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DISPLAYS, INSTRUMENTS, AND THE MULTI-DIMENSIONAL WORLD OF CARTOGRAPHY

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Cartographers are creators and purveyors of maps. Maps are representations of space—geographical images of the environment. Maps organize spatial information for convenience, particularly for use in performing tasks which involve the environment. There are many different kinds of maps, and there are as many different uses of maps as there are spatial problems to be solved.

MAPS AND THE DISPLAY-INTRUMENT DICHOTOMY

The many different uses of maps can be categorized into two groups. Some maps are used passively—they *display* information. They are subjected in some cases to only a glance, a moment of study, and little more; in some situations (although the author would no doubt prefer otherwise) they seem to be ignored. Information obtained from maps used as displays is gained by visualization—the eye-brain system processes the display without assistance from any device (e.g., ruler, planimeter).

Other maps, in order to fulfill their missions, must be studied, analyzed or measured. They are used as *instruments*. This is clearly the case with maps used in sea or air navigation or those used to carry out engineering operations. Map use in situations like these is an active process and the map cannot be ignored—it is used with precision, and the efficiency of performance of the task in which it is used depends, sometimes entirely, on the accurate use of the map.

The two parts of figure 1 indicate these extremes: A simple location map from a newspaper contrasts in many ways with the level of detail and the utility of the navigation chart (here shown not only with water depths and graticule marks, but also with electronic navigation system information). While these illustrations make this dichotomy obvious, this difference in approach to examining the uses of maps and to the understanding of the cartographic process presents a significant opportunity for clarifying concepts and procedures which have tended to be passed over by cartographers.

The approach taken here to the display-instrument dichotomy is not contradictory to that set forth by Ellis (1987), but it departs from his perspective in two ways. First, it is applied *only* to maps. Second, the focus is on the *use* of maps—not their creation.

Ellis considers all maps to be instruments, but there are some maps which must clearly be *displays,* even from his perspective. The very large paintings by Jasper Johns come immediately to mind (Crichton, 1977), along with those maps used quite often as a major element of the message in either advertisements or portraits—in these cases, the map serves a simple (often propagandistic) role, for it lends worldly credibility to the person or situation involved.

The representation of the land surface provides an excellent illustration of the display-instrument dichotomy in map creation and use. To create any map a considerable amount of data is required; for a long time there were no significant data available to create a detailed map of the land surface. At the outset there was only the relative location of the feature and some characterization of it (e.g., "over there, a hill"). At this point, there was no real need for a more detailed description. As science and technology developed, it became possible and necessary, first, to locate things more precisely (the graticule and other coordinate reference systems, as well as horizontal and vertical datums were established) and, second, to describe the surface of the land in more systematic terms (verbal characterizations yielded to graphic symbols in a map format, then to representations of slope and finally, with the availability of data, to the mapping of elevation using contours) (Hodgkiss, 1981; Harvey, 1980). The sequence of illustrations in figure 2 provides some high points in this evolution.

The inventory of techniques presented here ends not with the contour—an *instrument* for land surface representation—but with a shaded relief map. While the industrial revolution and the emergence of industries which required large quantities of natural resources needed the kind of information about the land surface that only contours could provide, another aspect of the land surface rose to importance. The contour provides a representation of the land surface suitable for measurement—it is an instrument, and it is a very poor device for *visualization*—it does not create a good display. It is difficult, even impossible, for even a sophisticated map reader to gain a good overall image of the landscape from a topographic map. Therefore, in a number of different map use situations where visualization of the characteristics of the land surface is important, cartographers have employed shaded relief methods on their maps.

The problems associated with land surface representation illustrate nicely the interrelationships among a culture, its science and technology, and the maps which were developed. Different cultures and different times generate different needs for maps, and cartographers have responded to these needs in different ways.

Consider the problem of accomplishing a single task—accurate sea navigation. What form of map—instrument—was and is available? At the outset there were probably no maps (as we understand the concept of the map as a two-dimensional representation); there were only verbal (at first oral and then, later, written) instructions. These yielded to the portolan charts, which codified the relationship between the magnetic "environment" and the land-seascape (given an origin and a destination, there is a straight-line magnetic course between them). While determining latitude has been understood for several thousand years, celestial navigation requires an accurate measurement of time to determine longitude—and the whole process required two instruments: the chronometer and the cylindrical conformal projection. While the former is an eighteenth century invention (Harrison won the prize awarded for creating the first accurate nautical timepiece, and LeRoy and Earnshaw made major innovations which made the chronometer more reliable and inexpensive; see Brown, 1949, and Bowditch, 1966), the latter was first used by Mercator in 1569 (and mathematically described by Wright in 1599; an earlier use, by Etzlaub in 1511, is much less notorious than that by Mercator (Maling, 1973)). Other navigation instruments came much later, including, for example, the electronic navigation LORAN system, and the inertial guidance and satellite-based systems in use today (Monmonier, 1985).

This sequence of development is presented in figure 3: Descriptive guide, portolan chart, Mercator projection, LORAN network, and so on. The final element in this sequence of instruments is a display: a map from an advertisement for a cruise. The sequence of development in navigation, piloting, dead reckoning, celestial navigation, electronic navigation, and—for the tourist—vicarious navigation, is mirrored by a sequence of instruments (and one display).

CATEGORIES OF MAP USE

While there are many different classification systems which have been created for maps, none take advantage of the display-instrument dichotomy. In terms of map use, this dichotomy can be paired with another to create a four-category system of map use. Maps are used either for navigation or for environmental management. One either uses a map to go from one place to another, or the map is employed to provide information about the environment, either for the sake of the information itself ("this map shows the major battles in the European theater in World War II") or so that the information can be used to organize or modify the environment (a map of election precincts or a house plan).

In most cases the navigation map is an instrument. In advertisements, travel guides, and the like, however, it is used as a display. An increasing number of maps are being produced as displays for environmental management; these occur not only in the news media, but also in professional and educational journals and books. Few, if any, of these require the analytical and measurement capabilities of the engineer's plan or the architect's drawing. As displays, these maps require the properties necessary for effective visualization. In such a case, the focus of the map creation process shifts from processes which are founded principally on geometric and geographic precision to those which accommodate the human eye-brain (visual information processing) system.

These four map use categories are compared in figure 4.

THE CHARACTERISTICS OF MAPS

Maps have many characteristics, but all fall into two categories: They are either aspects of the *structure of the map*—those things associated with the scale of the map and its "projection," or they are related to the *content of the map*—the graphic symbols which represent the features of the environment portrayed.

Structure: Space and its Transformations

The literature on map projections is extensive; here we find problems that have confounded and captivated the minds of cartographers for centuries. One will find in any single source only a few of "the answers," for as the uses of maps are very different, so too are the projections which have been used (and misused) for these different requirements. Some fundamental concepts will, however, enable us to resolve the projection problems in terms of the display-instrument dichotomy.

