A. The scope of the graphic system

ITS LIMITS

A sign-system cannot be analyzed without a strict demarcation of its limits. This study does not include all types of visual perception, and real movement is specifically excluded from it. An incursion into cinematographic expression very quickly reveals that most of its laws are substantially different from the laws of atemporal drawing. Although movement introduces only one additional variable, it is an overwhelming one; it so dominates perception that it severely limits the attention which can be given to the meaning of the other variables. Furthermore, it is almost certain that real time is not quantitative; it is "elastic." The temporal unit seems to lengthen during immobility and contract during activity, though we are not yet able to determine all the factors of this variation.

Actual relief representation (the physical third dimension) has no place here either and will be referred to only for purposes of comparison.

In this study, we will consider only that which is:
– representable or printable
– on a sheet of white paper
– of a standard size, visible at a "glance"
– at a distance of vision corresponding to the reading of a book or an atlas
– under normal and constant lighting (but taking into account, when applicable, the difference between daylight and artificial light)
– utilizing readily available graphic means.

Consequently, we will exclude:
– variations of distance and illumination
– actual relief (thicknesses, anaglyphs, stereoscopics)
– actual movement (flickering of the image, animated drawings, film).

Within these limits, what is at the designer's disposal? MARKS!

In order to be visible a mark must have a power to reflect light which is different from that of the paper. The larger the mark, the less pronounced the difference need be. A black mark of minimum visibility and discriminability must have a diameter of 2/10 mm. But this is not absolute, since a constellation of smaller marks is perfectly visible.

THE VISUAL VARIABLES

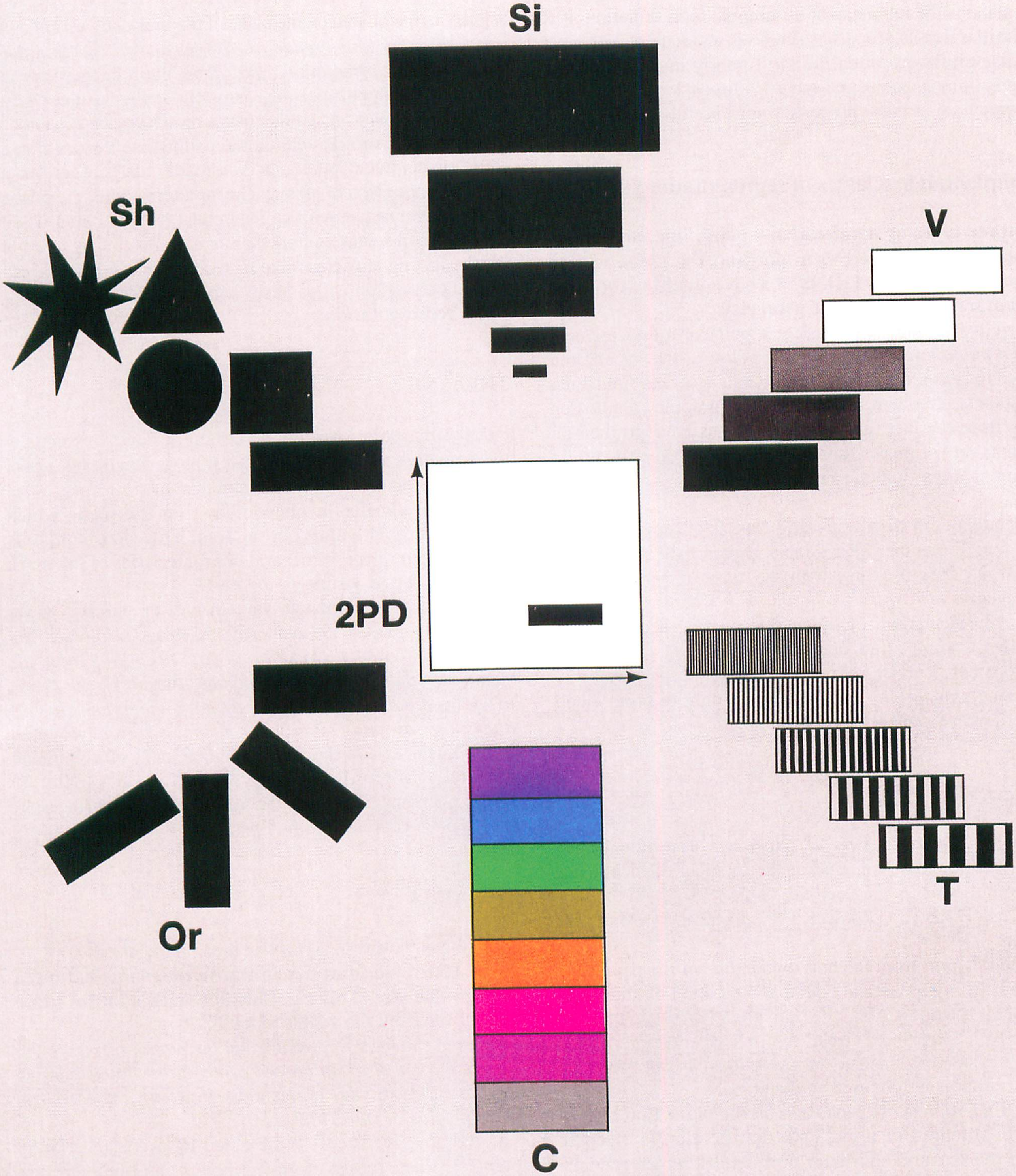
A visible mark can vary in position on a sheet of paper. In figure 1 on the opposite page, for example, the black rectangle is at the *bottom* and toward the *right* of the white square. It could just as well be at the bottom and toward the left, or at the top and toward the right.

A mark can thus express a correspondence between the two series constituted by the
TWO PLANAR DIMENSIONS
Fixed at a given point on the plane, the mark, provided it has a certain dimension, can be drawn in different modes. It can vary in
SIZE
VALUE
TEXTURE
COLOR
ORIENTATION
SHAPE
and can also express a correspondence between its planar position and its position in the series constituting each variable.

The designer thus has eight variables to work with. They are the components of the graphic system and will be called the "*visual variables*." They form the world of images. With them the designer suggests perspective, the painter reality, the graphic draftsman ordered relationships, and the cartographer space.

This analysis of a temporal visual perception in eight factors does not exclude other approaches. But, combined with the notion of "implantation," it has the advantage of being more systematic, while remaining applicable to the practical problems encountered in graphic construction.

These variables have different properties and different capacities for portraying given types of information. As with all components, each variable is characterized by its level of organization and its length. We will first study the properties of the PLANE, then those of the RETINAL VARIABLES which can be "elevated" above the plane.


Si
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C

B. The plane

The plane is the mainstay of all graphic representation. It is so familiar that its properties seem self-evident, but the most familiar things are often the most poorly understood. The plane is homogeneous and has two dimensions. The visual consequences of these properties must be fully explored.

(1) Implantation (classes of representation)

The three types of signification—point, line, and area—which can be assigned to a mark on the plane will be termed "IMPLANTATIONS."* They constitute the three elementary figures of plane geometry.

Along a line, one can consider a point or a line segment. *On the plane,* one can consider a point, a line, or an area. Failure to grasp the various ramifications of this fundamental notion is a frequent source of error in graphics. Confusion stems from the fact that points and lines have no theoretical area, yet the marks representing them require a certain amount of "area" to be visible.

Consequences of distinguishing classes of representation

- The length (number of available steps) of the retinal variables and their use vary with the class of representation involved.
- The representation of quantities varies according to whether a point, a line, or an area is utilized.
- Differences in classes of representation are selective.
- In a single image, the same concept cannot be represented by different "implantations."

THE POINT

A straight line on a sheet of paper has a certain length which can be measured. But, at the moment of measuring, its extremities are considered not to have length on the line. These are POINTS. However, they do have a position on the line.

A point 51 mm from the horizontal edge of the paper and 34.5 mm from the vertical edge has a position on the plane. Whether it is made visible by a "pin prick" 1/10 mm in diameter, or by a "preprinted circle" 5 mm in diameter, its center has a precise position, but the mark itself is not meant to signify either length or area on the plane.

A POINT represents a location on the plane that has no theoretical length or area. This signification is independent of the size and character of the mark which renders it visible.

Consequently, a point can vary in position, but will never signify a line or area on the plane of the image. *By way of contrast, the mark which renders it visible can vary in size, value, texture, color, orientation, and shape,* but it cannot vary in position. Positional meaning naturally applies to the visual center of the mark. Any other usage must he made explicit.

Numerous examples can serve to illustrate this idea: geodetic or confluent points, a crossroads, the "corner" of a forest, the position of an airplane, or a transmitter are points in the planar space, without theoretical length or area. Their graphic representation nonetheless requires the presence of marks having sufficient size to render them visible. Represented cartographically, these phenomena are said to have a **point representation**.

THE LINE

Parallel reasoning permits describing a line as essentially the boundary between two areas. It has a length and a position on the plane, but has no theoretical area.

