

Chapter 1

Space as a Basis for Abstract Thought

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How has humanity come to develop fundamental abstract abilities such as those seen in science, literature, and art? One answer is familiar to evolutionary theorists: by recruiting old parts for new uses. Pinker has suggested, for instance, that sensory processors and motor programs may have become adapted to more abstract tasks that share some of the same computational structure as sensorimotor tasks (1989). One of the primary candidates for sharing computational structure with abstract cognition is spatial cognition. As a domain, space is well learned across many species (Shettleworth, 1998), and it often involves the integration of information across multiple modalities and multiple dimensions (Millar, 1994). These characteristics make it an appropriate and appealing platform for building new structures essential for higher cognitive processes.

Whether spatial structures indeed play a significant role in abstract thought is an important question for cognitive psychologists, developmental psychologists, linguists, anthropologists, and computer scientists, and has been investigated for years in each of these disciplines. The theories and evidence from these disciplines have not yet been brought together. The aim of this book is to do so. The contributors include scientists from a variety of disciplines investigating spatial cognition and whether and how humans and other animals utilize spatial structures for abstract, non-spatial tasks. The chapters in this book primarily address three questions we take as our starting point: “What do we know about spatial cognition that may be relevant to the use of space in abstract thought?” “Is there evidence that spatial structures impact performance on abstract tasks?” “How can spatial structures be adapted for non-spatial cognition?” My hope is that in addressing these questions, this book not only assembles and evaluates current evidence for the role of spatial schemas in abstract thought, but also identifies common and

discrepant paradigms and findings across different disciplines, and defines directions for future investigations.

To begin, however, we must first have an idea of how space *could* be used in abstract cognition. The first part of this introduction seeks to illustrate what is meant by spatial schemas, what is meant by abstract cognition, and how the latter may benefit from the former. In the second part, the aim is to identify two important points in formulating accounts of spatial schemas. First, our account of spatial schemas explores the idea that space can be a mechanism for cognition, not merely a metaphor for cognition. Second, our account of spatial schemas aims to identify the nature of the correspondences between space and other domains, and how those correspondences, or mappings, are established. The third part of this introduction proceeds to provide an overview of the contents of the book.

1.1 Uses of Spatial Schemas

Schemas aid cognition because they are organized: they have a familiar structure, and people can rely on that structure to facilitate memory, communication, and reasoning. Spatial schemas share these qualities. What is unusual about the use of spatial schemas in abstract thought is their source. Presumably they are first acquired in a purely spatial context—we learn spatial schemas such as linear orders, directionality, and cognitive maps by observing the locations of objects, the movement of objects and people, and the configuration of our environment. To be useful for abstract cognition, however, spatial schemas must be adapted to contexts other than those in which they were acquired. Thus the use of spatial schemas in abstract thought requires transfer across widely disparate domains. Despite the far-reaching transfer required, a look at the world around us suggests that spatial schemas are adapted for three basic purposes in abstract cognition: they are used as memorial structures, as communicative structures, and as logical structures.

Spatial Schemas as Memorial Structures

Spatial schemas provide organization, and organization—particularly organization that links elements together the way spatial schemas do—improves memory (Cofer, 1973). As Neisser (1987) points out, our memory for personal history is tied to our sense of place, “that exquisite set of mechanisms that allow us to know the layout of an environment, includ-

ing positions and paths, regardless of whether we are explicitly aware of it.” Many people have experienced the sensitive relationship between personal history and memory for place when re-visiting a city after many years. Standing in St. Mark’s Square, for instance, may trigger a memory for the location of a particularly good gelateria, and along with that location, long-forgotten faces, emotions, or conversations.

The experience of re-visiting a place demonstrates that space can sometimes be a more powerful organizer of memory than time. When I remember a week I spent in Crete, for instance, I often don’t recall the order in which events occurred, but I do remember the location in which events occurred. I can use locations to guide a mental walk through the week, a week that in my memory is now ordered by the proximity of locations rather than temporal precedence. This effect is exaggerated by the availability of external representations of space, such as cartographic maps. When I survey a map of Paris from east to west, I recall shivering in the Cimetiere du Pere Lachaise, hungrily eating a crepe in front of the Bastille, and not buying a hat on the Ile St-Louis, even though that is surely not the order in which the events occurred, because that is the order of the locations. In such circumstances, maps allow space to become a post hoc organizer of memory.