The focus of the cartographic interest in projections has been on the transformation of the spherical earth to the plane. Here, after reduction to some particular scale, the primary considerations are the *properties* of the different transformations. For navigation at the instrument level, the Mercator projection comes immediately to mind. There are, of course, other projections used for navigation, and most of these are, like the Mercator, conformal; i.e., all angles are represented correctly. The Mercator projection is unique, however, for it is only on this projection that all rhumb lines (lines of constant compass direction) are shown as straight lines—an extraordinarily useful situation for a navigator.

There are, however, a number of other facets of the Mercator projection which make it very important to this discussion. First, it does not show great circles as straight lines (this is the property of the gnomonic projection—the gnomonic is the traditional companion to the Mercator; on it all straight lines are great circles—one plots the great circle route between two points, then compiles this path on the Mercator as a set of rhumb lines which are used in the navigation process.) Second, in the transformation of the spherical surface which is required to develop the property of conformality, the Mercator projection exaggerates the sizes of areas; this is a problem which has caused great difficulty when this projection has been used for maps of the world designed to display statistical data. It is a problem which has existed for several hundred years; like the durability of Greek scientific concepts in the Renaissance, it is the Mercator image of the world which has become the consensual view of people around the world. What General Frederick Morgan recognized as a key problem in gaining American support for Operation OVERLORD (Morgan, 1950) (fig. 5) has been documented in depressing detail by Saarinen (1987) (fig. 6).

The solution to the display problem is simple: If you are to make a map of the surface of the Earth, a display to provide information for visualization about some aspect of our environment, use an equivalent (equal area) projection. Here areas on the surface are shown in correct proportion. This has been done—and done again—and again. Unlike the Mercator, the cylindrical conformal projection, there is no unique solution for the cylindrical equivalent projection—there are a variety of possibilities. Further, when one relaxes a constraint on the transformation process, then an even wider array of possibilities emerges. While many have "solved" the problem once, others have created a series of solutions, all unique and all useful. None of these has, however, achieved universal acceptance. Why? None of them looks enough like the Mercator—the consensual—image of the world.

There are many equal area projections (fig. 7), and there are a growing number of compromises: projections which are neither conformal, not the Mercator, nor equivalent—just something between these two, with none of the properties of either. The compromise by Miller is widely used (Snyder, 1982)—it is not equal area, but it has a lot of Mercator-like properties. The one developed by Robinson (1974), and termed "orthophanic" (it "looks correct"), is based on several decades of study of the problem, and the author recognized (and published) its limitations. This is in marked contrast to the campaign mounted by Peters (1983) in support of his equal area projection—the list of "fidelities" associated with it are an insult to those who understand, but a great lure to those who seek a single solution to a problem which has none.

The final event in the organization of the structure of maps is the work with "cartograms"—topological transformations of geographic space on the basis of some set of statistical data. The sizes of areas (countries, states, etc.) are functions of their populations, economic level, or some other statistical measure (Tobler, 1963). Cartograms of this type are a recent invention (Raisz, 1934), but their navigational counterparts date to the Crusades. Automobile strip maps, the distorted maps used by railroads (and many rapid transit systems), and the diagrammatic maps employed by airlines are not only useful, but they are often much easier to understand (be it to visualize or to measure) than their geographically correct counterparts. They represent, as well, a sophistication in the handling of map structure well beyond the normal transformations (projections) generally employed. The earliest cartograms—maps based on a structure of a conceptual space—are the T-in-O maps. These medieval *mappae mundi*, generally considered as perpetrators of myth and dogma, simply reflect a view of the world organized more on the basis of theology than geography (Wilford, 1981) (fig. 8).

In handling the structure of a map (as either a maker or a user), one must turn to fundamentals in order to make an appropriate decision. Choose first the projection which has the properties necessary for the use of the map (conformal for navigation and surveying, equivalent for visualization of statistical information, or one of many other properties—such as equidistance—if the use requires it). Given the important property, then select the least distorted version possible (Robinson et al., 1984).

Content: Data and Their Transformations

Spatial—environmental—information can be conveyed in a number of different ways. One can use words, either written or spoken. Numerical data can be employed, and one is often confronted with great quantities of tabular data, all organized in a form more appropriate for an accountant than for an environmental analyst. These forms, among others, are found in the categories of what Moellering (1980) has called "virtual maps." In some cases verbal or numerical environmental descriptions—maps—are more effective for handling a task than "a real map"—a graphic description. In most situations, however, maps are much more effective for representing the environment, either for display or for use in measurement.

The question which concerns many people, however, is just how effective are these graphic displays. Are they understood more accurately than the verbal essay or the statistical table? While there is a legacy of nearly two centuries of "thematic maps" (Robinson, 1982), it has only been in the last half century that serious consideration has been given to the problems associated with reading—visualizing—these maps. It was only in 1967 that Jacques Bertin described and explored the six visual variables, the graphic vocabulary (Bertin's work was made available in English in 1983). While it is possible in 1988 to present information using graphic devices that provide a reasonable expectation that the message will be communicated appropriately, it is clear that other forms of presentation will fail to achieve the goal.

The six visual variables are illustrated in the ways that they can be used to represent point, line, and area data in figure 9.

It is not possible here to analyze the entire situation, but the use of symbol size (graduated circles) is illustrated in figure 10. In the first map, the sizes of the circles are directly proportional to the populations of the Kansas and Missouri counties which they represent; a circle representing 10,000 people is twice the size of a circle representing 5,000 people, and a tenth the size of one representing 100,000 people.

A large number of studies have shown that the human eye-brain (visualization) system does not respond to these circles in the same way that a mathematical measuring device would; it is clear that circle size differences are underestimated (Stevens, 1975). The second map compensates for this characteristic of the human system; the size of the smallest circle is the same here as on the first map, but all other sizes have been rescaled to overcome the size difference underestimation. Note that the largest circles are significantly larger here than on the first map; the map has been developed with the human eye-brain system as the focus—the numerical data have been transformed to a visual series which should present the information correctly to most map readers (McCleary, 1983).

This is a short, and highly simplified, explanation of a very complex problem. To do justice to it, one needs to explore each visual variable, alone and in combination and context. Each added factor makes the visualization situation more complex. In the same way that the addition of an adjective as a modifier to a noun changes the understanding of the noun (and the addition of an adverb modifies the idea even further), the use of visual variables in combination changes the message to the map user. When a symbol is placed in a context, it—like the noun phrase placed in a sentence or a paragraph—may assume a different meaning. There is a great amount of research to be done before there will be a clear understanding of all the processes and responses to problems in the visualization of maps. Achieving an understanding of the graphic vocabulary and adapting this knowledge to the many variations in graphic displays should not, however, dissuade people from developing and using innovative methods for information. Whether it be for a display or for an instrument, some new approach might elicit more appropriate user behavior for a particular task than a device or procedure which has a legacy of extensive use.

