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# Scale and Multiple Psychologies of Space

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**Abstract.** The importance of scale to the psychology of space (perception, thinking, memory, behavior) is discussed. It is maintained that scale has an important influence on how humans treat spatial information and that several qualitatively distinct scale classes of space exist. Past systems of classification are reviewed and some novel terms and distinctions are introduced. Empirical evidence for the need to distinguish between spatial scales is presented. Some implications of these scale distinctions are briefly considered and research needs identified.

## 1 Introduction

> "...the Schools of Cartography sketched a Map of the Empire which was of the size of the Empire and coincided at every point with it. Less Addicted to the Study of Cartography, the Following Generations comprehended that this dilated Map was Useless and, not without Impiety, delivered it to the Inclemencies of the Sun and of the Winters."
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> Suárez Miranda, *On Exactitude in Science* [2, p.123]

Of what import is spatial scale? As a problem for formal analysis, the absolute spatial scale of a geometric object is largely irrelevant. The relationships between sides, angles, etc., are scale-independent; the properties of an isosceles right-triangle hold no matter its size. As a problem for geography, the "science of space", scale has always been a concern of cartographic coding and decoding. But once the scale of the cartographic representation is fixed, all of the decisions made with the map become largely scale-independent. A clustered pattern is a clustered pattern. It is this scale-independence of maps, of course, that gives them their great power and utility. They represent spatial relations and patterns of any size at whatever convenient scale fits on our laps, in the glove compartments of our cars, or on the computer monitors of our geographic information systems.

So properties of space, or relations between objects in space, are typically treated as scale-independent when studied as formal problems and, for the most part, as geographic problems. But when studied as a problem for human perception, thought, and behavior (i.e., when studied as a *psychological* problem), it is the thesis of the present essay that space is not scale-independent. "Space is not space is not space" when it comes to human psychology. Instead, multiple spatial psychologies are called for. And these will not differ in a merely quantitative way, but as I hope to show, in a qualitative way. This thesis is not particularly novel, as such. Below I review previous conceptual distinctions about scales of psychological space but also introduce some terms and distinctions of my own. Furthermore, I add some empirical justification to the conceptual justifications for classifying psychological space into multiple scale classes. Finally, the importance of the issue is considered, and some pressing questions for future research are outlined.

A terminological confusion must be addressed at the outset. My dictionary defines *scale* as (among other things) the "ratio between the dimensions of a representation and those of the thing that it represents", in other words, the *relative* size of a representation. Thus, a *large-scale map* is large compared to the space it represents, at least relative to a *small-scale map*. Of course, even very large-scale maps are commonly much smaller than the spaces they represent. Behavioral scientists, on the other hand, speak of *large-scale spaces*, spaces that are relatively large compared to *small-scale spaces*. But more than a statement about the relative sizes of spaces, as I discuss below, this terminology reflects a concern for the size of a space relative to a person, more precisely, to a person's body and action (e.g., looking, walking). Thus large-scale spaces are large relative to a person. Large-scale spaces might be less ambiguously termed "large-size spaces", but such a terminology ignores the critical role that scale relative to the organism plays in the psychological properties of spaces differing in size [cf. 25]. The classificatory terms I introduce below will avoid this confusion because the word *scale* is not used in them.

## 2 Previous Scale Distinctions

Researchers studying orientation and navigation have long made a distinction between "proximate" or "near" space and "distal" or "far" space [see 23, 24, and the earlier references cited there]. The former can be apprehended from one spot; the latter require locomotion for their apprehension. In the literature on distance estimation, such a distinction is made between "perceptual" and "cognitive" distance [e.g., 3]. Piaget did not explicitly consider the importance of size or scale pér se in his extensive body of work on the development of spatial knowledge [e.g., 19], other than the problem of translating between different scales. He did imply that scale was important, however, in so far as a mature "Euclidean" knowledge of spatial layout, involving externally-based co-ordinate systems or reference frames, depends in his theory on experience with multiple perspectives. Knowledge of smaller objects in themselves does not require this.