A LINE signifies a phenomenon on the plane which has measurable length but no area. This signification is independent of the width and characteristics of the mark which renders it visible.

Consequently, a line can vary in position but will never signify an area on the plane of the image. *However, the mark which renders it visible can vary according to all the variables other than those involving position on the plane: in width, value, texture, color, orientation of its constituents, and shape of detail.* Positional meaning naturally applies to the linear axis of the mark. The boundary of a continent, a nation, or a property, a ship's course, or a bus route, are linear phenomena without theoretical area. In cartography, they will be **represented by lines**.

THE AREA

A mark can, however, signify an area on the plane.

AN AREA signifies something on the plane that has a measurable size. This signification applies to the entire area covered by the visible mark.

An area can vary in position, but *the mark representing it cannot vary in size, shape, nor orientation* without causing the area itself to vary in meaning. *However, the mark can vary in value, texture, and color.*

If the area is visually represented by a constellation of points or lines, these constituent points and lines can vary in size, shape, or orientation without causing the area to vary in meaning. In cartography, phenomena such as lakes, islands, land, urban areas, and countries will be **represented by areas**.

*See translator's note, page 7.

ANALYSIS OF THE QUANTITIES TO BE REPRESENTED

When enumeration units have variable dimensions, the representation of the quantities associated with these units must take into account:

(1) the point, line, or area representation of the units;

(2) the nature Q or QS of the quantities to be represented (see page 38).

Take the following information, concerning four communes (units) A B C D:

Units (communes)	A	B	C	D	
Areas (S)	4	4	1	1	(tens of km^2)
Quantity of pop. (QS)	4	8	2	4	(thousands of persons)
Density of pop. (Q)	1	2	2	4	(%)

In figure 1 the communes have a **point representation**. They are points in a scatter plot (distribution of the communes according to the percentage of agricultural [I] and industrial [II] population).

For each point a third factor can be added, either as quantities QS (figure 2), or quantities Q (figure 3) which will be perceived correctly.

In figure 4 the communes are represented by **vertical line segments**, whose lengths are proportional to S. If one constructs the quantities QS on the other dimension of the plane (figure 5), the eye perceives the QS horizontally, but it especially sees the constructed area, that is, QS^2, which it interprets as being the population QS. The area and the general outline are erroneous. One must therefore construct QS/S (i.e., Q) along the horizontal axis, as in figure 6, and this gives an exact image of the quantity QS, in area, and an exact image of the density Q, horizontally.

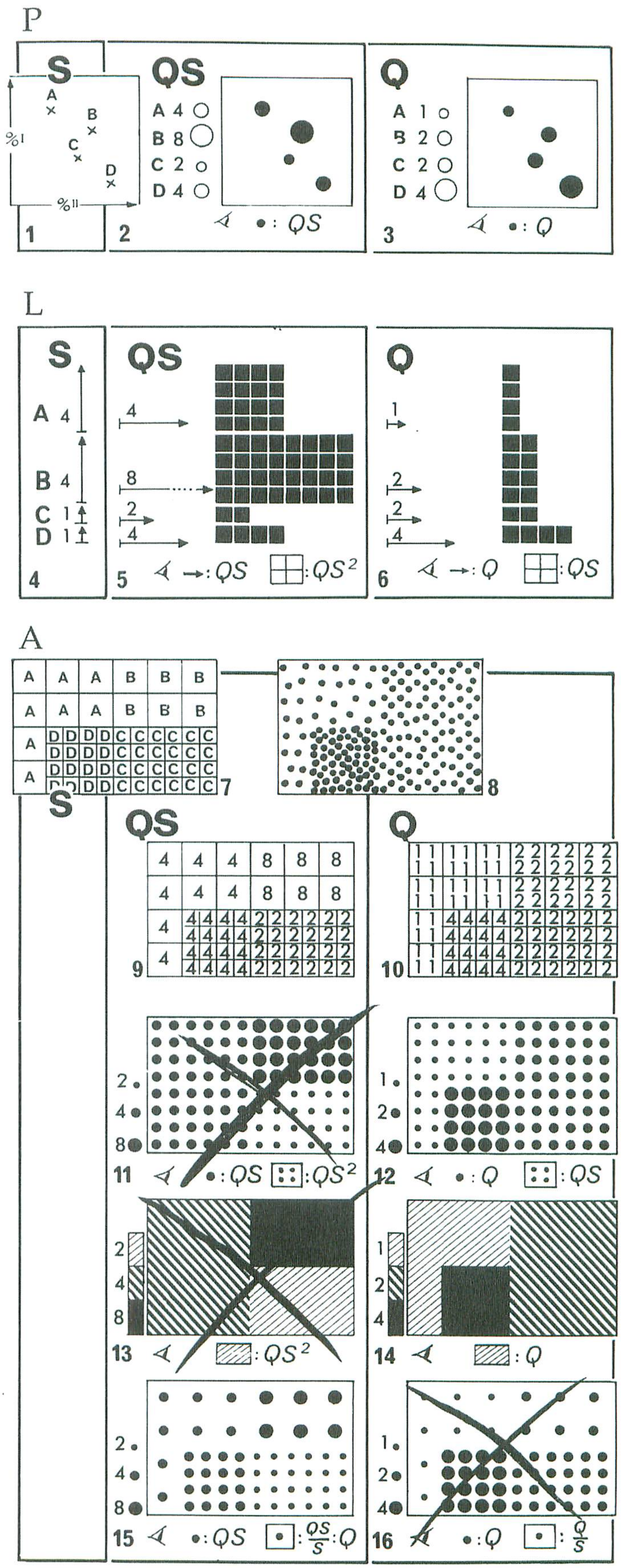
In figure 7 the communes are represented by **areas** proportional to S. The QS and the Q are distributed as in figures 9 and 10. The most simple representation (one point per 1000 inhabitants) produces figure 8, which is correct.

One can easily judge the visual confusion engendered by figures 11 and 13, which extend the value QS to the entire area.

The eye sees there, as in figure 5, QS multiplied by the area, that is, QS^2 (see also page 77, figures 5 and 6). The representation of the QS can, however, be useful (for example, in measuring the responsibility of the different mayors). In this case, figure 15, that is, a point QS per area, avoids the preceding visual confusion.

In contrast, constructing a point Q per area leads to an erroneous representation (figure 16), whereas figures 12 and 14 are correct.

It is interesting to note that the perceptual error seen in figure 5 is well known to statisticians and is nearly always avoided, whereas the erroneous perceptions produced by figures 11 and 13, where the error is expressed in a similar mathematical manner (perception of QS^2), are still found. Control of perception "above" the plane is less obvious than control of perception on the plane. It is no less important, since it is of concern to all cartography.



(2) The plane is continuous and homogeneous

The plane is capable of infinite subdivision. It is continuous. Its divisibility is limited only by the thresholds of perception and the limits of graphic differentiation. A line one centimeter in length easily supports ten identifiable divisions. Next to shape variation, *the plane offers the longest visual variable*. Therefore, it is to the plane that one will usually entrust the representation of the longest components.

Since it has no breaks in continuity, no "gaps," the plane will not admit informational *lacunae*. As a result, it is very difficult to evaluate fragmentary information within the plane. Even though it calls attention to missing data, the map in figure 1 gives an ambiguous impression of the distribution.

*It is very difficult to disregard a part of the signifying plane.**

The certainty of the uniformity of the plane entails a presumption of uniformity in the conventions adopted within the signifying space.

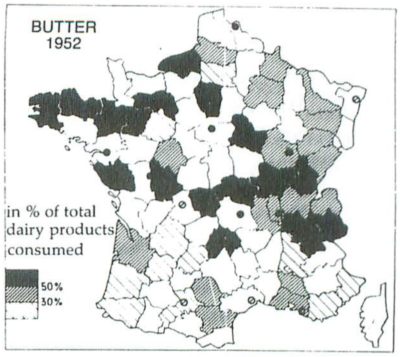
Consequently, **in a signifying space absence of signs signifies absence of phenomena.** Within a visible frame or limit, the space signifies something at every point. Any absence of signal signifies absence of phenomenon. This is the impression created by Figure 2. Therefore information must be applied to the entire area in such a way that the empty spaces signify *absence* of phenomena and not *missing* data.

In a signifying space any visual variable appears as meaningful; the introduction, for example, of a color variation whose only aim is aesthetic or decorative will lead to confusion if the color differences do not correspond to a component. This same property precludes spontaneity in the perception of logarithmic diagrams. Visible differences in length can only be disregarded after considerable training in perception.

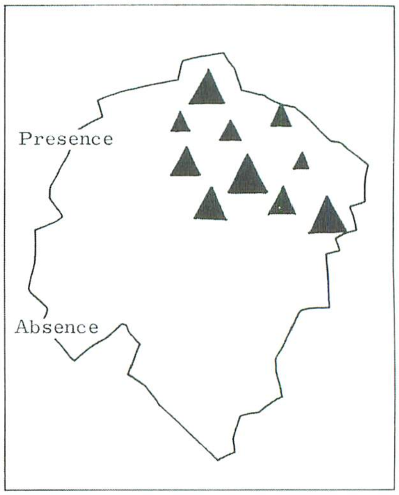
In figure 3, for example, one must learn that only the differences in the slopes of the curves are meaningful.