If one learns to write better by reading extensively, one will for certain be better prepared to present data on maps if he or she "reads" widely, examining maps in many different places, in many different forms, for many different purposes.

To this end, the reader might explore the work presented in several volumes. The statistical textbook by Schmid and Schmid (1979) provides a traditional benchmark approach. From the cartographic perspective, Dickinson (1973) focuses directly on the merger of statistics and maps. Monkhouse and Wilkinson (1971), on the other hand, provide an in-depth exploration of mapping techniques. The encyclopedic approach here contrasts greatly with the technical approach used in nearly all of the other cartographic textbooks available; see, for example, *Elements of Cartography* (Robinson et al., 1984).

Lockwood (1969) ranges among a wide variety of maps and graphs, while Fisher (1983) focuses on fundamental facets of the mapping problem. Herdeg (1982) has collected a wide array of material from an even wider array of resources. Southworth and Southworth (1982) focus on maps—a "scrapbook" approach. One might accompany their exploration of these with the text on *Map Appreciation,* by Monmonier and Schnell (1988); this volume focuses on types of maps. *Map Use,* by Muehrcke (1986), is more concerned with process.

All of these volumes have much to recommend them; all have their liabilities. Cartography is a field in transition. Maps are not the property of the product of the cartographer alone. In fact, as some of these volumes indicate clearly, innovation (and the associated excitement) occurs quite often outside the realm of the professional mapmaking clan.

THE HUMAN, MAPS, AND BEHAVIOR

All of the discussion which has gone before has ignored a major area of activity in cartographic research and instruction: cognitive mapping. Here, and in the other research areas associated with it (including environmental psychology, environmental cognition, and the like), the attention lies clearly on the maps which are integral components of the human system. Those who study cognitive maps are concerned with the characteristics of the maps "housed" in the mind of an individual, with the origins of these maps, including different sources of information and the environment, as well as with the behavior which is associated with the uses of these mental images (Downs and Stea, 1977).

This can be explained very simply in a diagram. Humans interact with the environment; on the basis of this interaction, information is transmitted from the environment. This information results from direct interaction with the environment as well as from resources (of all types) which describe the environment. This information can be said, simplistically, to form the basis for a *cognitive atlas,* a collection of maps resident in the mind of the person. While the contents of the atlas are derived principally from the environment, either directly or vicariously, the human imagination is often used in the same way that cartographers have always imaginatively filled the blank spaces on maps (fig. 11).

The "bottom line" in this process is the human response to the environment, the behavior which results from the application of a cognitive map in the solution of some environmental problem (McCleary, 1987). When map use is direct, and very significant to some environmental problem, the map will no doubt have a major effect on the behavior. (This has been demonstrated in a number of ways, in problems of different types; see McCleary and Westbrook (1974) for a very direct analysis of this system.) In many instances, however, the role of the map may be less obvious; as we have seen throughout this discussion, the impact of a map may be reflected in many subtle ways.

CONCLUSION

The world of the cartographer is one of many dimensions and complications. There are not only problems in understanding map structure (projections) and content (symbols, as well as the design of the map), but there is also a continuing series of changes in needs and requirements. Accompanying all of this there is the ever-present change in technology—and an evolving philosophy for the discipline.

What is significant here is that Ellis has provided one more way to "tie down" various parts of the map problem: some maps are displays, while others are instruments. This has been true from the beginning, but a clear recognition of these two major components of the cartographer's dichotomous existence and an implementation of this view in our teaching, research, and production—as well as in the philosophizing—should help a great deal in organizing the enterprise.

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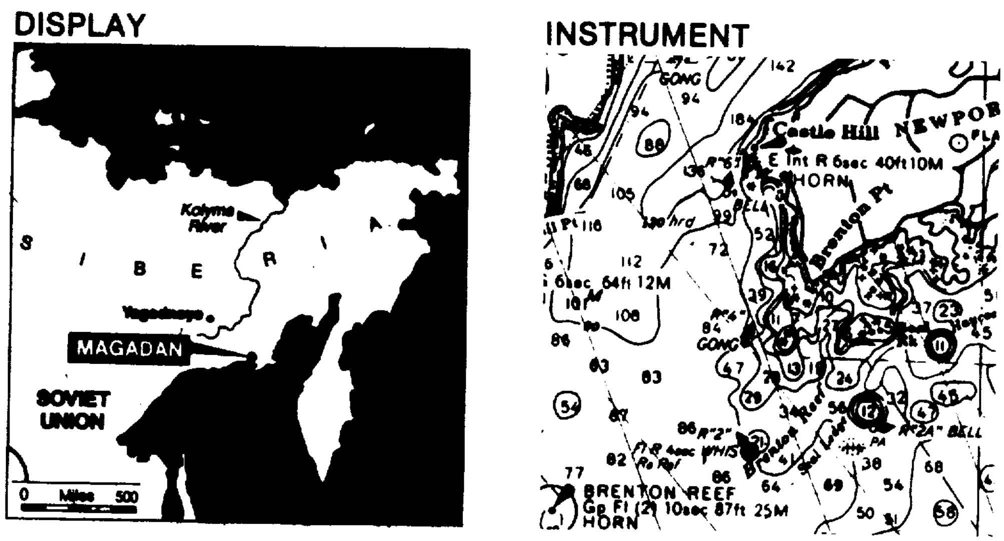


Figure 1.– The map as a display. Left: A newspaper map (Christian Science Monitor). The map as an instrument. Right: A coastal chart (National Ocean Survey).