The most influential work on this topic is certainly the chapter by Ittelson [11]. In it, he compared "environmental" space with the object space of traditional space perception research. He discussed several special aspects of environments as spaces and urged the need to study spatial perception within the context of environments. Unlike objects, the environment "surrounds, enfolds, engulfs" [p.13]. The role of scale is critical: "Environments are necessarily larger than that which they surround...large in relation to man....large enough to permit, and indeed require, movement in order to encounter all aspects of the situation....large-scale environments, extending from rooms through houses, neighborhoods, cities, countrysides, to the whole universe in size....require[s] some process of spatial and temporal summation" [p.13]. In addition, Ittelson noted that information about environments is acquired multimodally, not through a single sense, and that more information is provided than can be processed in any reasonably finite period of time. These distinctions clearly depend to a large extent on the relative size of environmental and object spaces.

Many writers have cited Ittelson's distinctions [1, 13, 25], typically in order to characterize "large-scale" and "small-scale" spaces. Especially important have been Ittelson's distinctions about the opportunity to view large-scale space from multiple vantage points, and the need for locomotion and information integration over time to apprehend large-scale space. The role of different motor systems in the exploration of spaces differing in scale has also frequently been emphasized [e.g., 20].

Mandler [16] distinguished three classes of psychological spaces: small-, medium-, and large-scale. Small-scale spaces are apprehended from a single perspective, outside of the space itself (e.g., table-top models). Medium-scale spaces are apprehended through locomotion about the space, but spatial relationships within them can still be directly observed from one point (e.g., rooms). The spatial relationships within large-scale spaces cannot be directly observed but must be "constructed" over time from locomotion within the space (e.g., houses, towns). Though not formally part of her classification, Mandler acknowledged that very large-scale spaces such as states and countries probably constitute a special case because they are normally apprehended via maps.

As did Mandler [16], Gärling and Golledge [6] further subdivided Ittelson's concept of environments. They distinguished between small-, medium-, and large-scale "environments". A room would be an example of a small-scale environment, a building or neighborhood would be medium-scale environments, and spaces at the scale of cities and beyond are large-scale environments. Gärling and Golledge did not specify exactly upon what these distinctions were based. One important consequence of the distinction, however, is that knowledge of large-scale environments is learned in a very "piecemeal" fashion and is hierarchically organized.

Zubin has discussed an interesting classification of scales relevant to spatial language [reported in 17]. He identified four categories of spaces: Types *A*, *B*, *C*, and *D*. Type A spaces are smaller than or equal in size to the human body; examples include pens and other hand-sized objects. They are visible within a static visual field and can be manipulated. Type B spaces are larger than the human body and can be viewed from a single point; examples include trees, the outside of a house, and a mountain. They can also be viewed, at least from one perspective, within a static visual field, but they cannot be manipulated. Type C spaces (he also calls them "scenes") are quite a bit larger than the human body and must be scanned to be perceived; examples include a large room, a field, and a small valley. Their apprehension as single spaces is a constructive process. Finally, Type D spaces (he also calls these "territories") are very much larger than the human body; examples include a forest, a city, a state, and an ocean. These spaces cannot be perceived as a unit, according to Zubin.

## 3 A (Slightly) Novel Classification

The distinctions made by previous authors provide insight into the issues surrounding a classification of psychological spaces (and of course the impetus to consider such a classification in the first place). My own classification largely integrates the distinctions made by earlier writers and provides some novel terms for the classes that focus on their functional properties. I distinguish four major classes of psychological spaces: *figural*, *vista*, *environmental*, and *geographical*. I distinguish these on the basis of the *projective* size of the space relative to the human body, not its actual or apparent absolute size. Large spaces viewed from a distance effectively become small spaces (more on this in my section below on research directions). The most critical functional consequences of the relative projective size of a space are the means by which it may be apprehended and its cognitive treatment by the mind.

*Figural* space is projectively smaller than the body; its properties may be directly perceived from one place without appreciable locomotion. It may be usefully subdivided into *pictorial* and *object* spaces, the former referring to small flat spaces and the latter to small 3-D spaces. Figural space is the space of pictures, small objects, distant landmarks, and the like. Although one may sometimes haptically manipulate (touch) objects to apprehend their spatial properties, no appreciable movement of the entire body is required.

*Vista* space is projectively as large or larger than the body but can be visually apprehended from a single place without appreciable locomotion. It is the space of single rooms, town squares, small valleys, and horizons.

*Environmental* space is projectively larger than the body and surrounds it. It is in fact too large and otherwise obscured to apprehend directly without considerable locomotion, and is thus usually thought to require the integration of information over significant periods of time. It is the space of buildings, neighborhoods, and cities. Although environmental spaces cannot be apprehended in brief time periods, I maintain that their spatial properties can be apprehended from direct experience alone, given enough exposure to them.