Likewise, different lengths cannot immediately signify equal lengths. However, such a change in convention is sometimes necessary, particularly with networks (page 275), and the reader must be rigorously informed of it.

*By this term Bertin means that part of the figure which is intended to convey meaning. This excludes, for example, the space lying outside a geographic border or the frame of the drawing (translator's note).



1 White signifies missing data



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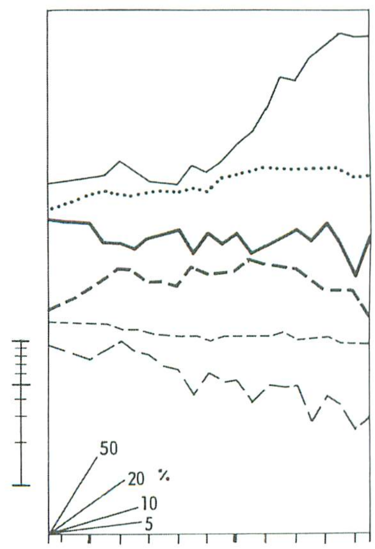

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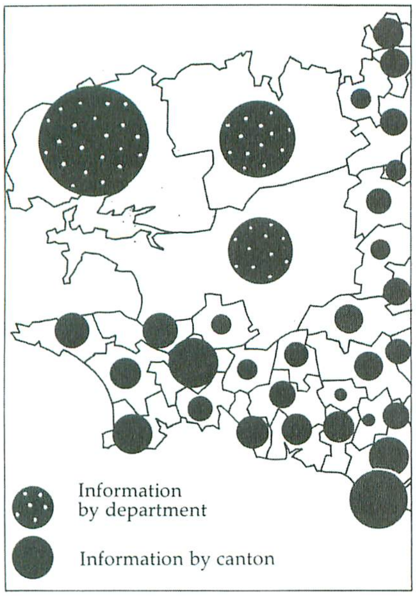

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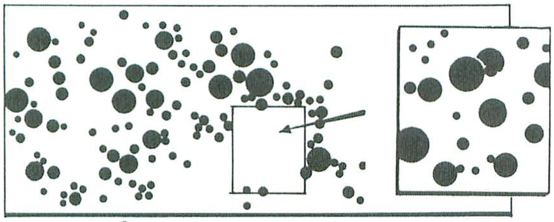

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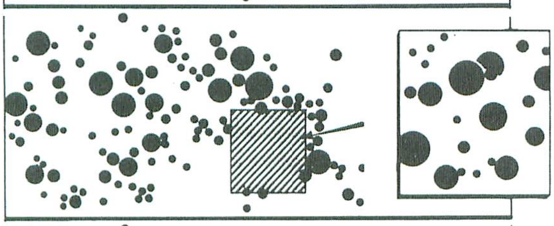

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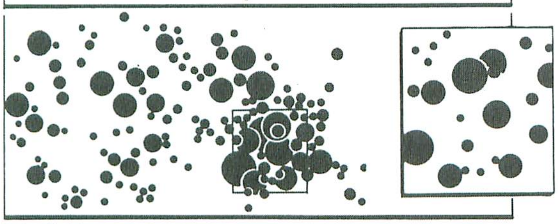

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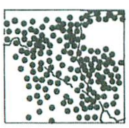
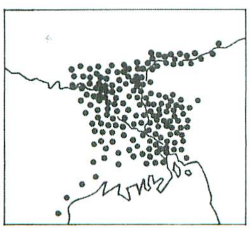


Jute production in Bengal

8



• 10 000 tons

9

In a signifying space a convention is invariable, and any change in the convention is naturally interpreted as a meaningful transformation in the structure of the distribution. Using a sign per department in one part of the image (figure 4), a sign per canton in another, will be interpreted as a meaningful change. The reader can correct this interpretation only by considering the two parts of the figure "separately."

The designer using an "inset" should be aware of these facts. In figure 5, however, the absence of signs immediately signifies an absence of phenomena, and in figure 6 the change in signs signifies a change in phenomena. Even if one understands that the sign refers to the inset, it is still impossible, in figures 5 and 6, to grasp the pertinent information, which only figure 7 enables us to comprehend and retain. Figure 7 creates the only homogeneous image, and the inset furnishes a clarification of it.

An "inset" is a supplementary image, which can never replace the main image (see, for example, page 188).

The frame of a graphic delimits the signifying space, but it does not necessarily delimit the phenomenon. A naturally circumscribed phenomenon, for example, the area of jute production in Bengal (figure 8), only appears spatially concentrated when it is circumscribed by a margin where the "absence" of the phenomenon is visible (figure 9). If the frame is too near, there is the presumption of an extension of the phenomenon beyond the frame (figure 8), and the demonstration of the spatial concentration of the phenomenon is not accomplished.

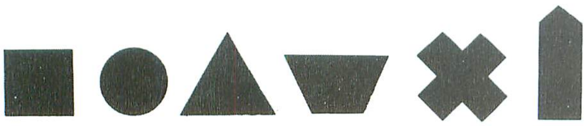
(3) The level of organization of the plane

THE LEVEL OF A VARIABLE

The perceptual properties of a variable determine its level.

Any individual will immediately class a series of values, ranging from black to white as in figure 1, in a constant order: A, B, C, D, or D, C, B, A, but never in another order. Value is ordered. But each individual will class a series of shapes, such as those in figure 2, differently: A, B, C, D, E, or B, A, D, C, E, or C, D, B, A, E. No visual classing asserts itself a priori. Shape is not ordered.

1



2

A value variation is thus capable of representing an ordered component: that is, of providing an easy visual response for any question implying an ordered perceptual approach. A shape variation, on the other hand, cannot represent an ordered component. If one adopts this variation, a question involving an ordered component will have no immediate visual response (see page 34).

The level of each visual variable can be defined as follows (see also page 65):

A variable is SELECTIVE (≠) when it enables us to immediately isolate all the correspondences belonging to the same category (of this variable).

These correspondences form "a family": the family of red signs, that of green signs; the family of light signs, that of dark signs; the family of signs on the right, that of signs on the left of the plane.

A variable is ASSOCIATIVE (≡) when it permits the immediate grouping of all the correspondences differentiated by this variable.

These correspondences are perceived "all categories combined." Squares, triangles, and circles which are black and of the same size can be seen as similar signs. "Shape" is associative. White, gray or black circles of the same size will not be seen as similar. "Value" is not associative. A non-associative variable will be termed dissociative (≢).

A variable is ORDERED (O) when the visual classing of its categories, of its steps, is immediate and universal.

A gray is perceived as intermediate between a white and a black, a medium size as intermediate between a small and a large size; the same is not true for, say, a blue, a green, and a red, which, at equal value, do not immediately produce an order.

A variable is QUANTITATIVE (Q) when the visual distance between two categories of an ordered component can be immediately expressed by a numerical ratio.

One length is perceived as equal to three times another length; one area is a fourth that of another area. Note that quantitative visual perception does not have the precision of numerical measurement (if it did, numbers would, no doubt, not have been invented). However, faced with two lengths in an approximate ratio of 1 to 4, unaided immediate visual perception permits us to affirm that the ratio being signified is neither 1/2 nor 1/10. Quantitative perception is based on the presence of a unit which can be compared to all the categories in the variable. Since white cannot provide a measuring unit for gray or black, quantitative relationships cannot be translated by a value variation. Value can only translate an order.

THE LEVEL OF ORGANIZATION OF THE PLANE

Among the visual variables, the plane provides the only variables possessing all four perceptual properties. The two planar dimensions have the highest level of organization and can thus represent any component of the information.

A variation in planar position is selective (≠)
Two similar marks, differing only in position on the plane, can be seen as different (figure 3), and we can immediately isolate all the correspondences, all the marks belonging to a given part of the plane. The best visual selection is obtained by the construction of separate images, juxtaposed on the plane (see, for example, figure 2, page 67).

A variation in position is associative (≡)
Two similar marks, differing in position, can also be seen as similar (figure 3), and, as a result, it is possible to perceive a whole group of points, lines, or areas, all positional characteristics combined.

A variation in position is ordered (O)
Marks A, B, C, when aligned as in figure 4, are ordered along the line, and this order will be universally perceived in the same manner: A, B, C, or C, B, A, but never B, C, A. Two examples of this are shown in figure 4. Thus for three aligned points, one is between the two others, and for three converging straight lines, one is between the two others.

This order can have a direction. Thus a point runs along a straight line in one or the other direction (figure 5), and a straight line rotates around a point in one or the other direction (figure 5).

Consequently, the plane permits representing an ordered collection, a ranking, or, in fact, any ordered component.