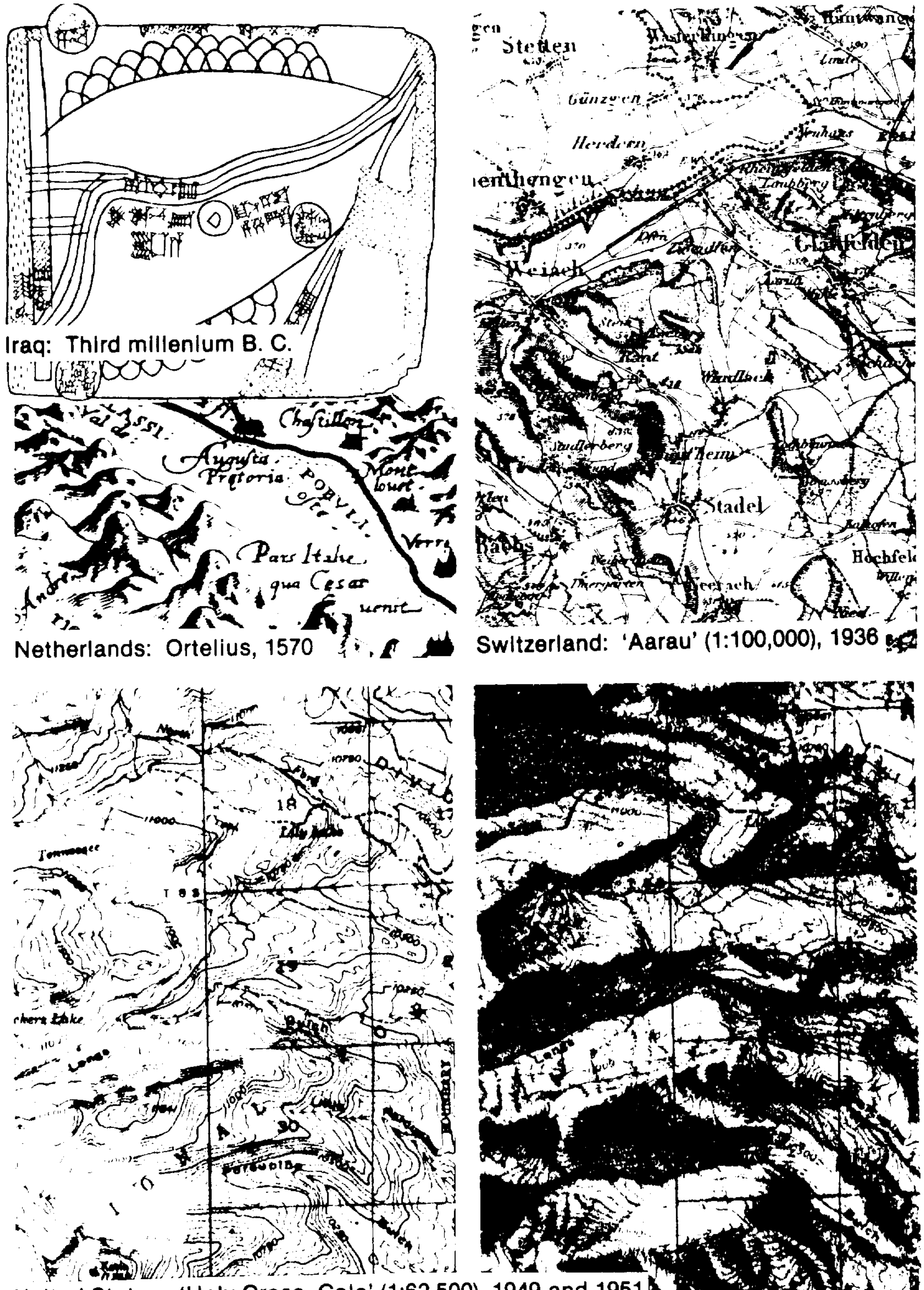


Figure 2.– Evolution of mapping the land surface. Upper left: Ancient map from a clay tablet (outline sketch, with mountains shown in horizontal perspective), with portion of "Sabaundia et Burgundiae" from Abraham Ortelius, Theatrum Orbis Terrarum (a simplified oblique view of hills and mountains). Upper right: Portion of a Swiss topographic quadrangle, using hachures to indicate slope. Lower left: From the U.S. Geological Survey, contours used to represent elevation—and (lower right) a shaded relief version of the same map.

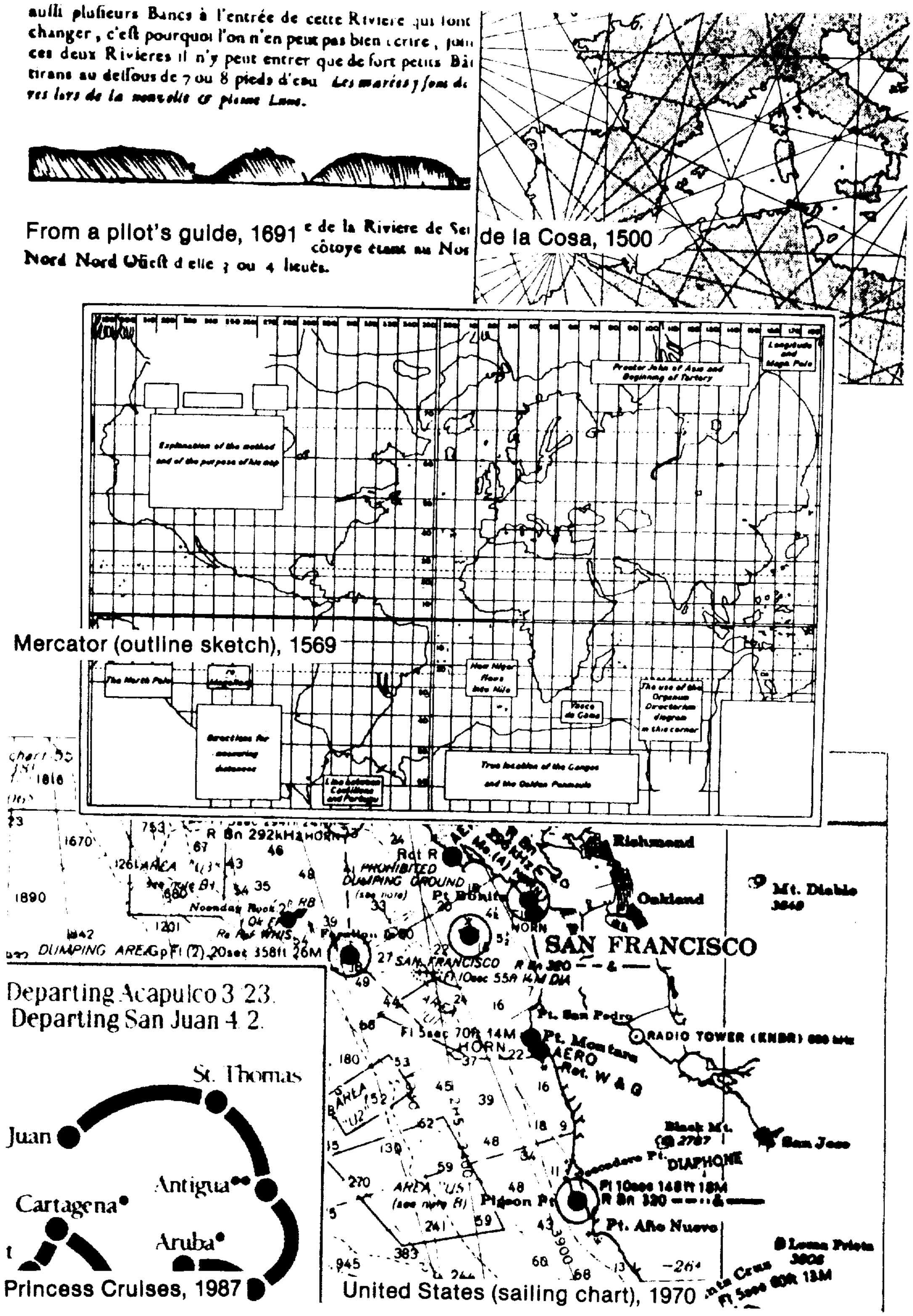


Figure 3.– Sequence of examples showing the evolution of maps used as instruments for navigation. Upper left: Portion of a pilot's guide. Upper right: An outline sketch of a portion of Juan de la Cosa's portolan chart. Center: An outline sketch of the Mercator world map. Lower: Portion of a sailing chart (from the U.S. National Atlas, 1970)—with a map from an advertisement for a Caribbean cruise.

