioned knowledge-based (Gentner and Stevens 1983) and speech comprehension and logical reasoning-based (Johnson-Laird 1983) accounts for mental models also differ at the neuropsychological level. In the first instance, mental models are considered to be structures in long-term memory, and in the second, they are thought to be temporary representations (i.e., “constructed at the moment”) in working memory, to make inferences or to solve problems.

The concept of a mental model as being a relatively stable cognitive structure at times overlapped with that of “schema”. Head and Holmes (1911) introduced the latter concept in the terms of neurology to explain control body posture and movement control mechanisms. They defined the term “body schema” as an “organized model of ourselves”. In psychology, the schema concept was applied by the German psychologists Otto Selz (1913) and Karl Bühler in the field of productive thinking and cognitive development. British psychologist Frederic Bartlett (1932) used the concept of schema to account for the constructive nature of the act of remembering. Bartlett viewed schemas (also called “schemata”) as organized mental structures, which provide a framework for understanding and remembering information. Thus, the schema concept was characterized early on in two different ways: one linked to sensorimotor experience and the other to abstract knowledge representation. Schemas also play a key role in the psychology and epistemology of Jean Piaget (1954), who considered them to be the mental structures children form to adapt to their physical and social environment. Piaget achieved a synthesis of the neurological and psychological approaches, by pinpointing the foundations of language and of abstract thought in young children’s eye-hand coordination schemas. Moreover, he proposed that this type of adaptation occurs via the two complementary processes of *assimilation* and *accommodation*, which refer, respectively, to the incorporation of new knowledge into a previously existing schema and to modification of the schema itself. During the 1970s and 1980s, the schema concept was popular in many theories of cognition. For example, in Neisser’s (1976) approach to visual perception, “anticipatory schemas” were viewed as being plans for perceptual action and readiness for particular kinds of sensory structures. They were therefore considered to make up part of the perceptual cycle we use to explore our environment, and are in turn modified by information picked up from the environment. The concept’s most important influence on cognitive psychology, however, occurred in Artificial Intelligence, which developed schema-like constructs—such as “frames”

(Minsky 1977) and “scripts” (Schank and Abelson 1977)—as ways to represent the generic knowledge people have about objects, situations, and actions in a computer program. For example, Mandler (1984) developed a schema theory based on findings from her research on the ways in which young children recall stories read to them. The theory proposed that a schema is an abstract knowledge framework for interpreting and constructing stories and that when children listen to a story, they implicitly place the story’s specific details into a schema’s categories, and then reconstruct the story based on these categories.

Rumelhart and Norman (1978) further developed the concept of schema in the psychology of learning, by viewing schemas as “active data structures”, which control and direct the comprehension process. These authors also proposed three qualitatively different mechanisms of learning, which were respectively based on:

- *schema accretion*, i.e., adding new information to an existing schema;
- *schema tuning*; i.e., modifying a schema by “fine tuning” its structure;
- *schema restructuring*; i.e., reorganizing an existing schema or creating a new one.

The reader might note that the schema accretion mechanism clearly corresponds to Piaget’s assimilation process and that schema tuning and restructuring correspond to his concept of accommodation.

This body of research also impacted educational psychology and instructional theories—e.g., in Anderson’s (1978) and Spiro’s (1980) theories on the role of schemas in text comprehension and recall.

Over the years, various authors have used the term “schema” in different ways and to different purposes. In its broadest sense, the term now denotes all forms of complex knowledge representation, although its narrower meaning refers to a form of mental representation pertaining only to generic and abstract knowledge. In fact, the limitations of the concept of schema for representing all form of knowledge led to the introduction of other cognitive structures, such as mental models and naive theories, to represent specific (i.e., non-schematic) aspects of knowledge.

Seel (2003, 2012b) recently investigated the relation between mental models and schemas in the context of his approach to model-based learning, which will be examined in [Chap. 5](#).