*Geographical* space is projectively much larger than the body and cannot be apprehended directly through locomotion; rather, it must be learned via symbolic representations such as maps or models that essentially reduce the geographical space to figural space. This bears repeating: Maps represent environmental and geographic spaces, but are themselves instances of pictorial space! I therefore expect the psychological study of map use to draw directly on the psychology of pictorial space rather than on the psychology of environmental space. States, countries, and the solar system are good examples of geographical spaces (not withstanding the earth-bound reference in the word *geographic*). The surface of the earth as seen from an airplane, however, would constitute a vista space because of its small projective size and our consequent ability to apprehend it directly from our seat in the plane. One point of clarification: Geographers have very commonly studied spaces at what I have defined as a geographic scale. But by choosing this label, I do not mean in the least to dictate the "appropriate" spatial scale for geographers. I have no problem with the view that geographers can profitably apply their spatio- temporal tool kit to whatever scale they wish. Indeed, as I have said, the maps and computer images studied so often by geographers are instances of figural spaces.

## 4 Some Empirical Evidence

I now review some empirical evidence that justifies classifying psychological space into several classes on the basis of scale. Very little research has been done explicitly for the purpose of establishing classes of psychological scales; the issue is a potentially fruitful one for generating researchable questions. Given this paucity of research and the limited space of the present format, I will only briefly discuss three bodies of evidence: (1) the effects of learning from maps vs. from direct environmental experience, (2) differences in the frames-of-reference used to organize and manipulate spatial knowledge at different scales, and (3) attempts to measure individual differences in spatial ability at different scales.

Some of the earliest work to look at maps vs. direct environmental experience was done by Evans and Pezdek [4; see also, 26]. They had subjects judge the accuracy of relative positions of triads of US cities. Time to respond was a linearly increasing function of the degree of rotation of the triad from 0° (north to the top, as in standard cartographic convention). This pattern was also found when subjects judged triads of campus buildings that were learned from a map. However, it was not found when subjects learned the campus layout from direct experience; response-time was roughly equal no matter in what orientation the stimuli were presented. Evans and Pezdek suggested that the multiple perspectives of direct experience was responsible for the lack of an *alignment effect.*

However, an important paper by Presson et al. [21] presents strong evidence that multiplicity of perspectives does not, in itself, explain how scale influences the way we treat spatial information. They had subjects learn simple paths marked on plastic sheets, imagine they were standing at one of the places on the path, and then make directional judgments between places on the paths. Thus, the orientations of the learned space and the judgment space could be aligned or misaligned. Several aspects of the paths and procedures were systematically and independently varied: the absolute size of the space from which the path was learned (.36 $m^2$ to 13.7 $m^2$, i.e., ranging from "map size" to "room size"), whether the space was described as a "map" or a "path", and the amount of scale translation necessary to match the space to another path. In all cases, the spaces were learned by inspection from a single vantage point. Only the absolute size of the path space (the plastic sheet) influenced the occurrence of alignment effects. That is, subjects retrieved spatial knowledge in an *orientation-specific* manner when they learned it from a small spatial representation; they made large errors when asked to indicate directions as if they were viewing the space from a misaligned perspective (e.g., they learned the space with point 3 in front of point 2, but when judging directions, they were asked to imagine they were standing so that 2 was in front of 3). When subjects learned the space from a large representation, on the other hand, they retrieved spatial knowledge in an *orientation-free* manner; their errors did not differ in size as a function of the perspective from which they were asked to imagine the space. The fact that a switch from orientation-specific to orientation-free coding occurred somewhere around 5-6 $m^2$ is consistent with the importance of body size in scaling spaces.

Empirical work on *frames-of-reference* provides another body of evidence for the importance of distinguishing psychological spaces according to scale. While spatial perception and knowledge at any scale involves reference frames (the points, objects, or axes relative to which spatial locations are defined), the particular type of frame differs at different scales. Models of spatial perception and knowledge commonly acknowledge this [e.g., 5]. Acredolo [1] reviewed evidence from her lab showing that the tendency to code space *egocentrically* (with reference to one's own location) depends in part on scale. Huttenlocher and Presson [10] asked subjects to answer questions about object locations in a small table-top space vs. a larger room space. The questions could be answered by mentally moving either the object array or one's body; the former was more common with the small space, the latter with the room space.