Our memory for place can be adapted for other memory tasks besides personal history. For example, the most familiar use of spatial schemas in memory is an ancient memory strategy, the method of loci, wherein a person remembers an ordered sequence of elements by attaching each to a location (Anderson, 1990; Yates, 1969). At recall the person mentally walks through the space from one location to the next, noting the elements as each is passed, much like one remembers a route by walking through it, relying on landmarks and other contextual perceptual cues to keep track of direction, turns, and so on. Interestingly, although the method of loci is highly effective for remembering serial orders, it seems to require special training to master. The method of loci thus raises two important questions about spatial schemas in abstract thought: whether adaptation of a spatial schema to abstract cognition is automatic or effortful, and the related question of how often such schemas are actually used.

The question of how frequently spatial schemas are used as memorial structures and how effortful that use is appears to be related to whether the relevant spatial organization is available in the environment or must be constructed (either internally in the form of a mental array or mental

model or externally in the form of a diagram or some other spatial representation), and the processing capacity of the animal or intelligent system. When ordered elements are organized into a linear array or some other useful spatial configuration, many animals can and do use spatial cues to aid memory. Studies with rats (described in Chapter 2 by Roberts) and with young children (described in Chapter 11 by McGonigle and Chalmers) indicate that when the spatial organization of items in the environment is congruent with a to-be-remembered order of elements, both humans and other animals exploit this congruence. Simulations of the process of mapping ordered elements to an internal spatial array (described by Hummel and Holyoak in Chapter 10) demonstrate however that the relational processing involved in the construction of arrays places a heavy computational load on limited-capacity processors. The processing load imposed by mapping may be one reason for spatial schemas to be more commonly used when the spatial structures are available in the environment—whether as diagrams or other explicit spatial representations, or as metaphorical structures implied by our communicative systems.

Spatial Schemas as Communicative Structures

The order and linking characteristics of spatial schemas are also apparent when spatial schemas are adapted for use as communicative structures. Other, more complex relations may also be expressed. For instance, spatial schemas are often used to represent an opposition between two entities or categories. Robert Hertz (1909/1973) argued that the right-left asymmetry of the human body, evidenced by right-handedness in a majority of people, is a universal basis for communication about social constructs. Hertz and other anthropologists (see Needham, 1973) cited numerous examples of the dual classification of social values, such as the oppositions between good and evil, superior and inferior, light and darkness, sacred and profane, all reflecting a right-left organizational scheme for social communication. In our own culture, the pervasiveness of the right-left metaphor for opposition is evidenced by the double meanings of right and left to refer to political and social orientation, and by the evaluative phrases “on the one hand . . . on the other hand” and their accompanying spatial gestures. More recently, cross-cultural studies of spatial representation systems have demonstrated that which spatial metaphor a culture uses for expressing contrastive relations depends on the culture’s system of spatial conception. In Chapter 5, Kita, Danziger and

Stolz report that when a culture's system of spatial conception does not include the spatial opposition of right and left, contrastive relations are communicated with an up-down or front-back spatial metaphor instead. Interestingly, though the reference frame used in spatial metaphors may vary depending upon a given culture's system of spatial conception, the use of spatial reference frames for communicating opposition appears to be common across many cultures.

In addition to conveying oppositions, spatial schemas may be used in communication to identify categories, directionality, and many other relations. When we communicate about relations using spatial schemas, the structure provided by a spatial schema facilitates understanding by establishing a metaphor for the relevant conceptual structure (Clark, 1973; Lakoff & Johnson, 1980). Such a metaphor may be communicated linguistically (such as the space $\rightarrow$ time metaphors discussed by Gentner in Chapter 8), visually (such as the diagrams and depictions described by Tversky in Chapter 4, and the diagrams and graphs described by Gattis in Chapter 9), or both (such as the configurations used by speakers gesturing, described in Chapter 5 by Kita, Danziger, and Stolz, and by signers signing, described in Chapter 6 by Emmorey). These and other chapters in this volume document a variety of spatial schemas used in communication and raise two important questions about space in language. These two questions are: "What is the nature of the mapping between spatial structures and communicative structures?" and "Do spatial structures actually influence understanding?"

Spatial Schemas as Logical Structures

The use of spatial schemas in reasoning is closely related to their use in communication and in memory. We use spatial schemas in reasoning because the structure provided by a spatial schema, combined with partial knowledge of a set of elements and relations between them, allows us to infer the elements or relations that are unknown. Spatial schemas do so by marking three aspects of structure that play a significant role in logical reasoning: order within a dimension, directionality within a dimension, and relations between dimensions (Gattis & Dupeyrat, 1999).