2.2 Mental Models as Simulations

The previously described analogy with molecular models and diagrams at times connoted mental models as static structures to be visually inspected, as occurs with a physical model or a picture. Yet, a mental model can represent causal or time relations among events, and is capable of making this information available to other cognitive subsystems by way of mental simulation. Indeed, this meaning underlies Hertz and Craik’s idea of mental model. Similarly, Norman (1983) noticed that “it should be possible for people to ‘run’ their models mentally”

(p. 12), and Gentner stated that “mental models often permit *mental simulation*: the sense of being able to run a mental model internally, so that one can observe how it will behave and what the outcome of the process will be” (2002, p. 9684). Johnson-Laird recently stated that “reasoning is a simulation of the world fleshed out with our knowledge, not a formal rearrangement of the logical skeletons of sentences” (2010, p. 18243).

Rumelhart et al. (1986) provided a very germane analysis of the relation between mental models and simulation by describing a view of mental models and sequential thought based on the parallel distributed processing (PDP) paradigm. In this approach, the cognitive system consists of two types of processing units:

1. an *interpretative system*, which obtains input from the world and produces action;
2. a *model of the world*, which obtains the actions produced by the interpretative system as input and predicts the way the input should consequently change (Fig. 2.2).

As the authors stated: “Now, suppose that the world events did not happen. It would be possible to take the output of the mental model and replace the stimulus input from the world with input from our model of the world. In this case, we could expect that we could ‘run a mental simulation’ and imagine the events that would take place in the world when we performed a particular action. This mental model would allow us to perform actions entirely internally and to judge the consequences of our actions, interpret them, and draw conclusions based on them” (p. 42). As shown in Fig. 2.2, this is a cybernetic model, because it structurally represents an internal control system, consisting of two units interacting through a feedback circuit. This characterization of mental models underscores the role of mental simulation and its adaptive value from an evolutionary perspective. For instance, one need only reflect on the need for prehistoric humans to mentally simulate a hunting strategy or to predict their group members’ social behavior.

The term “mental model” is also recurrently used in the branch of research examining the mental representations people form to understand the functioning of simple mechanical systems starting from their description in the form of texts and diagrams. For example, Hegarty and Just (1993) investigated participants’ thought processes concerning gears, pulley systems, and hydraulic devices. They consequently proposed a dynamic view in which people “run” a mental model of the

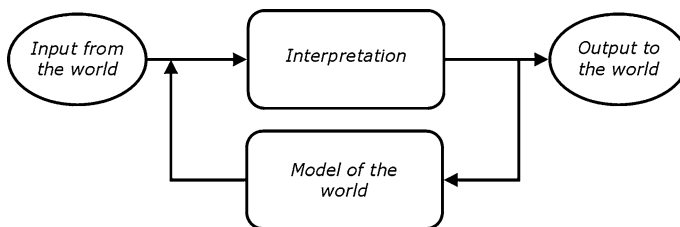
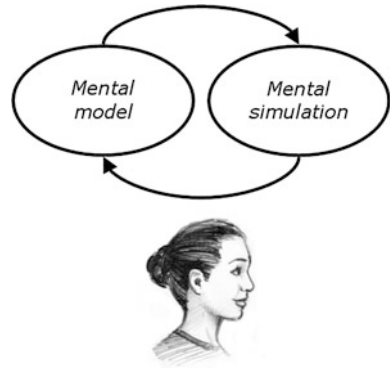


Fig. 2.2 A simplified representation of the PDP model of mental models (Rumelhart et al. 1986)

Fig. 2.3 The interaction between mental model and mental simulation



system in their heads to understand the working of these systems. Hegarty (2004) reviewed the evidence and concluded that mental simulation is a strategy available to humans to reason about mechanical systems. She also underscored a key difference between visual imagination and mental simulation, by stating that visual imagination is based on the holistic inspection of a mental image of the moving system, and that mental simulation is conversely based on:

- the piecemeal simulation of the events;
- some information, both visual or otherwise (e.g., force or density);
- the representation of the associated motor actions.

It is also important to note Schwartz and Black's (1996) findings, however, that participants knowing verbal rules to infer a movement rely on these rather than on simulation, so as to solve the problem more quickly. Figure 2.3 summarizes the interaction between mental model and mental simulation according to these ideas.