A difference in position is quantitative (Q)
This involves the interval and ratio properties of the plane. Anyone can evaluate the relationships displayed in figure 6 with a certain degree of accuracy:

$A > C > B \quad A = 2C \quad B = C/2$

The plane permits us to define equal segments or angles (superimposed) as well as to add segments (end to end; see figure 7), or angles (adjacent; see figure 8). This addition has all the properties of the addition of positive or negative numbers, once an orientation has been defined. As a result, the plane enables us to perceive ratios of length (figure 9), angle (figure 8), or area (figure 13); to measure (figure 10) or add (figure 13) areas; and to represent variable distances among categories, when they are represented by lengths (figure 11), angles (figure 12), or areas (figure 13).

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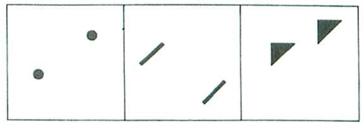

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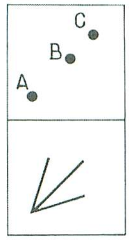

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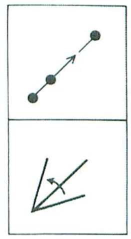

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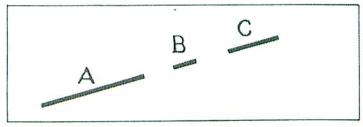

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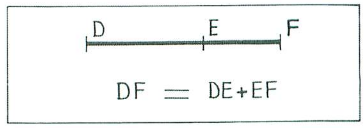

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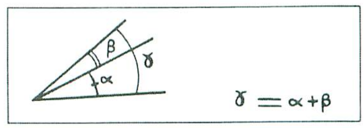

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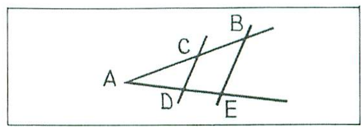

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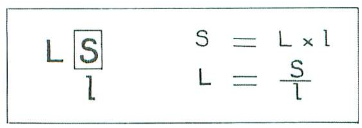

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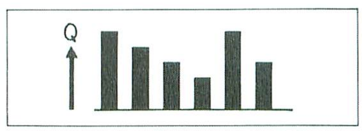

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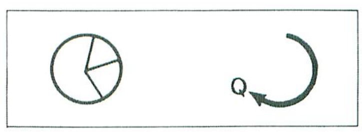

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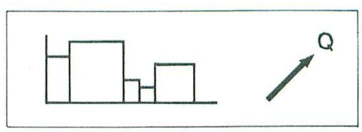


(4) Imposition (groups of representation)

The utilization of the two planar dimensions will be called "imposition." It depends primarily on the nature of the correspondences expressed on the plane, which enables us to divide graphic representation into four groups: diagrams, networks, maps, and symbols.

FIRST GROUP: DIAGRAMS

When the correspondences on the plane can be established between:
- **all the divisions of one component**
- **and all the divisions of another component, the construction is a DIAGRAM.**

Consider the information: trend of stock X on the Paris exchange. As shown in figure 1, the designer must first ensure that any date (component, time) can be correlated with any price (component, quantities). After that he or she will record the observed correspondences constituting the given information (figure 2). But the designer need not ensure a correspondence between two dates nor between two prices.

The process of constructing a diagram is as follows:
(1) defining a representation for the components;
(2) recording the correspondences.

SECOND GROUP: NETWORKS

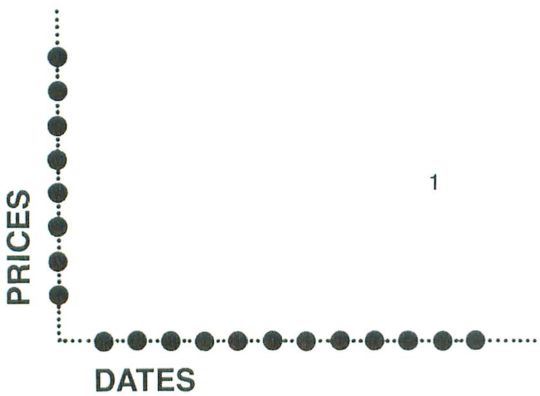
When the correspondences on the plane can be established:
- **among all the divisions of the same component, the construction is a NETWORK.**

Consider the information: verbal relationships among different individuals A, B, C, D . . . of a group.
INVARIANT *–a verbal exchange between two individuals*
COMPONENT *–different individuals A, B, C, D . . .*

The designer must first ensure that any individual (of the component "different individuals") is capable of conversing with any other individual (of the same component). This is accomplished in figure 3. After that he or she will record the observed correspondences constituting the given information (figure 4). In the present case, the designer can then try to simplify the image by ordering the elements in such a way as to obtain the fewest possible intersections (figure 5).

The process of constructing a *network* is the opposite of that outlined for a diagram:
(1) recording the correspondences in an initial manner;
(2) deducing from them the representation of the component which will produce the simplest structure (the fewest intersections).

To construct a *diagram* from the above information, it would be necessary to add a component. One could consider, for example, that the correspondences are between one series of people who speak and another series of people who listen, the two series being composed of the same elements. This can be represented as in figures 6 and 7.



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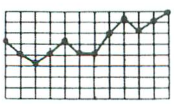
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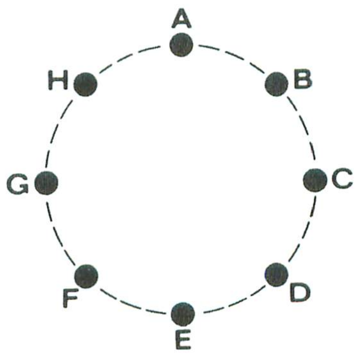

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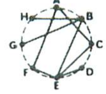

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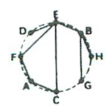

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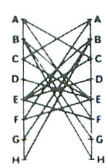

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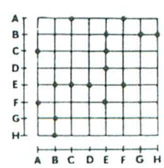


THIRD GROUP: MAPS

When the correspondences on the plane can be established:
- **among all the divisions of the same component**
- **arranged according to a geographic order, the network traces out a GEOGRAPHIC MAP.**

A geographic inventory of highways, for example, is constituted by the set of correspondences established among the elements of a geographic series, usually a series of towns arranged in a geographic order (figure 8).

Since a geographic network cannot be reordered arbitrarily, the image can only be simplified by eliminating certain correspondences.

The process of constructing a map is the simplest of all:
(1) reproducing the geographic order;
(2) recording the given correspondences.

It excludes any problem of choice between the two planar dimensions.

But a series of towns can obviously be arranged according to a reorderable *network*, a circular one, for example. After appropriate simplification, as in figure 9, the network provides another way of highlighting nodes and clusters, while displaying the function of each element. A series of towns can also be constructed in the form of a *diagram*, provided the series is represented twice; this permits orienting the correspondences and indicating, as in figure 10, that one can go from C to D, or B to A, for example, but not from D to C, nor from A to B.

FOURTH GROUP: SYMBOLS

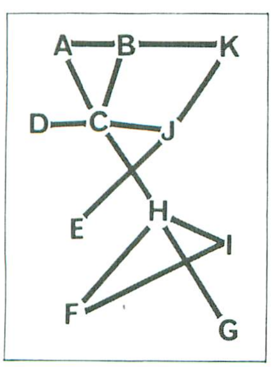
When the correspondence is not established on the plane, but between a single element of the plane and the reader, the correspondence is exterior to the graphic. It is a problem involving SYMBOLISM, which is generally based upon figurative analogies of shape or color.

These are merely the result of acquired habits and can never claim to be universal (unlike fundamental analogies of differentiation, resemblance, order, or quantity).

Such is the case for road or railway signs . . . , conventional codes utilized in topography, agriculture, geology, or industry . . . , codes involving shape or color (safety signs, military symbols . . .). They are meaningful only if one recognizes a previously seen shape (figure 11) or has learned the signification of a conventional shape (figure 12).

Diagrams, networks and maps permit us to reduce information to its essential elements, by *internal processing*; whereas symbolism, like language, seeks only to resolve the problem of *external identification*, through immediate recognition.