Reasoning about ordered relations between elements, often called linear ordering or seriation, is one of the most common forms of reasoning. Social psychologists, anthropologists, and biologists have observed that remembering and reasoning about the hierarchy of individuals in a social group is a significant problem for many species, not only humans (De Soto,

1960; Fiske, 1992). De Soto, London, and Handel (1965) have proposed that humans reason about multiple elements and the relations between them by creating a mental spatial array. For instance, when given logical reasoning tasks about relations between several persons (e.g., Tom is taller than Sam and John is shorter than Sam), many people report creating mental arrays of items and relations given in the premises (e.g., Tom-Sam-John) to make transitive inferences about the unstated relations (e.g., Tom is taller than John) (De Soto et al., 1965). Several chapters in this volume, including those from Bryant and Squire, Gattis, Gentner, McGonigle and Chalmers, Hummel and Holyoak, and Roberts, examine the role of spatial representation in linear ordering, transitive inference, and other forms of reasoning, and the processing mechanisms which may underlie these forms of reasoning.

The question of whether reasoners spontaneously adopt spatial structures for reasoning remains open (see Chapters 10 and 11). As with spatial schemas in memory, the frequency and effortfulness of using spatial schemas in reasoning is in part determined by the environmental availability of spatial organization and the processing capacity of the reasoner. What is clear is that humans and other animals are good at exploiting congruence between spatial and logical structures, but selecting and adapting an appropriate spatial structure is a demanding task.

1.2 Accounts of Spatial Schemas

Metaphor or Mechanism?

A notable question that arose in our discussions, and in our writing of the chapters presented here is “Are spatial schemas expressive tools for understanding abstract cognition, or actual internal representations or mechanisms?” Scientific metaphors of mental processes grounded in space abound—particularly semantic spaces of language and categorization (Fauconnier, 1985; Langacker, 1986; Osgood, Suci & Tannenbaum, 1957), and state spaces such as the problem space metaphor (Duncker, 1945; Newell and Simon, 1972)—but most of these metaphors are intended to be scientific tools, a means of understanding mental processes rather than a proposal that the mental processes underlying categorization, language understanding, or problem solving are fundamentally spatial. Spatial metaphors such as these are of course not proposing that old parts of spatial cognition are recruited for new uses of representation and thought. In contrast, evolutionary theorists and proponents of embodied cognition

propose that our experience in space and the cognitive structures we develop to perceive, navigate, and remember space are the indispensable foundation of more abstract cognitive tasks (Lakoff & Johnson, 1980; Pinker, 1989). Are spatial schemas a metaphor for cognitive processes, or a mechanism for cognitive processes?

A recurrent theme in all of these chapters is the importance of relational processing in abstract thought. It is this cognitive task—sometimes called relational learning, other times called relational coding, or relational reasoning—that more than any other seems to benefit from adaptation of spatial structures. This is not surprising. As Bryant and Squire note in Chapter 7, space *is* relational, and even young children demonstrate an understanding of the relational nature of space. In addition, space is a flexible base domain. As the wide-ranging content of these chapters demonstrates, spatial structures may be adapted for representing an enormous variety of abstract structures and concepts. These and other factors described throughout the book suggest that space is not simply a metaphor for abstract thought, it may actually be a basis for abstract thought. Nonetheless, as Hummel and Holyoak point out in Chapter 10, if spatial structures are to serve as the basis for abstract tasks such as reasoning about transitive relations, the mental representation involved “must make the mapping from non-spatial relations . . . onto spatial predicates transparent, and the cognitive architecture must be configured to exploit this language.”

Mapping Concepts to Space

A second significant question thus emerges: How is the mapping between spatial structures and non-spatial structures accomplished? Gentner (Chapter 8) suggests four possible levels of mapping from space to abstract cognition. The lowest level of interaction occurs when lexical relations for space and another domain are purely local, and no conceptual mapping exists. In this case, no causal link between space and another domain exists. Space and abstract cognition interact slightly more, though only as parallel domains, at the next level, that of structural parallelism. At this level of mapping, the similarity of structures common to both space and some other domain may be noted, but space does not structure the other domain, nor vice versa. When the structure of space has at one time been adapted for what is now an independent domain, Gentner refers to the level of mapping as cognitive archaeology, to capture the history of spatial origins and the lack of current influence of space on the abstract domain.

The strongest type of mapping between spatial structures and non-spatial structures is system mapping, in which a global spatial system is used to structure an abstract domain. These four levels of mapping provide criteria by which we can judge the extent to which space influences abstract thought, and provide hints about the origins of such mappings as well.