2.3 Simulating Other Minds

Mental simulation is one of the mechanisms that possibly underlies “theory of mind” (ToM), i.e., people’s ordinary capacity to refer to specific mental states, in particular beliefs and desires, to understand and predict other peoples’ thoughts, intentions, and emotions. Two conflicting arguments have been proposed to account for this capacity (known as “mindreading” or “mentalization”). In the “theory-theory” (TT) perspective, ToM is seen as a naïve theory (a “folk psychology” known by tacit agreement) with posits, axioms, and rules of inference (Stich and Nichols 1992). Developmental psychologists offer two different explanations for the origin of this theory during childhood. In one version, children are thought to acquire it through the same kind of empirical methods scientists use to test their scientific theories (Gopnik and Wellman 1994). This point of view, also known as the “child-scientist” perspective, is a part of a more general approach that aims to explain children’s cognitive development in terms of

analogy with change in scientific theories. In the second version of TT Theory, the basic elements of the theory are innate modules, which are progressively activated during children's early years in a process of biological maturation (Leslie 2000).

The "simulation theory" (ST) (Gordon 1986; Harris 1994) conversely states that human beings use their mental resources to simulate the psychological causes of other people's behavior, with no need for an internal body of knowledge structured as a theory. Two theories have been proposed to account for the ways in which this process might occur: In the *role-taking* approach (Gordon 1995), people pretend to be the person in a specific situation and simulate the thoughts of that person, by imagining what they might be (as in the metaphor "putting yourself in someone else's shoes"). For instance, to understand how John feels when he goes to school in the morning, we can imagine that we are John walking along the path he takes to school; we can also simulate the way he feels. Conversely, the *introspection* approach (Goldman 2006) holds that people take specific beliefs and desires as mental input and simulate possible and consequential mind states thereby. They then use analogy to infer from those states how another person might be thinking and/or feeling. For example, to understand the way Mary feels when she gets a good grade, we can simulate the way we might feel getting the same grade, and infer Mary's feelings from our own. These examples also indicate that simulation-based mindreading can be inaccurate at times: By mentally simulating the way John feels while walking to school, we risk counting too much on our own past experiences and feelings, and thereby attributing an emotional state to John that is not really his own. These kinds of errors, resulting from the projection of our mental states onto those of another person, are called "egocentric biases".

ST obtained a great deal of support with the discovery of "mirror neurons". These are a special kind of neurons found in the human and primate brains, which activate in individuals both when making specific movements and when they see others do the same movements (Rizzolatti et al. 2006). Mirror neurons activate not only when viewing an action, but also in comprehending the movement's goal and, therefore the intentions of other individuals making the same movement. Generally in cognitive neuroscience, the term "mirroring" (or "resonance") refers to a process of neural imitation of the behavior observed in another person which under normal conditions, is similar to the neural process underlying this behavior. For instance, neuroscientists have observed neuron populations that activate both when people report experiencing an emotion and when they observe someone showing the same emotion in a video. Gallese and Goldman (1998) therefore suggested that mirror neurons might represent the substratum of the human brain's simulation capacities. More recently Goldman (2006) introduced a distinction between two kinds of mental reading and two respectively corresponding types of simulation:

- "low-level" mental reading—i.e., simple ways to assign mental states to another person, such as attributing emotions to people based on their facial expressions; the associated simulation is based on automatic, unconscious mirroring responses such as the mimicking of facial expressions and body movements;

- “*high-level*” mental reading, involving imaginative reasoning, such as that involved in predicting someone else’s decision in a complex situation; in this instance, the associated simulation requires at times conscious effort and is guided by information in long term memory.

High-level simulation is similar to scientific simulation, because task-specific knowledge is used as a model to predict and anticipate behavior. Moreover, Shanton and Goldman (2010) outlined some similarities between mental reading and other cognitive skills, such as episodic memory (the capacity to consciously remember personally experienced events and situations with the accompanying feeling of mentally reliving them and prospection (predicting what will happen). They considered these similarities as indirect evidence that memory and mental reading actually tap the same kind of simulation mechanism.