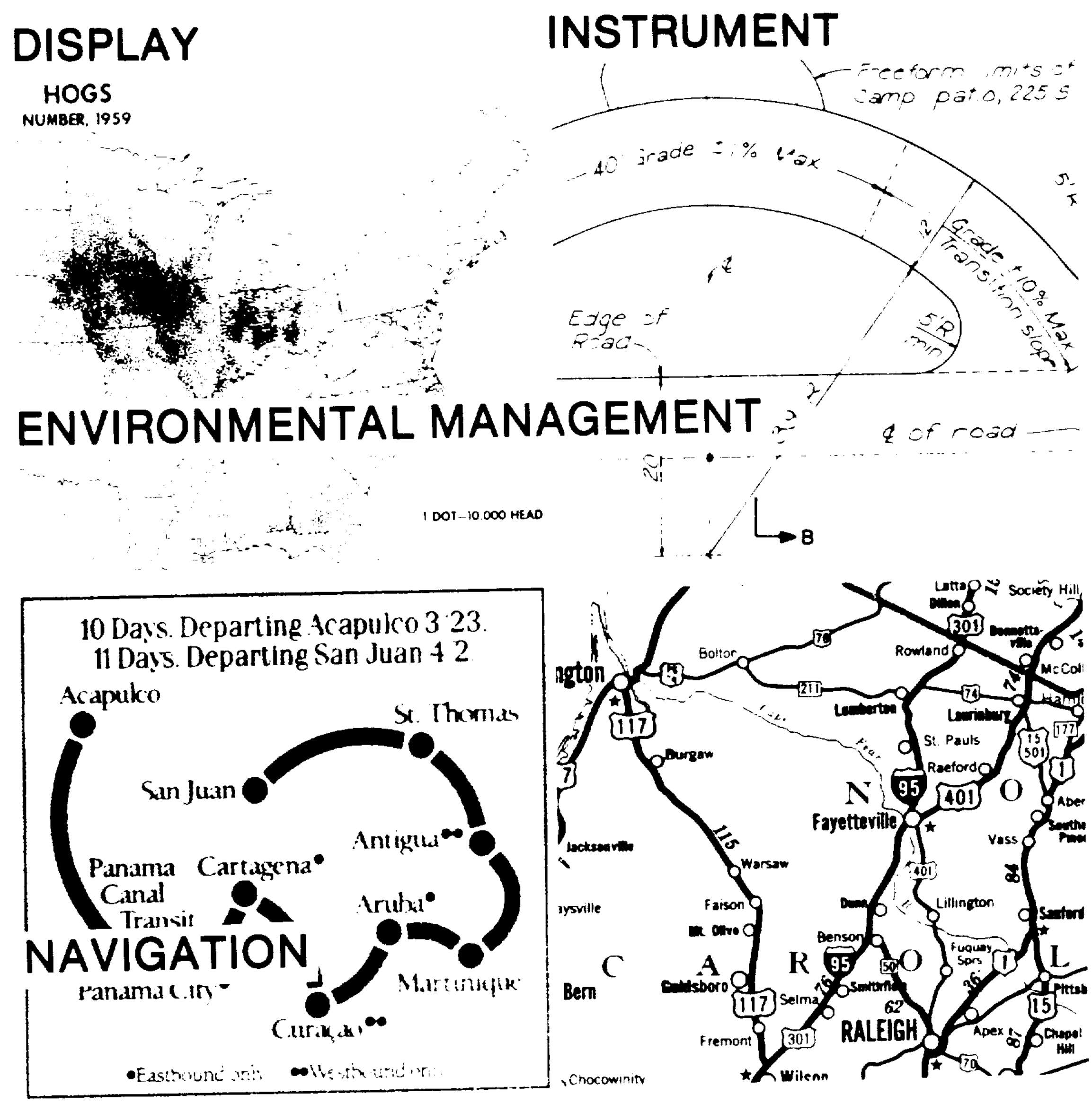
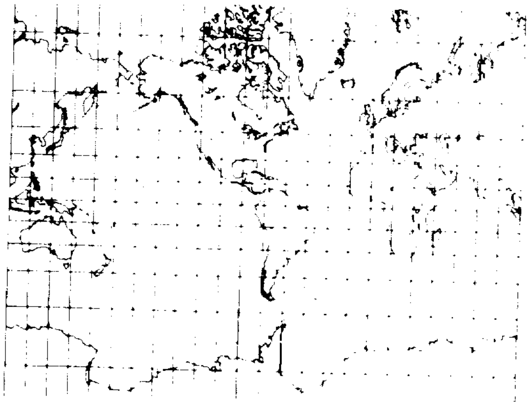
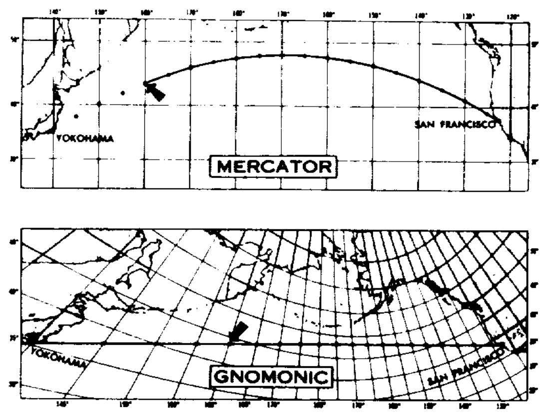


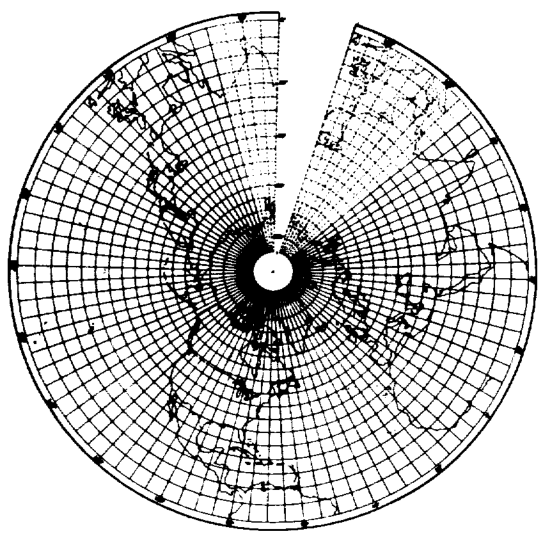
Figure 4.– The four categories of map use. Upper left: Environmental management, display (U.S. Depart. of Agriculture). Upper right: Environmental management, instrument (portion of an engineering drawing, Army Corps of Engineers). Lower left: Navigation, display (from an advertisement by Princess Cruises). Lower right: Navigation, instrument (portion of the "upside-down map" from New York to Florida produced for the ESSO Company).