In my own chapter, I propose four constraints on mapping concepts to space which help to further specify how the mapping between space and abstract cognition may be accomplished. These four constraints are based on different types of similarity, ranging from perceptual similarity to abstract similarities of organizational structure. Mappings based upon similarities between linguistic and spatial representation are discussed in other chapters as well. Hummel and Holyoak's LISA model assumes that the mapping process is mediated by language, and that aspects of linguistic structure such as markedness can constrain the construction of a spatial array representing transitive relations. In fact, most of the chapters in this volume touch on the relationship between spatial structure, linguistic structure, and abstract conceptual structures, and how that relationship influences mapping, suggesting that language plays an important role in mediating the adaptation of spatial schemas to abstract thought.

1.3 Overview of the Contents of this Book

The chapters in this volume are divided into three sections, each addressing a different aspect of the question of whether spatial structures play a significant role in abstract thought. The first section examines how humans and other animals represent space, and suggests how spatial representations might influence reasoning and memory for nonspatial relations, given what we know about the representation and use of space itself. The second section documents several interesting examples of spatial representations in specific cultural contexts. Two of the chapters in this section also present evidence that spatial representations influence memory and problem solving. The third section proposes mechanisms by which spatial structures might be adapted for non-spatial purposes, and considers alternatives to spatial coding as a basis for abstract thought.

Representing and Using Space

How humans and other animals represent space is an enormous topic, one to which several excellent volumes have been dedicated (Bloom et al.,

1996; de Vega et al., 1996; Gallistel, 1990; Healy, 1998; Millar, 1994). The purpose of this section is therefore not to provide a comprehensive review of spatial representation but rather to provide a concise review with special attention to which mechanisms for navigation and spatial representation are likely or unlikely to serve the purposes of nonspatial cognition. In Chapter 2, Roberts reviews the encoding of space in animals, and discusses a wide variety of internal mechanisms available for navigating through space. In contrast to the view that animals use cognitive maps to find food and home, Roberts proposes several alternative interpretations of existing data and notes some significant methodological challenges to showing that cognitive maps actually exist. Roberts also introduces a theme repeated in several chapters throughout the book—that three very likely uses of space are encoding time, encoding number, and encoding order—and presents provocative findings suggesting that rats use a spatial array to make transitive choices in a discrimination learning task.

In Chapter 3, Liben follows on Roberts' survey of internal spatial representations with an overview of the interpretation and use of external spatial representations. Liben reviews research on children's developing understanding of maps, and proposes three principles of cartographic map understanding which determine the interpretation and use of maps (purpose, duality, and spatialization). Liben's focus on spatial representations which are external and are culturally provided relates to an important question discussed in several chapters in this volume: do people spontaneously create spatial representations in the course of reasoning, or do they only use space when it is available as a ready-made tool?

In Chapter 4, Tversky builds on this background and moves beyond maps to many other forms of spatial representation, surveying an enormous variety of graphic inventions and conventions. Tversky notes that many graphics are fundamentally spatial arrays, and that this simple spatial schema can be used to convey several different types of information (nominal, ordinal, and interval). Which of those relations people infer from an array is strongly influenced by perceptual aspects of the representation, based on Gestalt principles of perceptual organization. As Tversky demonstrates, those perceptual principles lead to some interesting and unusual inferences about conceptual relations. The inferences described by Tversky make an important point—that even when space is available as a ready-made tool for reasoning, using that tool involves going beyond the information given.

Spatial Schemas in Cultural Contexts

The question of whether the spatial schemas used in communication are culturally provided tools or are adapted on-line is relevant to Chapter 5, a study by Kita, Danziger, and Stolz of gestures produced during story-telling. People from two language groups, Yucatec and Mopan, were asked to re-tell classic myths. Their spontaneous gestures during story-telling were analyzed with respect to which spatial schemas are involved in the encoding of location, motion, flow of time, plot progression, and paradigmatic contrast. Differences in spatial conceptualization between the two languages were reflected not only in gestures referring to spatial concepts, but also those referring to nonspatial concepts. For example, one Yucatec storyteller made a sweeping gesture from right to left when talking about the passage of time from one day to the next, whereas a Mopan storyteller moved her hand forward, away from the body, when talking about the passage of time. These differences were characteristic of all Yucatec and Mopan speakers. The influence of language on spatial conceptualization and thereby on gestures suggests that culture does play an important role in providing spatial structures for thought, while the spontaneity of gesture as a medium provides possible evidence for the on-line adaptation of spatial structures for communicating about non-spatial concepts. In this light, culture and cognitive mechanism are seen as not necessarily two alternative causes, but two intertwined causes.