2.4 Grounding Cognition in Simulation

Independently of ToM, the idea that many different cognitive abilities depend on the basic mechanism of simulation has developed in other areas of cognitive science, particularly in theories of “embodied cognition” (Gibbs 2006a; Shapiro 2010) and “grounded cognition” (Barsalou 2008a). The core idea of the embodied view is that cognition arises from the interaction of the brain with the body and with the rest of the world. In other words, the body and the social and physical world shape the very nature of our cognitive processes and thus, the ways in which we perceive and conceive the world. This embodied view runs counter to the neo-Cartesian stance, which is founded on an ontological separation between mind and body. This latter view is reflected in the separation between mental states and physical substratum in the functionalist philosophy of mind, between the algorithmic and implementation levels in artificial intelligence, and between cognitive and sensorimotor processes in psychology. We can find the origins of the embodied cognition account in many fields of cognitive science, and particularly, in:

- the cognitive linguistics literature on conceptual metaphor (Lakoff and Johnson 1980);
- the construction of robots based on biological principles (Brooks 1991; Pfeifer and Bongard 2006);
- the field of active perception in human and computer vision (Ballard 1991; Noë 2004);
- the dynamical approach to developmental psychology (Thelen and Smith 1994);
- studies on the role of action in cognition and meaning (Glenberg and Kaschak 2002).

Barsalou (2008a) summarized a large body of research supporting the existence of modal representations and simulations in all aspects of cognition—e.g., in

perception and action, memory, knowledge and conceptual elaboration, language comprehension, reasoning, social cognition, and developmental psychology. All of these different branches of research are critical towards the traditional cognitive science view, which is based on formal logic and computer science. In this latter approach, human cognition is considered to be the result of a “physical symbol system”, i.e., a set of symbol structures manipulated by processes to produce other symbol structures (Newell and Simon 1976). Specifically, a symbol structure is made up of a certain number of fixed instances (or tokens) and of processes acting on the symbol structures in concert with syntactic rules, similar to those of a formal language. Newell (1980) considers this kind of system as equivalent to a universal Turing machine (an early, abstract model of what later became the digital computer). It is the cognition-computation analogy established thereby (and similarly between mind and software) that informed the classic cognitive approach in psychology (Pylyshyn 1980).

Embodied cognition diverges from classical cognitive science on the issue of the nature of mental representations and of processes operating on them. In particular, symbols are not viewed as fixed entities to be manipulated from formal rules, but neural activity elements that are analogically coupled with perceptual and motor states.² According to the “dynamical hypothesis” (van Gelder 1999), cognitive processes are best described not in the language of formal systems, but in the language of dynamical systems theory, i.e., as “a set of quantitative variables changing continually, concurrently, and interdependently, over quantitative time in accordance with dynamic laws described by some set of equations” (ibid., p. 245). A further difference from traditional cognitive science concerns the semantics of mental representations. In the traditional approach, the meaning of a symbol has a conventional nature, as occurs with the words of a language or with the *zero* and *one* sequences of a computer’s binary code. Searle (1980), however, criticized the idea that a system can be intelligent if the meaning of its symbols originates only out of its internal relations with other symbols, as in a dictionary or in a semantic network. According to Harnad (1990), symbols must be somehow based on direct relations with their external referents, and the issue of specifying the nature of this relation has been called the “symbol-grounding problem”. These ideas were further developed in embodied cognition theory, which states that a symbol takes on meaning through perception and action, i.e. through the causal pairing with external objects or environmental features. What happens, however, when this sensorimotor pairing is not possible, because the external object is unavailable, as occurs, e.g., when we recall a past event, attempt to grasp an abstract concept, or to make future plans? As illustrated below, in this instance, the symbol-grounding problem solution might lie in the concept of mental simulation.

² A radical version of the embodied cognition view, influenced by dynamical systems theory and by ecological psychology, actually denies the existence of mental representations (Chemero 2009). Most proponents of embodied cognition, however, continue to view representational states as being fundamental to a theory of cognition.