CONFORMAL PROJECTIONS, THE GNOMONIC, AND NAVIGATION

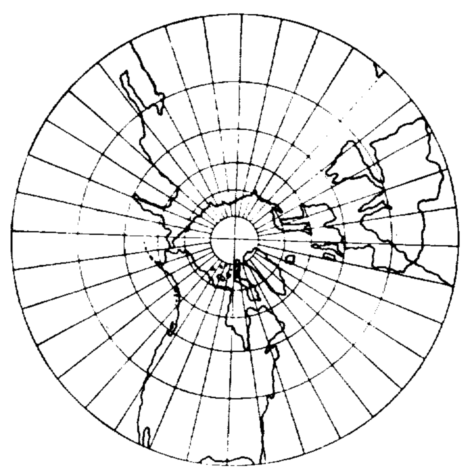


CYLINDRICAL (Mercator), 1569

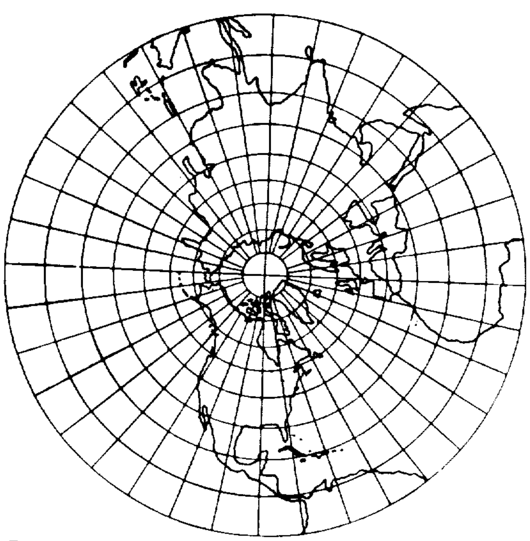




CONIC (Lambert), 1772



GNOMONIC (Known before 600 B. C.)



PLANAR (STEREOGRAPHIC, Hipparchus), 160-125 B. C.

Figure 5.– Conformal projections and the gnomonic: instruments used for navigation.

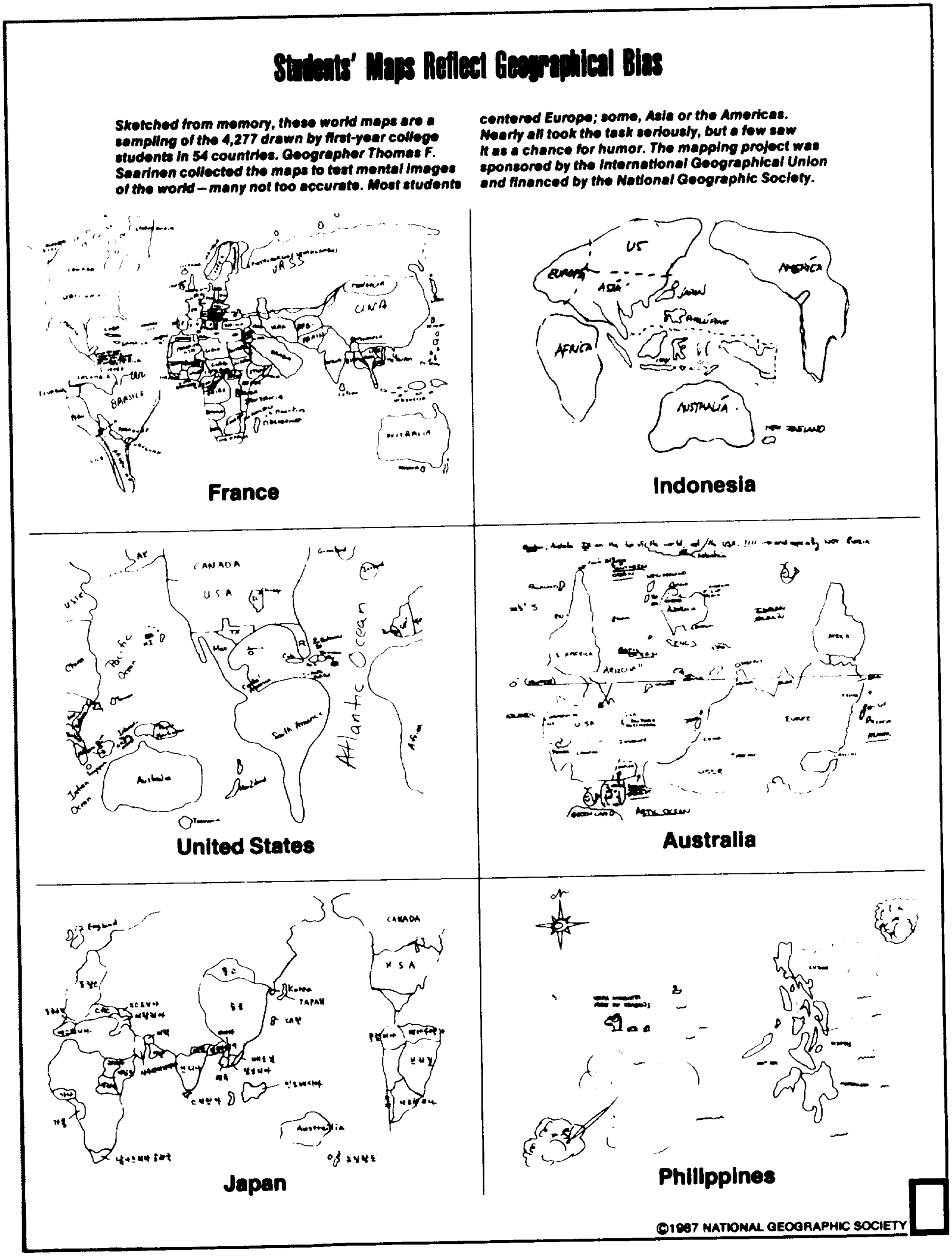


Figure 6.– A summary of key points from a research study by Thomas F. Saarinen: Mental images of the world are generally organized very similarly, no matter where the student lives—the basic organization is a sixteenth-century perspective: The Mercator structure of the world.

