Are reasoning with large-scale and small-scale space different? (and why should we care?)

Merideth Gattis

Most researchers of spatial cognition have assumed, either implicitly or explicitly, that large-scale space and small-scale space involve independent and distinct cognitive processes. This is a rational and well-justified assumption from the perspective of studies concerned with how an organism *finds its way in space*, involving tasks such as navigation or orientation, because the requirements of locating oneself in space are very different depending on whether that task is with reference to large-scale or small-scale space. The assumption that large-scale and small-scale space involve different cognitive processes seems less justified when we focus on *reasoning about space*, where reasoning refers to making inferences from spatial information, whether those inferences be about partial spatial information, or about conceptual information that is represented by spatial information. Making inferences on the basis of spatial information is a commonality between what would otherwise appear to be very different tasks – such as taking shortcuts, and reasoning with graphs and diagrams. Using these two types of spatial tasks as key examples, I would like to discuss the aspects of reasoning about space that are (or may be) common to small-scale and large-scale space, and how looking at those commonalities may influence our theories of cognitive architecture. I would also try to address to some (limited) extent questions about modularity in spatial reasoning and the role of language in conjoining discrete bits of spatial information.

In attempting to functionally describe spatial cognition, psychologists have proposed several distinctions between different types of environmental knowledge, including egocentric and allocentric knowledge (Piaget, 1971), layout and route knowledge (Gauvain & Rogoff, 1986), categorical and coordinate relations (Kosslyn et al., 1989), internal and external or deictic and intrinsic frameworks (Bryant, Tversky, & Franklin, 1992; Miller & Johnson-Laird, 1976), and small-scale and large-scale space (Nadel, 1990). Though some have debated exactly which distinctions are most accurate and useful (see e.g. Pederson, 2003), in general these distinctions are supported by evidence such as behavioural analyses, individual differences, and neurological methods such as imaging and lesion studies suggesting that environmental knowledge is not represented by a single system but is divided between two or more systems (for example, Aguirre & D'Esposito, 1997). Such studies have contributed a great deal to our knowledge of the component mechanisms of spatial cognition.

In this workshop I would like to discuss the possibility that these distinctions, though useful for our understanding of the basic mechanisms by which an organism locates itself and other objects in space, are less useful for our understanding of how an organism reasons or makes inferences about space. Making inferences from spatial information can take at least two forms (it may take other forms, but these are the two I have been able to think of): integrating spatial information from orderable or alignable components, and filling in missing information. Below I briefly describe what each of these tasks involves and how they are or might be related.

Integrating spatial information occurs whenever an organism has multiple pieces of information that may be related to one another in a unified fashion. One example of integrating spatial information is combining pairwise relations to form a linear order. For example, when A has some relation *r* to B, and B has that same relation *r* to C, and so on, the pairs can be combined to form the linear order A*r*B*r*C. Some linear orders are also transitive, so that in addition to the ordered relations A*r*B*r*C holding, relations such as A*r*C also hold. Representing serial order seems simple, but in fact holds a special status for comparative and cognitive psychologists interested in representation because it provides a task by which we can assess the existence of an organized internal representation (because only pairs are presented in training, and not the order itself), because it is a relatively late-developing skill in humans and because it seems to be the basis for several more sophisticated cognitive skills such as number (Bryant & Trabasso, 1971; Halford, 1984). Over the last 25 years there have been several reports that non-human primates can integrate pair-wise relations to form a linear order and can respond transitively to new pairs (D'Amato & Colombo, 1988; Gillan, 1981; McGonigle & Chalmers, 1977), but not until recently have these abilities been demonstrated in other mammals such as rats (Davis, 1992). Interestingly, the ability to do so seems to rely upon spatial order. Roberts and Phelps (1994) trained rats on pair-wise reward relations that formed the order A>B>C>D>E>F. Pairs of stimuli (e.g. A>B or C>D) were presented in either a linear or random spatial organization until the rats performed to a criterion indicating they had learned the relations. In a subsequent transfer test (a choice between B and D), rats that learned the paired relations from a linear arrangement performed transitively, while rats that learned the paired relations from a random spatial arrangement did not. Schnall and Gattis (1998) reported the same pattern of results with 6 and 7 year old children. The finding that rats and young children perform better when external spatial cues are provided indicates that integrating pair-wise relations to form an integrated array requires some additional step beyond simply learning the relations.