Barsalou (1999, 2008a), in fact, examined the idea of mental simulation as a solution for the grounding of conceptual and abstract mental representations. In his “grounded cognition” approach, simulation is considered a fundamental form of computation in the brain, and this simulation ability is thought to underlie many cognitive skills such as perception, memory, language, and problem-solving.³ In Barsalou’s definition: “Simulation is the re-enactment of perceptual, motor, and introspective states acquired during experience with the world, body, and mind” (2008a, p. 618). At the basis of cognition there are “perceptual symbols”, i.e., subsets of perceptual states extracted from the above-mentioned states to serve as symbols and to support superior cognitive functioning. These symbols are called “modals” because they preserve the modality-specific information of the perceptual states from which they derive, as opposed to the “amodal” symbols of computational theories, which are arbitrary transductions of perceptual states. Some examples of modal symbols in the human brain are mental images and feature detectors. The different modalities’ information is combined in neuron populations called *convergence zones* (Damasio 1989). Representations of conceptual knowledge are conversely multimodal, as they integrate visual, auditory, motor, tactile, gustatory/olfactory, emotional, and motivational information. Barsalou explains how mental simulation works thereby “As an experience occurs (e.g., easing into a chair), the brain captures states across the modalities and integrates them with a multimodal representation stored in memory (e.g., how a chair looks and feels, the action of sitting, introspections of comfort and relaxation). Later, when knowledge is needed to represent a category (e.g., chair), multimodal representations captured during experiences with its instances are reactivated to simulate how the brain represented perception, action, and introspection associated with it.” (2008a, p. 618). Barsalou also suggested the possible neuronal architecture of these processes: during the storage phase, the superior associative areas in the temporal, parietal, and frontal lobes capture the modality-specific sensory, motor, and introspective activation patterns, and integrate them in a multi-modal mental representation. In the simulation phase, the same associative neurons reactivate the original patterns, allowing for simulation to begin thereby. It is important to note, however, that simulations:

- never completely recreate the original experience, but are always partial recreations and can therefore contain biases and errors;
- can be unconscious, as most frequently is the case, or conscious (as in mental imagination).

Barsalou proposed a “simulator” mechanism—essentially, a distributed multimodal system—to account for how simulations can represent not only individual instances, but also categories. In this view, a “simulator” forms after several

³ Barsalou calls his approach *grounded cognition*, as he believes that the term *embodied cognition* places too much emphasis on the role of the body in cognition, and that cognition can be grounded in many ways, including through simulation and situated actions, not only through body states.

experiences with individual instances of a category, and corresponds to the *concepts* or *types* of traditional cognitive theories. Importantly, once a simulator is formed, it can reactivate its perceptual symbol subsets as specific simulations and can create an infinite number of simulations depending on the situation. For instance, as described above, a simulator for the concept of “chair” forms after several experiences with this type of object; it can then create simulations of events, such as those of standing on a chair, sitting in the armchair of a cinema, lifting a chair and taking it to another room, etc... . It is the context that determines which simulation will be activated. Simulators for abstract concepts form in the same way, but tend to capture even more multimodal simulations of events extended over time and their corresponding introspective states. For example, a simulator for the concept of “success” can create the simulation of a sports race, including the start, race, and finish line phases, as well as internal perceptions, such as motivation to continue the race, the belief you can win, and the emotion of winning.

2.5 Simulation and Metaphor

Simulation has also been gaining ground in another area of cognitive science—Cognitive Linguistics—which analyzes natural language through the lens of the conceptual and experiential bases of linguistic categories (Evans and Green 2006). The fundamental assumption of cognitive linguistics is that language reflects the organization of thought and is therefore a window on cognitive functioning. The most well-known cognitive linguistics studies were conducted by George Lakoff and Mark Johnson during the 1980s (Lakoff and Johnson 1980; Lakoff 1987) and investigated the topic of conceptual metaphor. These authors found that metaphor is not only a figure of speech, but also the way in which the conceptual system organizes abstract concepts in terms of concrete experiences. In conceptual metaphor, a conceptual domain (target) is understood in terms of another conceptual domain (source), which is typically less abstract or complex than the target domain. This process is achieved through a series of systematic correspondences, or “mappings”, between elements and relations in a source domain and those in its target domain. For example, in the conceptual metaphor of LIFE IS A JOURNEY, the domain “life” is comprehended in terms of the domain “journey”, as the latter is less abstract and complex than the former.⁴ According to Lakoff and Johnson (1980), metaphorical relations between conceptual domains do not emerge from their intrinsic similarities but from recurring physical experiences that provide the bases for correlations between specific domains. For instance, in the metaphor MORE IS UP, which is inherent in phrase such as “the temperature rose” or “high

⁴ In cognitive linguistics, conceptual metaphors are usually written in capital letters to distinguish them from corresponding expressions in everyday language.

energy particles”, the abstract conceptual domain of “amount” (target) is based on the domain of “level” (source). This latter domain is more concrete because it is grounded on the common experience of pouring a liquid into a container and watching the level rise, or of placing an object on a pile and watching the pile grow as more objects are piled on. In this example, the experiential basis is that of the behavior of physical objects, but in other cases, it can be of a bodily nature, as in *DESIRE IS HUNGER*, or of a social and cultural nature, as in *LIFE IS A GAMBLING GAME*.