Another property of reference frames that has been investigated is the way they explain patterns of distortions in locational judgments. Huttenlocher et al. [9] found that subjects distorted their memories for the location of dots within a small circle towards the center axes of the four quadrants of the circle (i.e., towards the diagonals) [but see 27]. A very different pattern was found by Sadalla and Montello [22], however, who had vision-restricted subjects estimate headings after walking a pathway in a large room. Their subjects distorted path headings towards the orthogonal quadrant boundaries themselves (defined by orthogonal axes emanating from the subjects' bodies).

A third body of evidence suggests that ways that individuals differ in their abilities to solve spatial problems may be different at different spatial scales. There has been surprisingly little work using traditional psychometric paper-and-pencil tests (pictorial spaces) of spatial ability to assess performance in environmental spaces, on tasks such as navigation or landmark location. Perhaps an uncritical assumption of the irrelevance of scale has operated here. One extensive attempt to do this revealed only a very weak prediction of environmental abilities with pictorial measures [15]. This would be expected if environmental space is in fact psychologically distinct from pictorial space. Similarly, Loomis et al. [14] performed a principal-components analysis on performance of several table-top and room spatial tasks. In the resulting factor structure, the table-top tasks grouped together in one component, and the room tasks grouped together in two other components. More work on individual differences in environmental spatial abilities is clearly called for.

## 5 Importance of the Issue

In this section, I briefly suggest some answers to the question: Why is the topic of scale and psychological spaces important? I provide three reasons; others could undoubtedly be given.

**5.1 Effective Spatial Communication:** Clearly, differences between spatial scales should have implications for spatial communication and the optimal design of a variety of spatial information systems. Examples include maps, other navigation guides such as personal navigation systems, and effective user-interfaces for GIS. A concern for effective communication involves both linguistic and nonlinguistic information [see 17, 12].

**5.2 Validity of Simulations:** This reason partially overlaps with the first, though the emphasis here is primarily methodological. What are the implications for the validity of spatial simulations if space at different scales is processed differently? To give a common example, research that uses maps, models, or other figural spaces to study the psychology of environmental space may be questionable. For instance, Hanley and Levine [8] used table-top spaces to make general statements about spatial learning and "cognitive maps". McClurg and Chaillé [18] provocatively entitled their paper "Computer games: Environments for developing spatial cognition?". Considerations of scale suggest that computer screens are not environments. Of course, this issue is not only a methodological one; simulations also have practical applications such as flight simulation training. Research comparing results using simulation and real environments is quite germane to the question of scale in spatial psychology.

**5.3 Scale and Spatial Choice:** Models of spatial choice [e.g., 7] incorporate factors such as time and effort that are scale-dependent. Thus, we wouldn't expect choice patterns and decision processes underlying choice to be identical at different scales.

## 6 Research Directions

I conclude by offering some comments on the important directions for future research. The most critical is certainly to obtain more evidence of the validity and utility of a qualitative scale classification. Both new findings and replications of existing findings are needed. How many classes are necessary and what should they be? Of particular importance to theories of spatial learning are questions pertaining to what humans can learn about environmental and geographic spaces from direct experience. To what extent can the layout of a city be learned without maps? When does a space become too large to learn directly (thus becoming a geographic space)? Finally, what is the relevant way to treat size in such a scheme? I proposed above that projective size is the determining factor in how spaces are psychologically treated. It is also plausible, however, that apparent or *visual size* is the crucial factor (the size the space appears to be, regardless of its projective size). Is a city seen from an airplane treated as a vista space or an environmental space?

## References

1. L.P. Acredolo: Small- and large-scale spatial concepts in infancy and childhood. In: L.S. Liben, A.H. Patterson, N. Newcombe (eds.): Spatial representation and behavior across the life span. New York: Academic 1981, pp. 63-81

2. J.L. Borges, A.B. Casares (eds.): Extraordinary tales. New York: Herder and Herder (1971)

3. D. Canter, S. Tagg: Distance estimation in cities. Environment and Behavior 7, 59-80 (1975)

4. G.W. Evans, K. Pezdek: Cognitive mapping: Knowledge of real- world distance and location information. Journal of Experimental Psychology: Human Learning and Memory 6, 13-24 (1980)

