places on campus, knowledge presumably acquired from direct experience (see also Presson, DeLange, and Hazelrigg 1989). However, subsequent research by others questioned the meaning of the proposed difference between map-acquired and directly acquired knowledge and whether surrounds are even stored in memory in an orientation-flexible manner at all (Roskos-Ewoldsen et al. 1998).

Psychologists came to the study of perceptual and cognitive cartography later in the twentieth century than did cartographers. (Educational psychologists were an exception.) However, perceptual and cognitive map research by psychologists was a busy enterprise in the last two decades of the century, and it actively continued in the early twenty-first century, when ongoing research examined a wide spectrum of maps and newer forms of geographic symbol systems and technologies, including animations, multiscale displays, sonifications, virtual and augmented environments, and more. Psychologists and others continued to apply a variety of methods to study maps, including analyses of errors in spatial judgments, response times, verbal protocols, and eye movements. The advent of new brain imaging techniques in the late twentieth century, notably functional magnetic resonance imaging (fMRI), fostered innovative studies of the neuroscience of map perception and cognition in the early twenty-first century.

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SEE ALSO: Academic Paradigms in Cartography; Color and Cartography

BIBLIOGRAPHY:

Evans, Gary W., and Kathy Pezdek. 1980. "Cognitive Mapping: Knowledge of Real-World Distance and Location Information." *Journal of Experimental Psychology: Human Learning and Memory* 6:13–24.

Levine, Marvin, Irwin N. Jankovic, and Michael Palij. 1982. "Principles of Spatial Problem Solving." *Journal of Experimental Psychology: General* 111:157–75.

McNamara, Timothy P., Roger Ratcliff, and Gail McKoon. 1984. "The Mental Representation of Knowledge Acquired from Maps." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 10:723–32.

Presson, Clark C., Nina DeLange, and Mark D. Hazelrigg. 1989. "Orientation Specificity in Spatial Memory: What Makes a Path Different from a Map of the Path?" *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15:887–97.

Roskos-Ewoldsen, Beverly, et al. 1998. "Mental Representations of Large and Small Spatial Layouts Are Orientation Dependent." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 24:215–26.

Shepard, Roger N., and Shelley Hurwitz. 1984. "Upward Direction, Mental Rotation, and Discrimination of Left and Right Turns in Maps." *Cognition* 18:161–93.

Thorndyke, Perry W., and Barbara Hayes-Roth. 1982. "Differences in Spatial Knowledge Acquired from Maps and Navigation." *Cognitive Psychology* 14:560–89.

Thorndyke, Perry W., and Cathleen Stasz. 1980. "Individual Differences in Procedures for Knowledge Acquisition from Maps." *Cognitive Psychology* 12:137–75.

Tversky, Barbara. 1981. "Distortions in Memory for Maps." *Cognitive Psychology* 13:407–33.

Psychophysics. Perceptual and cognitive cartography is an approach to cartographic research and design that emerged during the twentieth century. This approach recognizes that maps provide symbolic representations to people, offering perspectives on the world that must be interpreted by human minds; maps do not simply present the world to people directly and transparently. Thus, perceptual and cognitive cartographers realize that the content of maps—the information they potentially provide to map viewers—depends not just on the graphical marks placed on the page or computer screen but also on the perceptual and cognitive processes of the viewer.

One of the earliest systematic expressions of the perceptual and cognitive approach to cartography was the application of psychophysics in map design research. Psychophysics is a subdiscipline of experimental psychology that studies the relationship of variation in a physical stimulus dimension, such as the amount of energy emitted by a light source or the concentration of sugar in a solution, to variation in a person's subjective responses to that stimulus, such as perceived brightness or sweetness (Boring 1942). The logic of applying psychophysics to map design, particularly the design of thematic maps, was straightforward and sensible in intent. For example, proportional-area symbols represent the values of a quantitative variable (e.g., graduated circles for population size), according to variations in their graphical area. In order to decode such symbols, map viewers must perceive the area of the symbol and then relate this to the corresponding value of the variable being mapped. It is clear that the map viewer will interpret the symbol according to its perceived or apparent size, not its actual size. If the perceived area of the symbol differs much from its actual area, and if it does so in a sufficiently consistent way across time and viewers, then it makes sense to determine the relationship of perceived area to actual area and use this relationship to design the symbols.