The mutual causality of culture and cognitive mechanism are also apparent in Chapter 6, where Emmorey describes how signers use the three-dimensional space in front of them to represent physical space as well as abstract conceptual structure. Emmorey observes that in American Sign Language, signers use physical elements—handshapes—to represent physical and conceptual elements. Signers also use movements of handshapes to represent motion of elements, and locations in signing space to represent both physical and conceptual locations. Similar patterns of mapping elements to elements and relations to relations are noted by Tversky and by Gattis in conventionalized and invented graphics. It makes sense then, that Emmorey argues that signing space sometimes functions much like a diagram, and offers many of the same benefits to memory and reasoning that have been noted with diagrams, both because of spatial determinacy, and because of aspects of order inherent to spatial representation. Emmorey also notes that signing space is particularly expedient for representing time and order (similar to the proposals of Roberts, Tversky, Kita et al., Gentner, Hummel and Holyoak, and

McGonigle and Chalmers), as well as relational aspects of conceptual structure (a point expanded upon in a later chapter by Gattis).

In Chapter 7, Bryant and Squire tackle the difficult relation between space and mathematics by examining how children's use of space can facilitate mathematical problem solving. In the face of evidence that spatial cues at times lead to misjudgments in mathematics, Bryant and Squire propose that children are poor at remembering absolute spatial values but very good at encoding spatial relations. Spatial relations plus the inferences that follow from those relations become a tool-kit for getting started in mathematics. Like Tversky, the authors make a convincing case that Gestalt principles of perceptual organization are implicated in inferencing from spatial relations, and demonstrate clearly how grouping plays a significant role in young children's solving of division problems. Bryant and Squire also note that children's ability to exploit spatial correspondence to solve problems is often matched, sometimes even exceeded, by their ability to exploit temporal correspondence to solve problems, a point returned to in the next section in a chapter by McGonigle and Chalmers.

Adapting Space for Abstract Thought

In Chapter 8, Gentner sets the stage for an examination of the relation between spatial and temporal domains by proposing four possible levels of mapping from space to abstract cognition in general (lexical relations, structural parallelism, cognitive archaeology, and system mapping, as described above in the section Mapping Concepts to Space). Gentner presents studies examining which of these mappings explains temporal reasoning with two kinds of space-time metaphors (the time-moving metaphor, and the ego-moving metaphor). From the results, Gentner concludes that spatial mappings do influence the processing of temporal metaphors, but is cautious about claiming that space structures time.

In Chapter 9, I review three constraints on mapping abstract concepts onto spatial representations (iconicity, associations, polarity), and argue that structural similarity should be considered a fourth important constraint. While the importance of structural similarity in similarity and analogy is well-established, the claim that it influences mapping between space and abstract concepts is not. To support this argument, I present recent studies with artificial sign languages and graphs. Children's and adults' interpretations of these spatial representations reflect a pattern of mapping elements to elements, relations to relations, and higher-order relations to higher-order relations.

The question of the causal precedence of spatial schemas in reasoning is addressed by McGonigle and Chalmers in Chapter 10. McGonigle and Chalmers review reasoning and seriation studies with nonhuman primates and human children, and ask whether the results of those studies indicate that spatial coding plays a role in the development and evolution of relational encoding. They point out that although some findings indicate that spatial coding does play a role in relational encoding, other findings provide evidence that temporal coding also plays an important role. They argue that spatial schemas may not be the earliest cause of the very special ability to understand order, and suggest that other mechanisms, such as rule stacks, must be considered as plausible alternatives.

Finally, in Chapter 11, Hummel and Holyoak present a process model of human transitive inference demonstrating that both structure and flexibility are important for modeling spatial schemas in abstract thought. Their LISA model, a hybrid connectionist model, creates a spatial array representation of relations between elements based on linguistic inputs such as “Bill is better than Joe. Joe is better than Sam.” The spatial array representation not only allows valid inferences about relations that have not been specified, but successfully models human performance on transitive reasoning problems. Hummel and Holyoak argue that an array representation does not need to be imagistic, pointing to a crucial difference between spatial schemas in abstract thought and imagery in thought. Hummel and Holyoak also point out that they are not claiming that visuospatial processes are the only basis for reasoning, nor that they are developmentally or evolutionarily the first basis for reasoning. The success of Hummel and Holyoak’s LISA model demonstrates clearly, however, that space is a possible and actual basis for reasoning.

1.4 Conclusion

The question of how spatial cognition influences abstract cognition is usually raised as a tantalizing but speculative prospect near the end of a conference or book about more well-understood research questions, rather than being given a thorough and rigorous review. This book attempts to put those tantalizing but speculative ideas to the test. Our hope is to lead you (and ourselves) to new and more vigorous questions about the role of spatial schemas in abstract thought.