According to a theory developed by Grady (1997), more complex metaphors can be broken down into elementary structures called “primary metaphors”. For instance, the metaphor *THEORIES ARE BUILDINGS* depends on expressions such as “the foundation of a theory”, “facts solid enough to support the hypotheses” or “a shaky argument”. It can result from two primary metaphors: *ABSTRACT ORGANIZATION IS PHYSICAL STRUCTURE* and *VIABILITY IS ERECTNESS*. In a primary metaphor, the source domain is always made up of a body experience having a sensorimotor or interoceptive nature, whereas the target domain does not consist of an abstract concept, as generally occurs, but of a subjective one. For example, in the metaphor *AFFECTION IS WARMTH*, both concepts are linked to direct experiences, but the former is more personal and subjective than the latter. Their role of linking mind and body allow primary metaphors to be considered a solution offered by cognitive linguistics to the symbol-grounding problem. Another solution has been suggested by image-schema theorists.

In 1987, in his book “The Body in the Mind”, Mark Johnson described image-schemas as being abstract structures emerging from sensorimotor experiences, such as a movement in space and the handling of objects, or from introspective experiences, such as sensations and emotions. For instance, the image-schema *PATH* results from the physical experience of following a movement with your eyes or of moving from one place to another. The image-schema *CONTAINER* results from several experiences with physical objects, such as glasses, boxes or closets, and from interoceptive body experiences, for example, sensations linked to the consumption of drink and food. Some image-schemas have a complex structure, such as *CONTAINER* (once again), as it can be considered to be made up of the elementary image-schemas of *INSIDE*, *OUTSIDE*, *BOUNDARY*. Table 2.3 lists our most basic image-schemas.

In language comprehension, a word describing spatial relations, such as “in”, activates an instance of the schema *CONTAINER* and of its elements. Thus, when we hear the phrase “in the bottle”, we naturally associate the parts of the bottle with the elements of the schema. The reader should note that image-schemas are non-propositional representations and are therefore non-linguistic in nature. At the same time, however, they are also not mental images, as they represent knowledge at a more general and abstract level than that of a specific image. Moreover, they are analogical, because they maintain a relation of similarity with the same type of sensorial experience that creates them. In cognitive linguistics, image-schemas are commonly illustrated via diagrams (Fig. 2.4) with the accompanying caution to

Table 2.3 List of image-schemas (from Evans and Green 2006, p. 190)

Space	Up–down, front–back, left–right, near–far, centre–periphery, contact, straight, verticality
Containment	Container, in–out, surface, full, empty, content
Locomotion	Momentum, source–path–goal
Balance	Axis balance, twin–pan balance, point balance, equilibrium
Force	Compulsion, blockage, counterforce, diversion, removal of restraint, enablement, attraction, resistance
Unity/ multiplicity	Merging, collection, splitting, iteration, part–whole, count–mass, link (age)
Identity	Matching, superimposition
Existence	Removal, bounded space, cycle, object, process

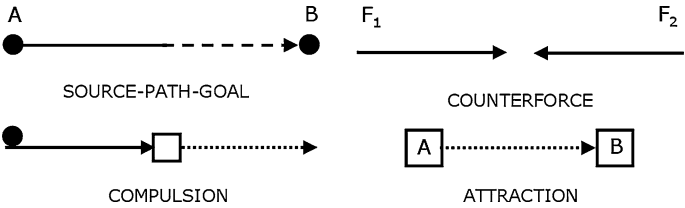


Fig. 2.4 Examples of graphic representation of image-schemas

consider them simple visual aids. In fact, image-schemas are not directly available for conscious introspection, and should therefore not be confused with any type of image.

The importance of image-schemas lies in the fact that, in addition to organizing the experience and comprehension of concrete events, they are also the foundation of abstract thought, given that they serve as source domains for many conceptual metaphors. For example, the image-schema SOURCE-PATH-GOAL is the source domain of the metaphor PURPOSES ARE DESTINATIONS, linked to phrases such as “going ahead with our plans” and “working our way around obstacles”. The dynamic and knowledge-organizing nature of image-schemas leads us once more to the topic of simulation.