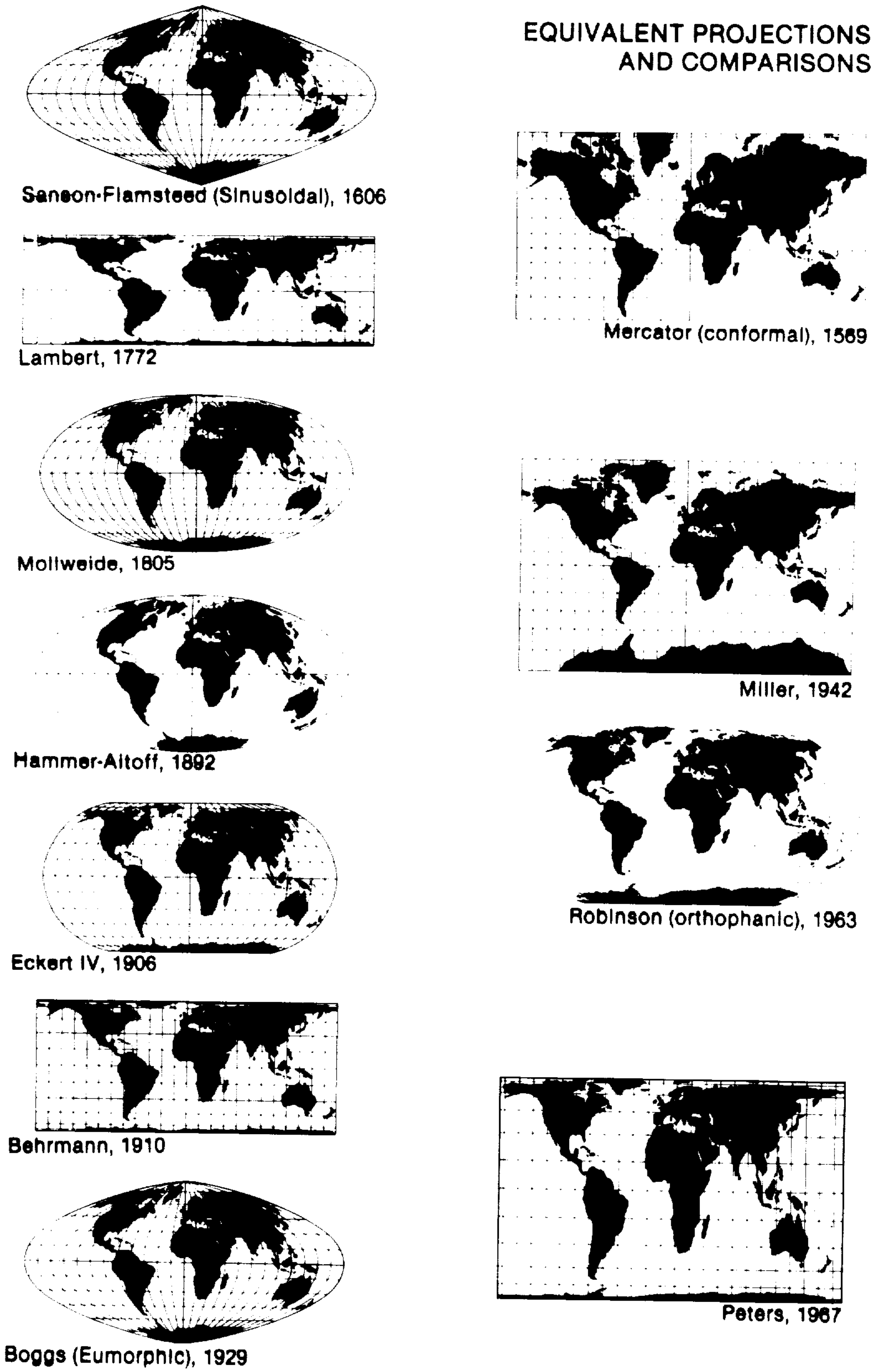


Figure 7.– Seven equivalent projections, from 1606 to 1929. For comparison, note the Mercator projection, the compromises by Miller and Robinson, and the "new" (equivalent) projection by Peters.

OTHER
PROJECTIONS
TOPOLOGICAL
TRANSFORMATIONS
(CARTOGRAMS)

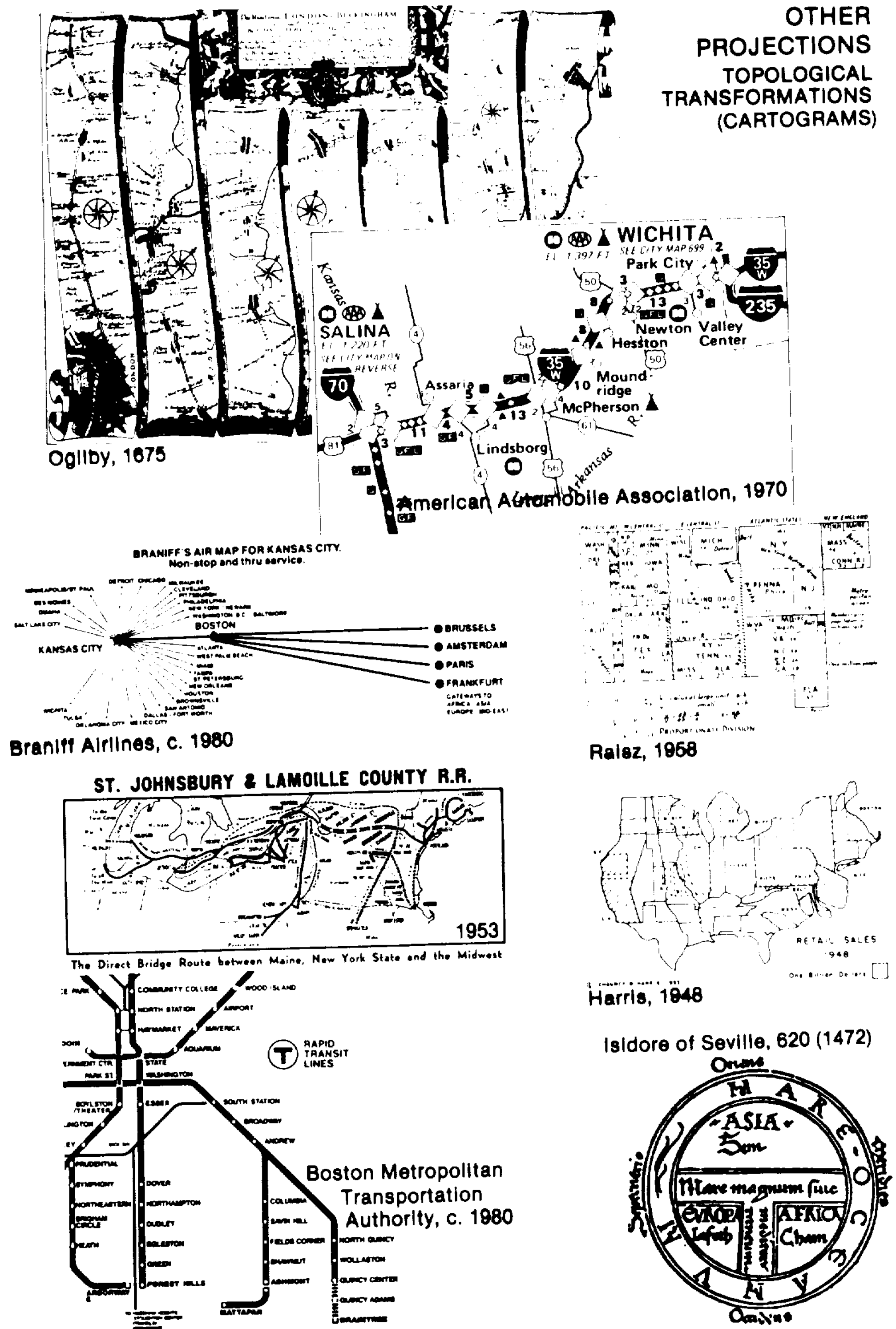


Figure 8.– Topological transformations. Two road maps, three centuries apart. Maps from an airline, a railroad line, and a rapid transportation system—with varying levels of schematic development. Two examples of cartograms—with areas on the maps proportional to statistical values (Population by Riasz, and retail sales by Harris). The oldest printed map, a schematic view of the world drawn originally by a seventh-century Christian scholar—a graphic display of the world derived from the Bible.