Generally speaking, any construction within the graphic sign-system, whatever the group to which it belongs, will be termed a *"representation"* or a *"graphic."*



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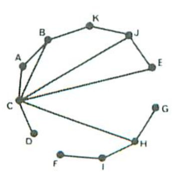

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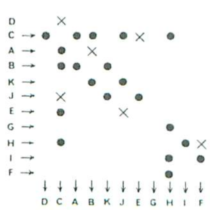

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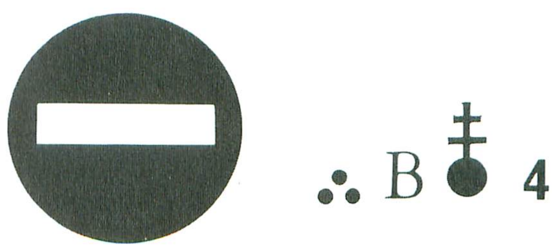

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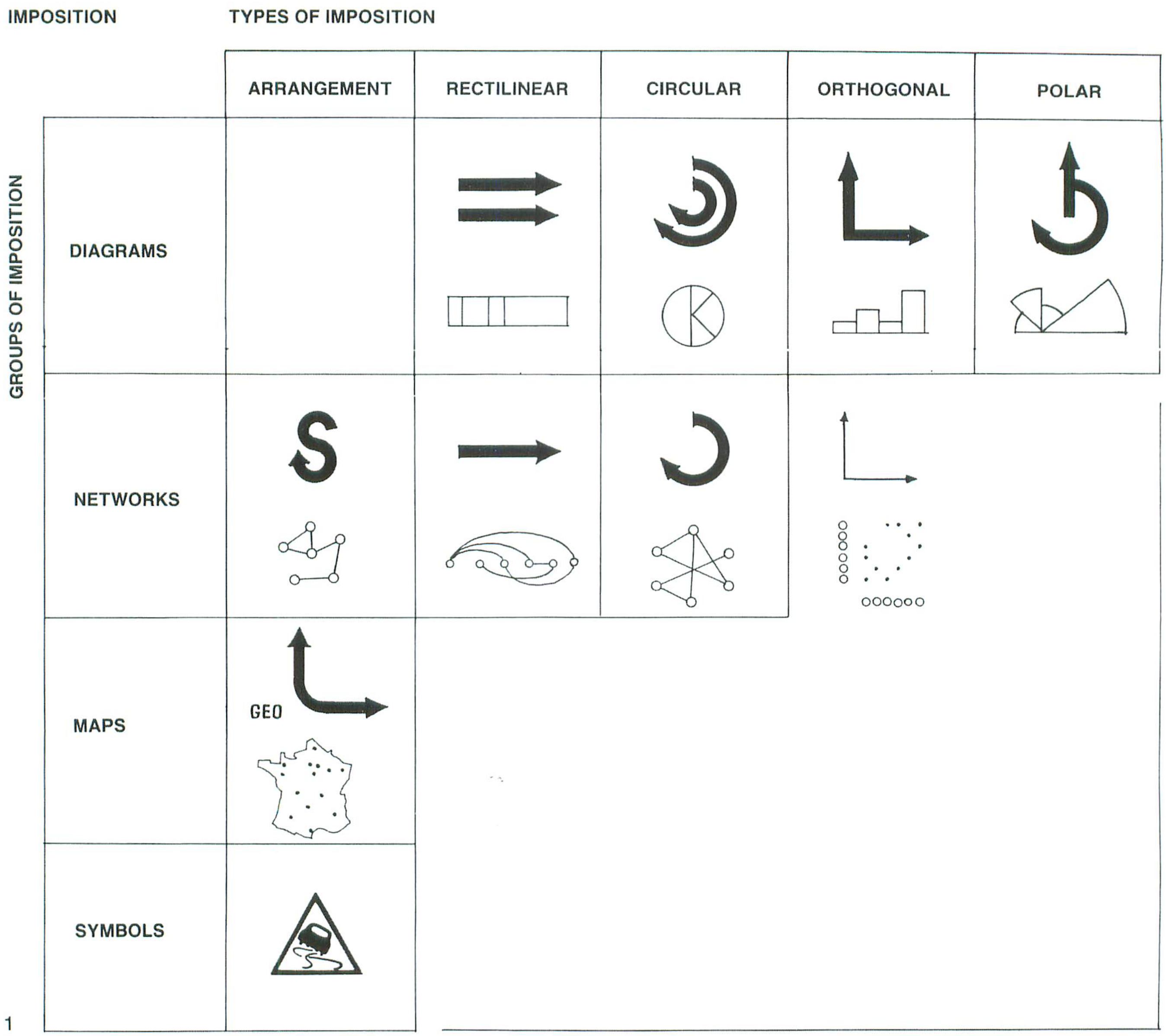

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GROUPS OF IMPOSITION AND TYPES OF IMPOSITION

With diagrams and networks, imposition is varied; the plane can be utilized in many different ways. The components can be inscribed:

- according to an ARRANGEMENT dispersed over the entire plane
- or according to a construction which is
- RECTILINEAR
- CIRCULAR
- ORTHOGONAL (rectilinear)
- POLAR (circular and orthogonal)

These will be called *types of imposition*. Our notion of IMPOSITION thus involves a first stage, the division of graphic representation into four GROUPS, and a second stage, the division of diagrams and networks into TYPES OF IMPOSITION (this is all shown in figure 1).

The use of retinal variables, either to represent a third component or to replace one of the planar dimensions, produces "ELEVATIONS," which can he combined with all the types of imposition in order to form TYPES OF CONSTRUCTION.

Note the wide variety of constructions possible with a diagram or a network; this poses a problem of choice of construction which does not occur in cartography.

The principal types of construction are expressed in figure 1 by SCHEMAS OF CONSTRUCTION, which will be developed later (see pages 172 and 270) to form a system of conventions capable of defining or analyzing any graphic construction.

PRINCIPAL TYPES OF CONSTRUCTION

Consider the following information:
Distribution of traffic accident victims according to type of vehicle:

INVARIANT —*victim of a traffic accident in France in 1958*
COMPONENTS —*Q of persons according to*
≠ four categories (pedestrians, bicyclists, motorcycles, four-wheeled vehicles

The data are as follows:

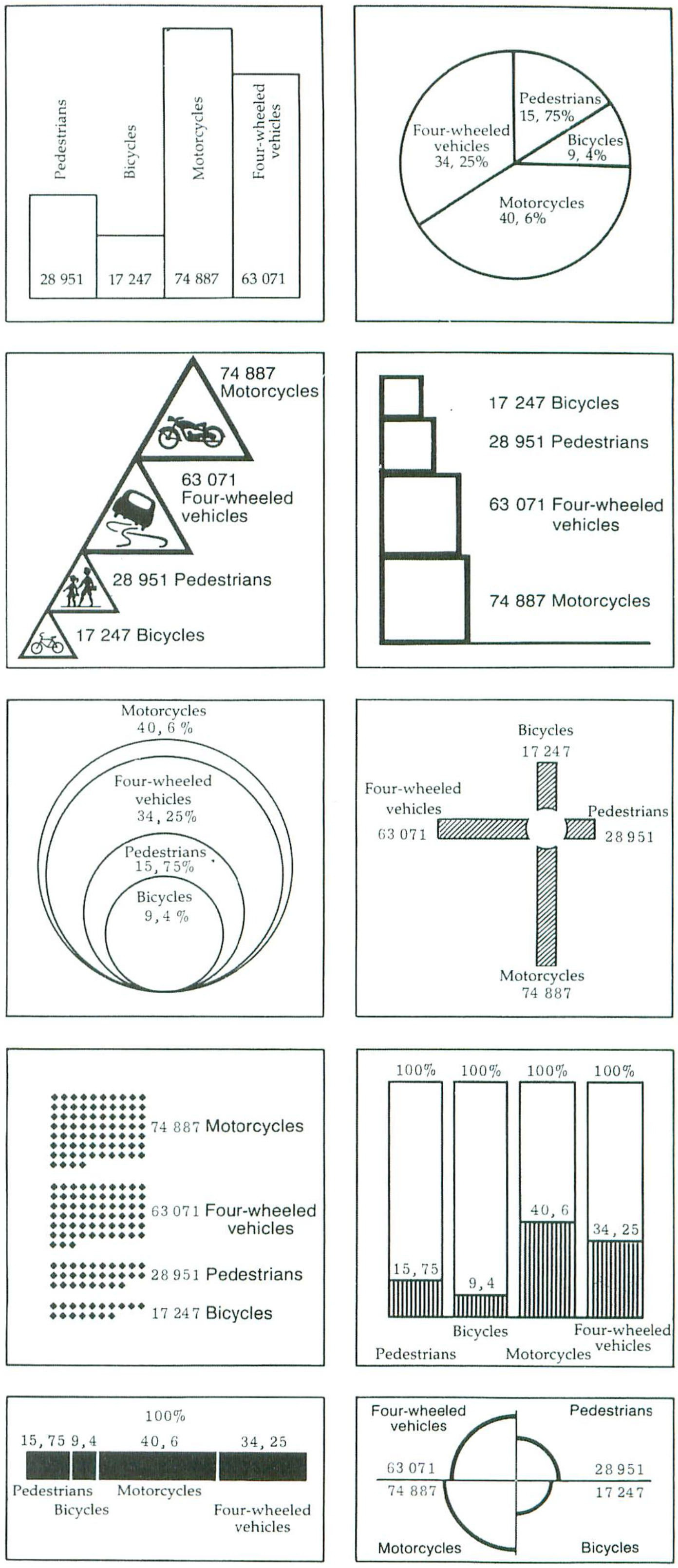
pedestrians	28 951	motorcycles	74 887
bicycles	17 247	four-wheeled vehicles	63 071

All the representations in the opposite margin portray this information.

The figures differ in the size of the lines, the arrangement of the text, the form of the letters, the precision of the drawing, its geometric or figurative style, the amount of black, and the shape of the whole. They could be further differentiated by the size of the figure, by the use of shading or value, by their colors, etc.