In cognitive linguistics, mental simulation has been proposed as a comprehension mechanism for figurative language and conceptual metaphors.⁵ Matlock (2004) experimentally studied the comprehension of fictive motion sentences such as “the road runs through the valley” or “the trail goes from El Portal to Yosemite”. These kinds of sentences use a motion verb in a non-literal way, to communicate the idea of a situation in which nothing is actually moving. To understand these metaphors, the listener assumes a perspective in the scene and

⁵ Several psycholinguistics studies (see Fischer and Zwaan 2008, for a review) have examined the role of perceptual and motor simulation in the comprehension of literal, and thus non-metaphorical, language.

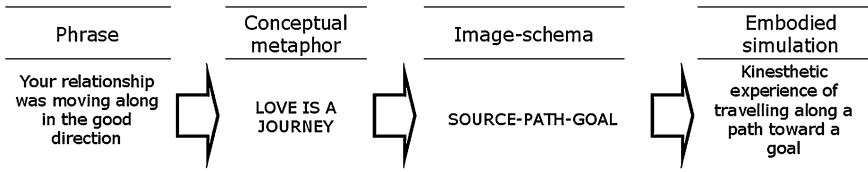


Fig. 2.5 The comprehension of a metaphorical sentence based on embodied simulation

unconsciously simulates moving through it or scanning it. According to Gibbs (2006b), when people encounter abstract conceptual metaphors or metaphors concerning physically impossible actions, they create mental simulations of their bodies performing the actions described in the metaphor. For example, in the context of a romance, understanding the sentence “Your relationship was moving along in the right direction” induces listeners to imagine they are physically moving along a path to a destination. The image-schema SOURCE-PATH-GOAL constitutes the model underlying the simulation (Fig. 2.5).

Embodied simulations such as these allow us to understand abstract entities as if they were concrete objects and to mentally act on them thereby, as for example, in phrases such as “grasping a concept”, “chewing on an idea”, “swallowing one’s pride”, “coughing up a secret”, or “breaking off the relationship” (Gibbs 2006b, p. 444). Also in this case, simulation presumably involves the automatic recruitment of the brains’ perceptual and motor areas corresponding to the execution of real action. It is underscored, however, that these research findings do not suggest that people necessarily use embodied simulations every time they hear metaphorical phrases. The conventional nature of these phrases suggests that in ordinary discourse, people rely on lexical (and thus more automatic) comprehension mechanisms. Simulation processes are most probably marshaled, conversely, when reasoning and problem solving tasks require that a given metaphor phrase be used to make inferences.

Lastly, Ritchie (2008) proposed a mechanism for the interpretation of conceptual metaphors based on Barsalou’s perceptual symbol theory. In this account, global actions described in the metaphor are not simulated, but the partial simulations of perceptual experiences, moods and emotions are, and remain uncoupled from any particular experience. The simulation of a specific perceptual symbol depends on its importance in a given context. Thus, “the perceptual simulations activated by a metaphor such as *depths of a dark cave* or *filled with discoveries* are complex and subtle; they will be experienced differently by each reader, and they defy simple labels” (ibid.). Ritchie moreover maintains that three processing levels can be identified, in function of whether the construction of meaning is based on:

1. linguistic relations among lexical elements;
2. the partial activation of perceptual simulations;
3. the complete activation of the body action simulations.

The first level is considered more “superficial”, and the other two, of respectively increasing depth.⁶

In the 1970s, Newell and Simon concluded their presentation of the Physical Symbol System Hypothesis, by stating that, “the principal body of evidence for the symbol system hypothesis that we haven’t considered is negative evidence: the absence of specific competing hypotheses as to how intelligent activity might be accomplished whether by man or machine” (1976, p. 120). Nowadays, however, embodied cognition has indeed become a competing hypothesis by attributing simulation with a key role as a form of computation that is a plausible alternative to the one traditionally conceptualized in classical cognitive science.

⁶ The difference between superficial and deep processing is crucial in instructional contexts and will be examined in reference to simulation, in [Chap. 7](#).



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