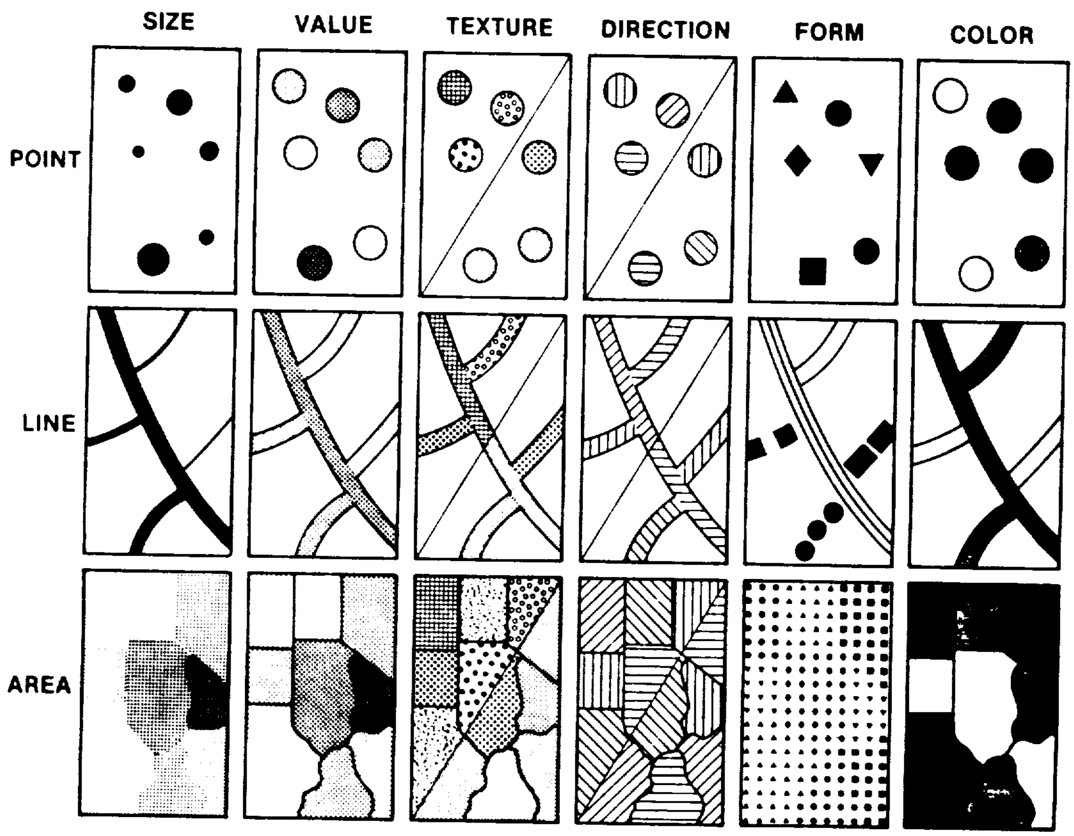


Figure 9.– The visual variables (after the work of Bertin).

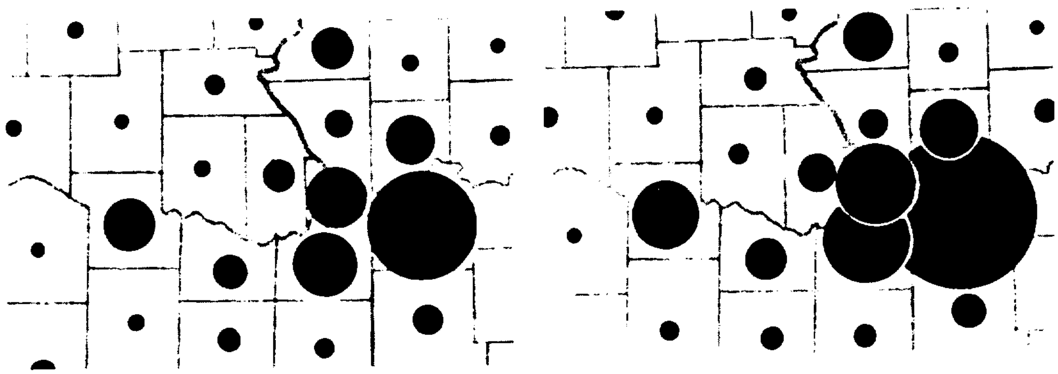


Figure 10.– Two maps, prepared to represent county populations in Kansas and Missouri. The circles on the map at the left are scaled so that their physical areas are directly proportional to the county populations. In the map at the right, the circles have been rescaled so that their size differences are increased, an effort to overcome the "natural" tendency of most map readers to underestimate size differences of point symbols.

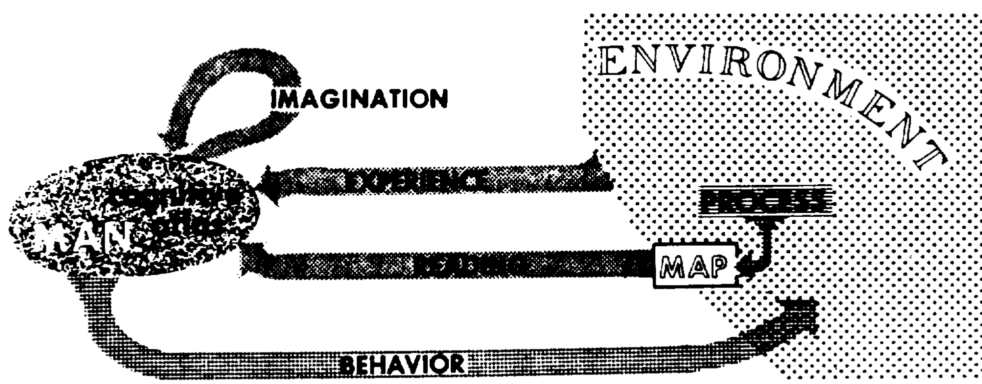


Figure 11.– Model of the cartographic process.