The development of psychophysics played a fundamental role in the emergence of psychology as a separate scientific discipline in the nineteenth century. The year 1879, when Wilhelm Max Wundt opened his psychology lab in Leipzig, Germany, is conventionally identified as its start. Along with Ernst Heinrich Weber and Gustav Theodor Fechner, Wundt was a pioneer in the study of psychophysics. These researchers worked on problems including identifying the absolute and difference thresholds for various stimulus continua, such as the brightness of lights or the volume of sounds. The absolute threshold is the weakest stimulus intensity that can be discriminated from no stimulus; the difference threshold is the weakest increment in stimulus intensity that can be discriminated as an increment. Based on many studies, Weber derived a law (a mathematical equation) that related subjective to objective stimulus magnitude as a logarithmic relationship.

In the mid-twentieth century, the American psychologist S. S. Stevens developed and popularized a slightly different mathematical relationship for subjective and objective stimulus magnitude known as the Power Law (Stevens 1957). The Power Law says that the subjective magnitude of a stimulus equals its actual magnitude raised to the power of an exponent and multiplied by a scaling constant. Such power equations have been empirically derived for a wide range of stimulus types in all of the sensory modalities. Scientific interest has typically focused on the size of the exponent, which indicates a linear relationship when it equals 1.0, an accelerating positive relationship (perceived stimulus magnitude grows more quickly than actual magnitude) when it is greater than 1.0, and a decelerating positive relationship (perceived stimulus magnitude grows more slowly than actual magnitude) when it is positive but less than 1.0.

Perhaps the first explicit call to apply psychophysics to the study of cartographic symbolization came from the German cartographer Max Eckert. He presented ideas about the importance of cartographic perception to the development of cartography as a science most prominently in his two-volume *Die Kartenwissenschaft* (1921–25). In this book, Eckert advocated the application of psychological research to cartography, although he did not describe in detail how this should be done, nor did he present any studies of this kind with maps.

Eckert's call for applying psychophysical research to map symbols was picked up and promoted by the American cartographer Arthur H. Robinson, long-time professor at the University of Wisconsin. In 1952, Robinson published a slim book titled *The Look of Maps*, which was based on his 1947 dissertation at Ohio State University. This book has been widely recognized as seminal in cartography, especially in the area of map design research. In *The Look of Maps*, Robinson cited research by both Weber and Fechner, along with more specific experimental and marketing psychology from the early twentieth century on the perception of lettering, color, and graphical structure. He also cited Eckert, describing him as the only person to examine exhaustively the bases of cartographic method. Robinson called for cartographic researchers to systematically observe and measure—collect data on—how people look at and interpret maps. This call led to, among other things, the application of psychophysical methods to map design research.

Most of the earliest empirical map design research was on the psychophysics of area perception in proportional-area symbols, especially graduated circles but also squares, triangles, and other symbols, including three-dimensional symbols. Among the first examples of psychophysical research applied specifically in a cartographic context was reported by Robinson's student at Wisconsin, James John Flannery, whose dissertation (Flannery 1956) derived a formula to describe the psychophysical function for the area of graduated circles (fig. 665). Based primarily on magnitude-estimation tests given to over 1,000 human subjects (students at various colleges), Flannery's work took the median of the results from several parts of the data and offered the following formula as his best estimate of the relationship of apparent circular area Y_c to actual area X, raised to the power of an exponent and multiplied by a scaling constant (p. 112):

$$Y_c = 0.98365\ X^{0.8747}.$$

About the same time Flannery conducted his studies, Robert L. Williams was conducting similar experiments for the U.S. Office of Naval Research (Williams 1956). Williams's work, which in 1957 became his dissertation at Harvard in the Division of Geological Sciences under Erwin Raisz (Geography no longer formally existed at Harvard), compared filled, outlined, and colored squares, triangles, and stars as well as circles. It also included an early study of gray tone scale perception and observations on the perception of volumetric symbols—spheres and cubes. Averaging the results of several tasks in which viewers matched symbols according to their apparent size, Williams produced tables of visually equivalent symbols (fig. 666). He also derived a power