A second example of integrating spatial information is conjoining different types of spatial information. Ken Cheng (1986) developed a paradigm for studying reorientation, in which a rat placed in a rectangular chamber observed food being hidden in one of the chamber's four corners, each of which had been marked with distinct olfactory and/or visual cues. The rat was then taken out of the chamber, and disoriented by being spun around. When placed in the chamber again, the same number of rats searched for the hidden food in the target corner and in its geometrical equivalent - the corner diagonally opposite. Cheng interpreted this result to mean that rats were relying on geometric rather than landmark information to reorient themselves – because landmark information uniquely specified the target corner. Hermer and Spelke (1994, 1996) used a similar paradigm to investigate reorientation in children and adults, and found that very young children demonstrated similar response patterns to that reported by Cheng, but adults responded in a way that indicated they were able to use both geometric and landmark information. Interestingly, Hermer and Spelke demonstrated that young children were able to use landmark information to search for a hidden toy, but were less likely to use it to re-orient themselves. Like Cheng, Hermer and Spelke argued that re-orientation, and more generally spatial cognition, involves specialized modules that rely on just one type of information for inputs (such as landmarks or geometric relations) and are encapsulated so that they also do not receive outputs from one another. To address the question of when and how these different outputs or types of information can be integrated in spatial cognition, Hermer-Vazquez, Spelke and Katsnelson (1999) asked adults to perform the reorientation task while concurrently performing some other task, such as shadowing a political speech, or tapping a rhythm. Verbal shadowing interfered with adults performance on the reorientation task in such a way that they, like rats and younger children, responded on the basis of geometric information only, but non-verbal shadowing did not. Based on this result, and on the developmental differences previously reported, Hermer-Vazquez, Spelke and Katsnelson argued that language, in particular spatial language such as "left" and "right," provides the basis for conjoining different types of spatial information.

My own work has mostly been concerned with reasoning with spatial representations such as diagrams and graphs. I have proposed that reasoning with spatial representations is much like analogical reasoning, in that it involves a process of mapping or aligning aspects of the concept being reasoned about with aspects of the spatial representation itself, and that this process of mapping is influenced by similarities between the relational structure of the concept and the spatial representation (Gattis, 2001, 2002, 2003; Gattis & Dupeyrat, 2000). The process of alignment is a third example of integrating spatial information (and an alternate candidate to language for the process of integration).

Using several different paradigms, I have demonstrated that aligning conceptual and spatial structures can be the basis for judgments about unspecified information in a graph or diagram. For example, in one set of experiments (Gattis, 2001, 2003), I gave people novel diagrams of gestures, and told the meaning of those gestures in terms of simple statements such as "This means 'Monkey and Mouse'" or "This means 'Monkey or Mouse." When given new diagrams and asked to choose between two similar meanings, people assigned meaning to the diagrams in a way that indicated that they were assigning conceptual objects (such as Monkey) to perceptual objects (such as the hand or ear in the diagram) and conceptual relations (such as "and") to perceptual relations (such as the relation of the arm to the body in the diagram). An important aspect of the task was that people were given a general meaning for each diagram, but were not told what particular aspect of a diagram carried a particular meaning. That ambiguous assignment of meaning to the diagram meant that people had to fill in or infer information that was not specified. The results indicated that in order to do so, people aligned the diagrams and their meanings according to similarities in relational structure. In other studies investigating how young children without prior experience with graphs first begin to make interpretive judgments, I found that this pattern extended to other types of diagrams and other relations. When children were asked to reason about differences in quantity or rate using Cartesian line graphs, their quantity judgments were consistent with the height of a line and their rate judgments were consistent with the slope of a line (Gattis, 2002). Thus integration is an important precursor for the second type of spatial inference, that of filling in missing information.

All of the examples of spatial reasoning discussed here involve judgments about bounded or small-scale space, but it seems to me that the processes involved (integrating spatial information from orderable or alignable components, and filling in missing information) ought to hold equally for reasoning about large-scale space. I welcome discussion of examples and counter-examples of why this relation between reasoning about small-scale space and reasoning about large-scale space either does or doesn't hold, and about the converse relation as well (that the processes involved in reasoning about large-scale space are also involved in reasoning about small-scale space).

Finally, here is why I care about this issue, and why I think you should too (though this may be the least articulate part of this paper). The study of cognition is a pendulum that swings between domain-specificity and domain-generality. The increase in domain-specific models of cognitive architecture has had the benefit of bringing realistic tasks based on aspects of everyday cognition to the forefront, so that how people understand space, time, and number is now just as legitimate a question as how people come to speak a language. A further benefit of the increasing interest in domain-specific models of cognitive architectures is the insightful hypothesis of modularity – that at least some problems are solved in isolation, without reference to all the other wonderful things we know. But at least some of the time, we are solving problems by comparing the current problem with a problem from the past (the solution to which we know), or are integrating a small chunk of knowledge acquired in one place with a small chunk of knowledge in another place, and those occasions are really what reasoning is all about. For that reason, my hunch is that if we want to understand the components of reasoning about large-scale spaces, we will do well to look next door among the components of reasoning about small-scale spaces, and upstairs among the components of reasoning in general.

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