5. J.A. Feldman: Four frames suffice: A provisional model of vision and space. The Behavioral and Brain Sciences 8, 265- 289 (1985)

6. T. Gärling, R.G. Golledge: Environmental perception and cognition. In: E.H. Zube, G.T. Moore (eds.): Advances in environment, behavior, and design (Vol. 2). New York: Plenum 1987, pp. 203-236

7. R.G. Golledge, G. Rushton (eds.): Spatial choice and spatial behavior. Columbus: Ohio State University (1976)

8. G.L. Hanley, M. Levine: Spatial problem solving: The integration of independently learned cognitive maps. Memory & Cognition 11, 415-422 (1983)

9. J. Huttenlocher, L.V. Hedges, S. Duncan: Categories and particulars: Prototype effects in estimating spatial location. Psychological Review 98, 352-376 (1991)

10. J. Huttenlocher, C.C. Presson: The coding and transformation of spatial information. Cognitive Psychology 11, 375-394 (1979)

11. W.H. Ittelson: Environment perception and contemporary perceptual theory. In: W.H. Ittelson (ed.): Environment and cognition. New York: Seminar 1973, pp. 1-19

12. W. Kuhn, M.J. Egenhofer: Visual interfaces to geometry (NCGIA Technical Paper 91-18). National Center for Geographic Information and Analysis (1991)

13. B. Kuipers: The "map in the head" metaphor. Environment and Behavior 14, 202-220 (1982)

14. J.M. Loomis, R.L. Klatzky, R.G. Golledge, J.G. Cicinelli, J.W. Pellegrino, P.A. Fry: Nonvisual navigation by blind and sighted: Assessment of path integration ability. Journal of Experimental Psychology: General 122, 73-91 (1993)

15. C.A. Lorenz, U. Neisser: Ecological and psychometric dimensions of spatial ability (Rep. No. 10). Atlanta, GE: Emory University, Emory Cognition Project (1986)

16. J.M. Mandler: Representation. In: P. Mussen (ed.): Handbook of child psychology, Vol. III (4th ed.). New York: John Wiley & Sons 1983, pp. 420-494

17. D.M. Mark, A.U. Frank, M.J. Egenhofer, S.M. Freundschuh, M. McGranaghan, R.M. White: Languages of spatial relations: Initiative Two specialist meeting report (NCGIA Technical Paper 89-2). National Center for Geographic Information and Analysis (1989)

18. P.A. McClurg, C. Chaillé: Computer games: Environments for developing spatial cognition? Journal of Educational Computing Research 3, 95-111 (1987)

19. J. Piaget, B. Inhelder: The child's conception of space (F.J. Langdon & J.L. Lunzer, Trans.). New York: W.W. Norton & Company. (Original work published 1948) (1967)

20. H.L. Pick, J.J. Lockman: From frames of reference to spatial representations. In: L.S. Liben, A.H. Patterson, N. Newcombe (eds.): Spatial representation and behavior across the life span. New York: Academic 1981, pp. 39-61

21. C.C. Presson, N. DeLange, M.D. Hazelrigg: Orientation specificity in spatial memory: What makes a path different from a map of the path? Journal of Experimental Psychology: Learning, Memory, and Cognition 15, 887-897 (1989)

22. E.K. Sadalla, D.R. Montello: Remembering changes in direction. Environment and Behavior 21, 346-363 (1989)

23. C.I. Sandström: Orientation in the present space. Stockholm: Almqvist & Wiksell (1951)

24. F.N. Shemyakin: Orientation in space. In: B.G. Anan'yev et al. (eds.): Psychological science in the USSR (Vol. 1). Washington: U.S. Off. of Tech. Services (No. 11466) 1961, pp. 186-255

25. A.W. Siegel: The externalization of cognitive maps by children and adults: In search of ways to ask better questions. In: L.S. Liben, A.H. Patterson, N. Newcombe (eds.): Spatial representation and behavior across the life span. New York: Academic 1981, pp. 167-194

26. P.W. Thorndyke, B. Hayes-Roth: Differences in spatial knowledge acquired from maps and navigation. Cognitive Psychology 14, 560-589 (1982)

27. B. Tversky, D.J. Schiano: Perceptual and conceptual factors in distortions in memory for graphs and maps. Journal of Experimental Psychology: General 118, 387-398 (1989)