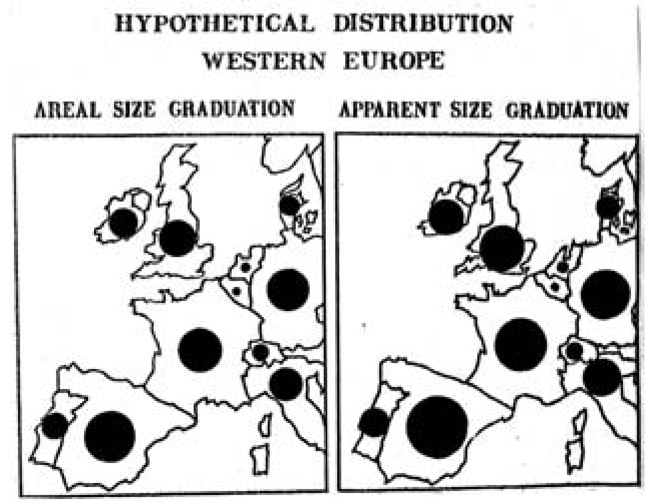

FIG. 665. GRADUATED CIRCLES SCALED ACCORDING TO ACTUAL AREA AND TO APPARENT AREA.
Size of the original: 12 × 15.8 cm. From Flannery 1956, 136 (fig. 20).

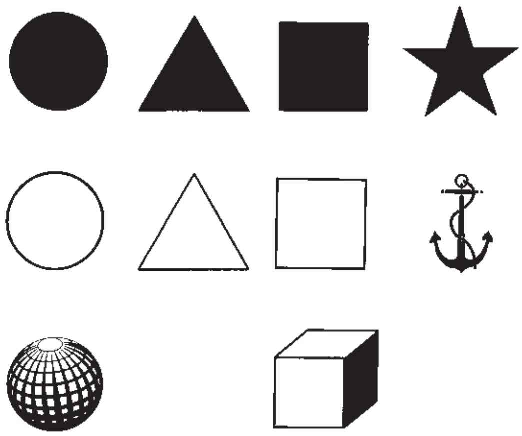

FIG. 666. SYMBOLS FOUND BY WILLIAMS TO BE VISUALLY EQUIVALENT IN SIZE.
Size of the original: 11 × 13.2 cm. From Williams 1956, 38 (fig. 43).

function for symbol size with an average exponent of 0.813. (Williams prudently rounded the exponent to a correction factor of 0.8 [p. 74], in contrast to the spurious precision of Flannery's 0.8747.) This exponent was a little smaller than that reported by Flannery, who commented on Williams's result in his dissertation (p. 134). Flannery was uncertain what the difference in the exponents meant, but he thought that it must have been due in part to the greater variety of stimuli Williams used.

During the next twenty-five years, many additional studies were done on the psychophysics of graduated circles and other proportional-area symbols and on such qualities of cartographic symbols as lightness (value), hue, and dot density (e.g., Castner 1983, 92–98; Ekman, Lindman, and William-Olsson 1963; Kimerling 1989, 692–94; McCleary 1975). However, the value and meaning of psychophysical research in cartography was questioned during the 1970s and 1980s, along with other perceptual and cognitive map design research. Although graduated circles, in particular, were examined in study after study—Kimerling (1989, 692) referred to them as "the 'white rat' of perceptual research"—some writers claimed that work on the Power Law did not add up to conclusions that were very useful to mapmakers. A variety of difficulties were noted with the results of psychophysical studies in cartography. The value of the exponent seemed inconsistent and context dependent. Changing the nature of the map task or the precise design of the test materials often led to variability in the results. Even instructing study participants to estimate apparent size instead of actual size affected the exponent. Other problems included the existence of individual differences—different map viewers produce different exponents. Flannery and Williams both recognized the individual variation in their data but managed to offer single exponents to describe the relationship of apparent to actual circular area by using an average value of some type.