In fact, there is an infinite number of possible figures. But we know that they are alike in two ways:
- The pertinent correspondences are the same;
- The construction is a diagram utilizing at least two visual variables.

The manner in which the two planar dimensions are employed permits us to classify them and to define types of construction.



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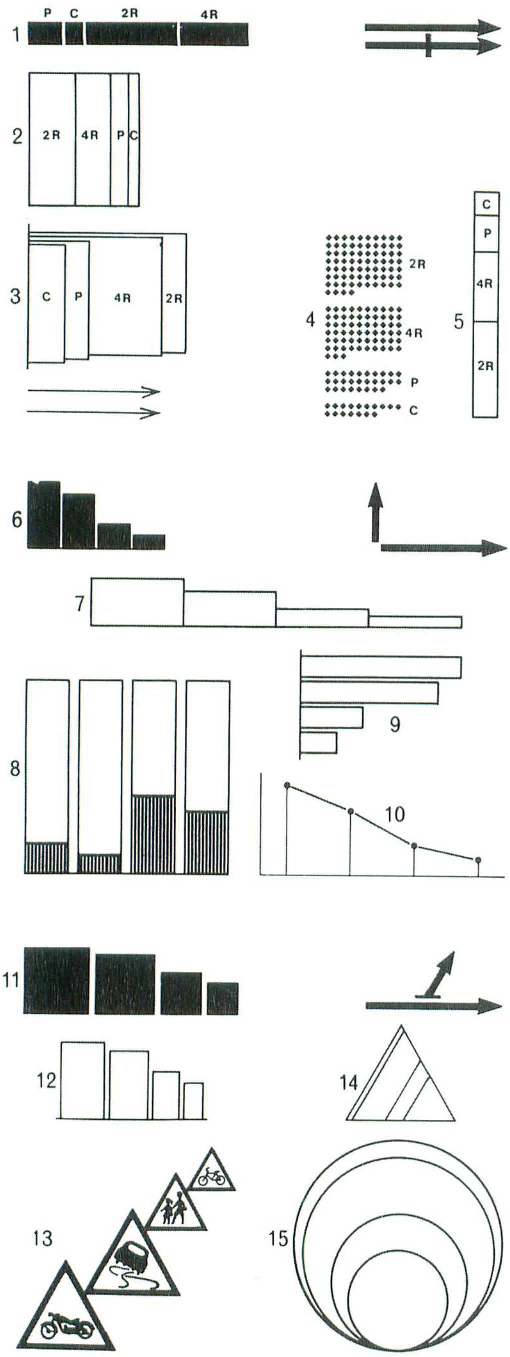


PRINCIPAL TYPES OF CONSTRUCTION FOR A DIAGRAM INVOLVING TWO COMPONENTS

Rectilinear (or linear) construction

In figure 1, a straight line represents the total number of accident victims. It is divided into parts proportional to the quantities in each category. Thus, the component Q and the component $\neq$ are portrayed on the same axis.

In figures 2, 4, and 5, the qualitative component "different vehicles" can be reordered by using the quantities in each category. The width of the straight line has no numerical meaning; it is simply the means for rendering the straight line visible.

In these examples the total is portrayed, which we indicate schematically by putting a bar through the arrow. The second dimension of the plane is not used; it remains available for representing any further component introduced into the information.

Orthogonal construction

If, as in figure 3, the partial quantities are not added but are related to the same base, we must employ a means of differentiation which will permit identification of the parts. The simplest way is to juxtapose them (figures 6–10). This juxtaposition forms an orthogonal construction, in which each dimension of the plane represents a component.

In these examples the total is not portrayed, but the different parts are easily comparable.

Rectilinear elevation

In figure 11, the areas are proportional to the quantities.

The signs are similar (homologous sides in a constant ratio).

The linear dimensions are proportional to $\sqrt{Q}$. The second dimension of the plane does not, therefore, represent the quantities. These are depicted by the amount of area, the amount of "black"; that is, the component Q is represented by a retinal variation (a variation in "size"). We indicate this by using an inclined arrow.

The quantities could also be juxtaposed along a straight line, as in figures 11, 12, and 13, or superimposed, as in figures 14 and 15. However, the total is not portrayed, and comparison of the parts is difficult.

Circular construction

By curving the construction in figure 1 we obtain a figure such as figure 18. This construction is a circular version of the rectilinear construction. The total is portrayed.

When the quantities making up a circular area are given equal radii, the amounts are designated both by their lengths on the circumference and by their angle at the center (figure 16).

The eye has acquired a great precision in judging this angle (figures 17 and 19), and this is easier to grasp than the circular length (figure 18).

Polar construction

By curving the construction in figure 6, we obtain figure 20. The polar construction is a circular version of the orthogonal construction. The total is not portrayed, and the parts are not easily comparable (figures 21 and 22).

Circular elevation

By curving the construction in figure 11 we obtain figure 24. The difference between this construction and the polar construction can be illustrated by comparing figures 23 and 26, or figures 22 and 27. The circular construction often appears as in figure 25. Circles are used to facilitate identification of the parts, whose areas are proportional to the Q.

These principal types of construction permit classing all the drawings on page 53 and, in fact, all planar constructions. Their diversity poses a problem of choice, which can only be solved by the notion of efficiency and by the rules of construction resulting from it.

We will discuss these constructions in later sections on diagrams (classed according to their perceptual properties on page 195) and networks (page 270).

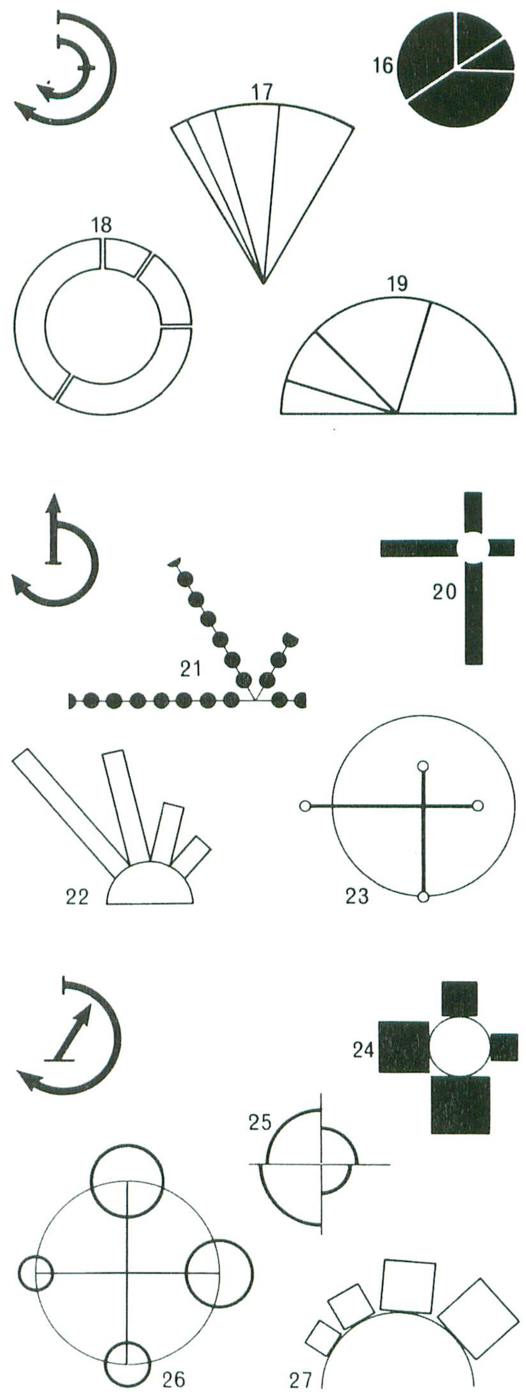
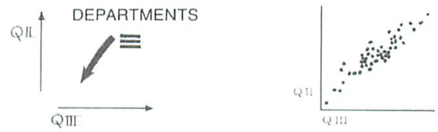
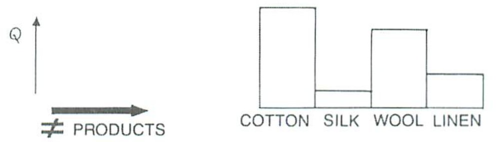
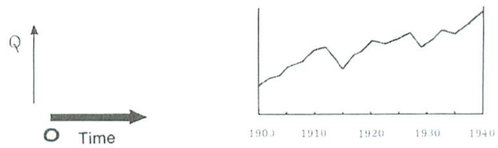
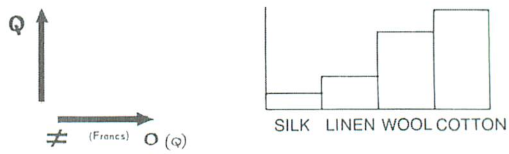


TABLE OF LEVELS AND IMPOSITIONS

To define a graphic construction, we will use the conventional signs below. They enable us to analyze all imaginable constructions and to indicate *schemas of construction* for them. When applied to the most efficient constructions, these signs denote *"standard" schemas*.