A frequent criticism of psychophysics was that it kept researchers from considering the active thinking mind of the map user (e.g., Petchenik 1975), supposedly because it was part of the paradigm of behaviorism in psychology. Although psychophysics predated behaviorism, and was not particularly closely related to it, there was some validity to criticizing psychophysics for focusing so much on low-level map tasks like feature detection and size perception. In response to some of these critiques, researchers in the 1970s and 1980s began to focus more on higher-level cognitive tasks, like reasoning and inference making; these tasks required a more holistic consideration of relations on maps, not just of isolated symbols. It should be remembered, though, that while a focus on the perception of isolated symbols certainly characterized psychophysical studies, this does not warrant their complete dismissal insofar as such low-level tasks are an essential precondition for seeing anything on a map.

Although psychophysical research in cartography deserved some of the criticism directed at it, its pursuit clearly led to theoretical and practical advances in cartography. For example, perceptual scaling of proportional-area symbols has been shown to work (McCleary 1975, 243), and it has been implemented in the ESRI (Environmental Systems Research Institute) GIS (geographic information system) software ARC/INFO under the label Flannery scaling. As another example, Williams (1956) and others showed conclusively that three-dimensional volumetric symbols do not work; map viewers see spheres as nearly equivalent to circles of the same radius. The logic of such proportional-volume symbols assumes that viewers equate values of thematic variables with perceived volume, rather than perceived area, but this assumption does not hold. Thus, psychophysical research effectively put a stop to the application of what seemed like a clever idea that would have been quite ineffective in practice. Research on color is another success story for psychophysical research. The color scheme developed and tested by Judy M. Olson and Cynthia A. Brewer (1997) for the color vision impaired has been used by the U.S. Center for Disease Control in its *Atlas of United States Mortality* and has been widely applied elsewhere.

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SEE ALSO: Academic Paradigms in Cartography; Robinson, Arthur H(oward); Visualization and Maps

BIBLIOGRAPHY:

Boring, Edwin Garrigues. 1942. *Sensation and Perception in the History of Experimental Psychology*. New York: D. Appleton-Century.

Castner, Henry W. 1983. "Research Questions and Cartographic Design." In *Graphic Communication and Design in Contemporary Cartography*, ed. D. R. F. Taylor, 87–113. Chichester: John Wiley & Sons.

Eckert, Max. 1921–25. *Die Kartenwissenschaft: Forschungen und Grundlagen zu einer Kartographie als Wissenschaft*. 2 vols. Berlin: Walter de Gruyter.

Ekman, Gösta, Ralf Lindman, and William William-Olsson. 1963. "A Psychophysical Study of Cartographic Symbols." *Geografiska Annaler* 45:262–71.

Flannery, James John. 1956. "The Graduated Circle: A Description, Analysis, and Evaluation of a Quantitative Map Symbol." PhD diss., University of Wisconsin–Madison.

Kimerling, A. Jon. 1989. "Cartography." In *Geography in America*, ed. Gary L. Gaile and Cort J. Willmott, 686–718. Columbus: Merrill.

McCleary, George F. 1975. "In Pursuit of the Map User." In *Proceedings of the International Symposium on Computer-Assisted Cartography: Auto-Carto II*, ed. John C. Kavaliunas, 238–50. [Suitland, Md.]: U.S. Dept. of Commerce, Bureau of the Census; [Falls Church, Va.]: American Congress on Surveying and Mapping, Cartography Division.

Olson, Judy M., and Cynthia A. Brewer. 1997. "An Evaluation of Color Selections to Accommodate Map Users with Color-Vision Impairments." *Annals of the Association of American Geographers* 87:103–34.

Petchenik, Barbara Bartz. 1975. "Cognition in Cartography." In *Proceedings of the International Symposium on Computer-Assisted Cartography: Auto-Carto II*, ed. John C. Kavaliunas, 183–93. [Suitland, Md.]: U.S. Dept. of Commerce, Bureau of the Census; [Falls Church, Va.]: American Congress on Surveying and Mapping, Cartography Division.

Robinson, Arthur H. 1952. *The Look of Maps: An Examination of Cartographic Design*. Madison: University of Wisconsin Press.

Stevens, S. S. 1957. "On the Psychophysical Law." *Psychological Review* 64:153–81.

Williams, Robert L. 1956. *Statistical Symbols for Maps: Their Design and Relative Values*. New Haven: Map Laboratory, Yale University.

Permanent Committee on Geographical Names (U.K.). Geographic (or geographical) names, otherwise known as toponyms, are essentially labels that distinguish one part of the earth's surface from another. As such they must be considered with great care. Because they reflect the human imprint on the global landscape, geographic names provide important information concerning politics and culture. They have long been vital for navigation, communications, trade, census and statistics purposes, planning, the environment, tourism, and a host of other factors necessary for the successful functioning of daily life. In particular, geographic names form a uniquely important part of any map or chart—the part with the most immediately accessible information.

The need to consider the importance of geographic names and avoid the application on official products of carelessly discrepant names and spellings was identified by the British Admiralty as an absolute necessity during World War I. Operations during those hostilities had demonstrated to the British government the dangers involved in using products with discrepant names. As soon as the war ended the Admiralty led an initiative within the British government to form a committee specifically designed to resolve such matters. That initiative led to the establishment in 1919 of the Permanent Committee on Geographical Names (PCGN). The Royal Geographical Society was deemed the natural home for the new committee. Thus the PCGN began life as a committee of that Society, housed in the Society's building and staffed by its personnel, principally Arthur R. Hinks, then secretary of the Society (fig. 667).

Within a short amount of time the volume of work confronting the committee became too great for the Royal Geographical Society's staff to handle on top of their normal duties, and the committee assumed its own independence, though the Society continued to supply the administration for two more decades. Hinks stepped down in favor of the first independently recruited secretary of the PCGN, John H. Reynolds, who assumed the post in 1924. Reynolds was succeeded in 1936 by Marcel Aurousseau, who oversaw a substantial if temporary increase in staff during World War II, when the PCGN was very active in producing gazetteers of areas of operational interest such as Greece (PCGN 1942).

That wartime experience suggested that the administration of the committee ought to be a matter for government rather than the Royal Geographical Society, and in 1949 the Admiralty assumed administrative responsibility for the PCGN. That arrangement continued until 1964, when a widespread reorganization of the civil service in the United Kingdom saw responsibility for the committee pass to the Ministry of Defence and the Foreign and Commonwealth Office, both new creations resulting from a major rationalization and amalgamation of previously existing government departments. Those two weighty ministries jointly financed the committee, the Ministry of Defence providing two thirds of the committee's annual budget and the Foreign and Commonwealth Office providing one third.

Despite the changing administrative and financial circumstances of the PCGN over the years, three essential defining characteristics endured: the interdepartmental nature of the committee, under independent chairmanship; its housing within the Royal Geographical Society, to serve the government's interdepartmental interests without partiality; and the independent recruitment of the committee's own dedicated specialist staff.

The 1940s and 1950s saw work on several glossaries of geographic terms in foreign languages such as Turkish (PCGN 1945) and further gazetteers exemplified by that for Czechoslovakia (PCGN 1958). The same decades saw a revised reprint of the well-received *Alphabets of Foreign Languages* (Gleichen and Reynolds 1956).