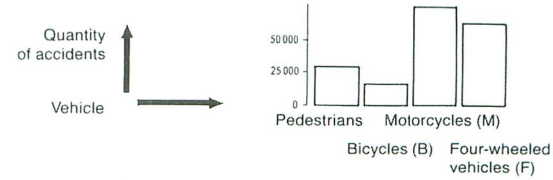
LEVEL OF ORGANIZATION OF THE COMPONENTS		EXAMPLES
≡	Component whose elements can all be considered as SIMILAR	
≠	Qualitative component (DIFFERENTIAL)	
O	ORDERED component (not reorderable)	
Q	QUANTITIES	
Q %	Percentage	
log Q	Quantities on a logarithmic scale	
REORDERABLE component, ordered by quantities		

UTILIZATION OF THE DIMENSIONS OF THE PLANE

EXAMPLES

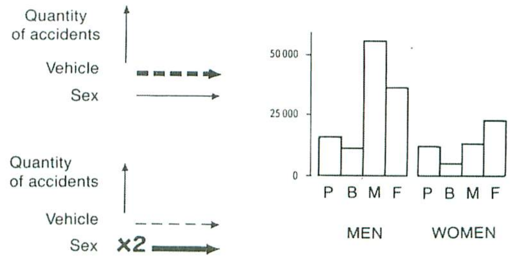
RECTILINEAR UTILIZATION

Dimension of the plane utilized in a HOMOGENEOUS manner (the categories are established once and for all)

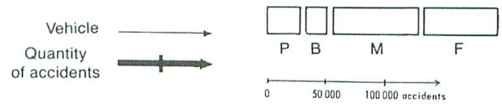


Dimension of the plane utilized in a HETEROGENEOUS manner (the categories are repeated several times)

n indicates the number of images or figures



Dimension of the plane representing CUMULATIVE QUANTITIES

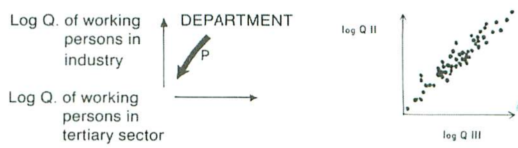


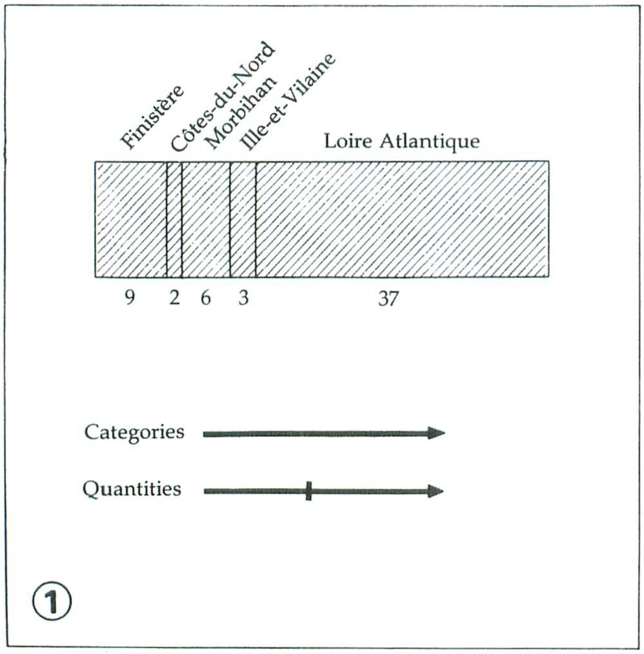
CIRCULAR UTILIZATION of the plane

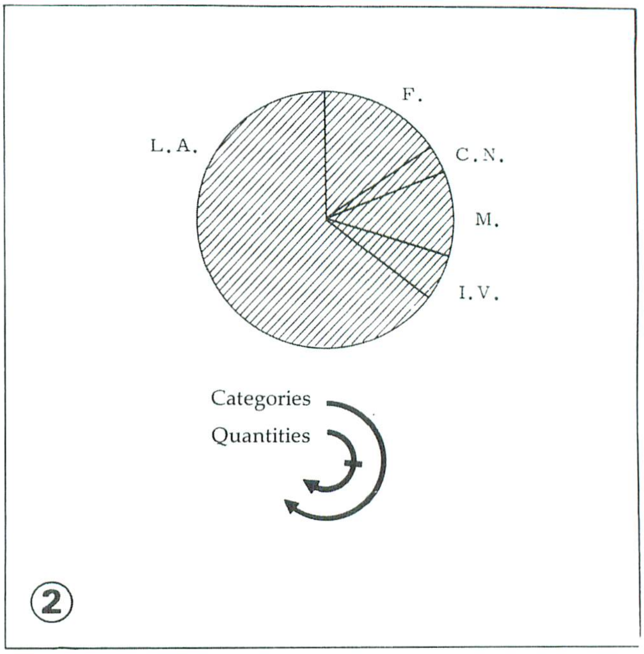
ARRANGEMENT, TREE

RETINAL VARIABLE
(read as an "elevation" above the plane)

POINTS, LINES or AREAS
(not differentiated)







UTILIZATION OF THE PLANE

In cartography, the geographic component occupies the two planar dimensions. Consider the following information:

INVARIANT –*salaried workers in establishments with more than 500 employees*

COMPONENTS –*Q (in thousands of salaried workers), according to*
≠ five departments in Brittany

This information has two components. Its graphic representation must utilize at least two variables, and, depending on the type of construction, will result in *diagrams* (figures 1, 2, or 3).

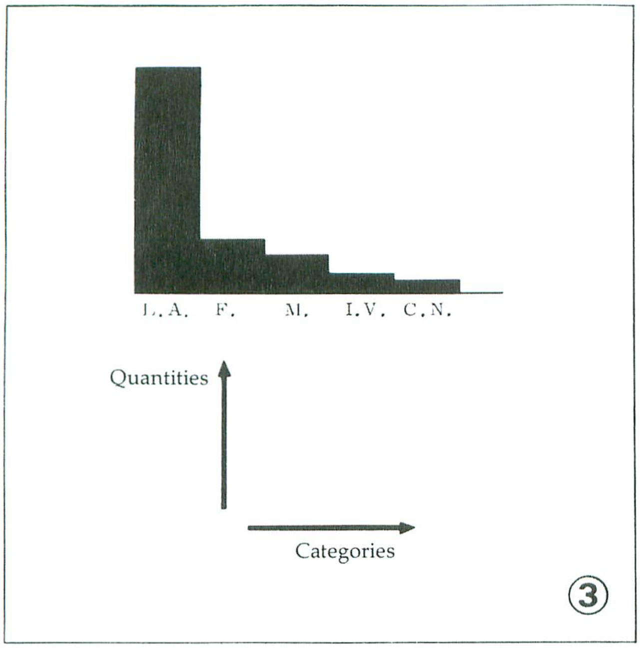
However, the qualitative component ≠ is geographic in nature. The various categories are spatially defined—they are departments—and the information can also produce a *map* (figure 4). In this representation, the reader is invited to superimpose on the natural map, as seen from an airplane, elements which are invisible but nonetheless "real."

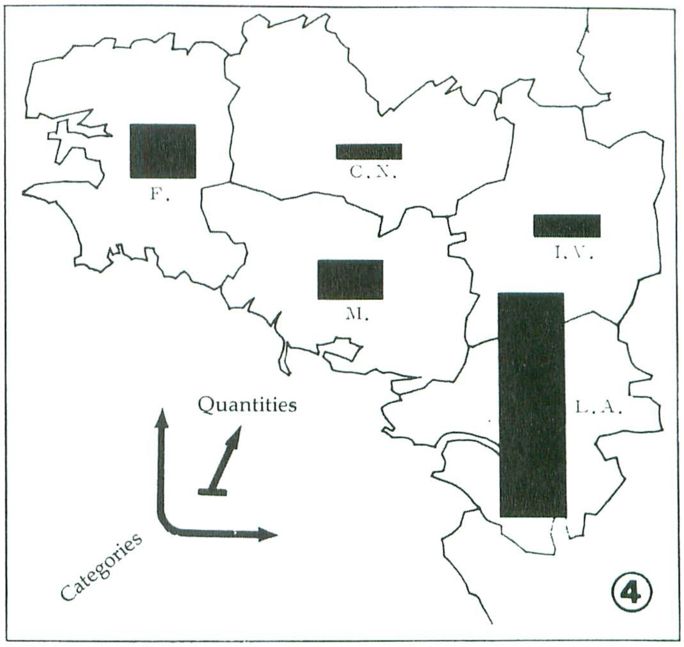
The reader is invited to perceive the sheet of paper, not as a medium, but as a geographic space. The surface of the paper signifies the surface of the earth; an excellent analogy, since space is utilized to signify space.

This is more natural, more readily comprehensible than the analogies used initially in figures 1, 2 and 3, or, say, the correspondence of a planar dimension with time. Perhaps this explains why figurative representation and cartography were used several millennia earlier than the diagram, whose analogies imply a higher degree of abstraction.

However, this natural analogy is obtained at the price of the complete utilization of the two planar dimensions, and it leaves no dimension of the plane available to represent the quantities.

They must become secondary to the geographic



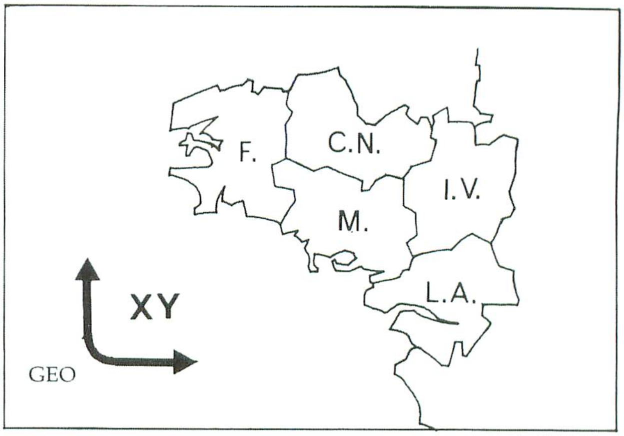


arrangement. The perception of the quantities can no longer be based on the comparison of the juxtaposed elements of a whole, as in figures 1 and 2, nor on the differences in the length of the elements aligned along a base, as in figure 3. Their perception must call upon other visual variables, upon new "stimuli" whose utility was not considered as long as the planar dimensions were sufficient for the representation. In figure 4, it is not so much the height of the column as the amount of "black" which permits perceiving the quantities. This becomes all the more evident as the number of correspondences increases (pages 360 and 374).

When two components occupy the plane, we must seek new variables to represent additional components. These are the "elevated" or "retinal" variables.

C. The retinal variables

With the introduction of a third component into the information (or a second component in cartography), the graphic representation must utilize the retinal variables.



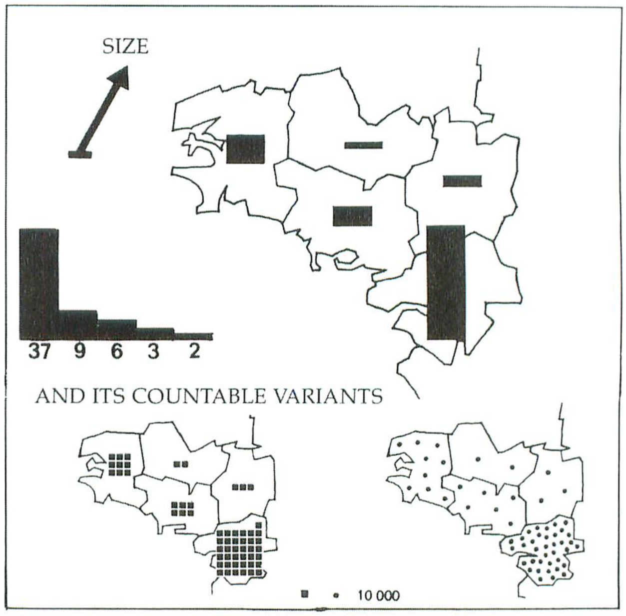
1

THE VISUAL VARIATIONS AVAILABLE "ABOVE" THE PLANE

Experimental psychology defines depth perception as the result of multiple factors:
- binocular vision, within a limit of several meters
- the apparent movement of objects when the observer moves
- a decrease in the size of a known object
- a decrease in the values of a known contrast
- a reduction in the known texture of an object
- a decrease in the saturation of the colors of known objects
- deformations of orientation and shape (perspective).

All these variations, with the exception of the first two, are at the disposal of the graphic designer, who can use them to add a third component to those of figure 1, for example. The designer can relate the categories of the additional component with any one of these variables:

- categories of **SIZE**: height of a column, area of a sign, number of equal signs (figure 2)



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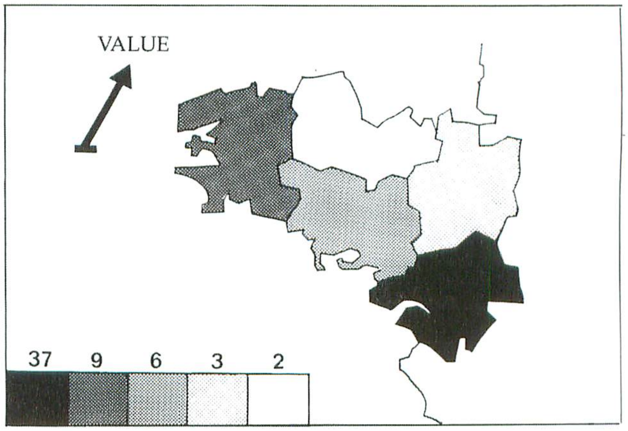
- categories of **VALUE**, the various degrees between white and black (figure 3)



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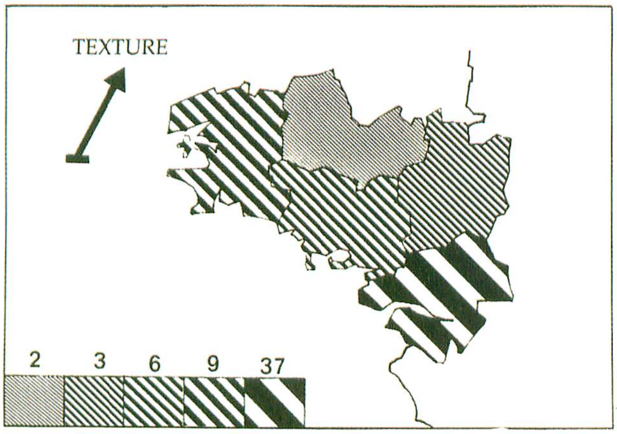
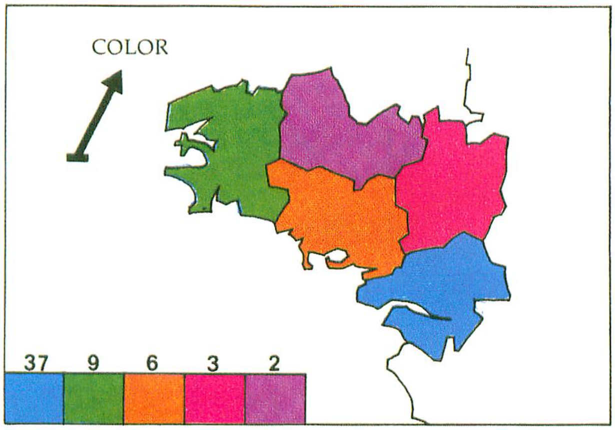
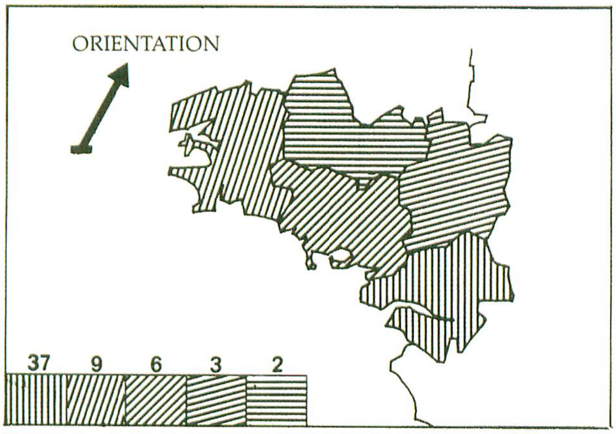


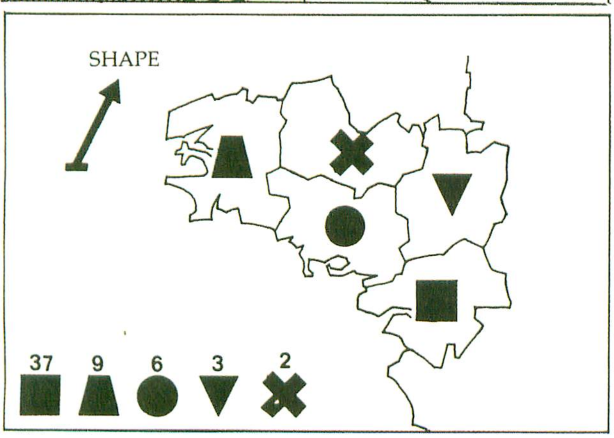
4 – categories of **TEXTURE**, that is, with a variation in the fineness or coarseness of the constituents of an area having a given value (figure 4). This variation can be obtained by enlarging or reducing a ruled photographic screen



5 – categories of **COLOR** (hue), using the repertoire of colored sensations which can be produced at equal value (figure 5)



6 – categories of **ORIENTATION**, various orientations of a line or line pattern, ranging from the vertical to the horizontal in a distinct direction (figure 6)

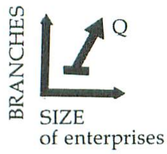


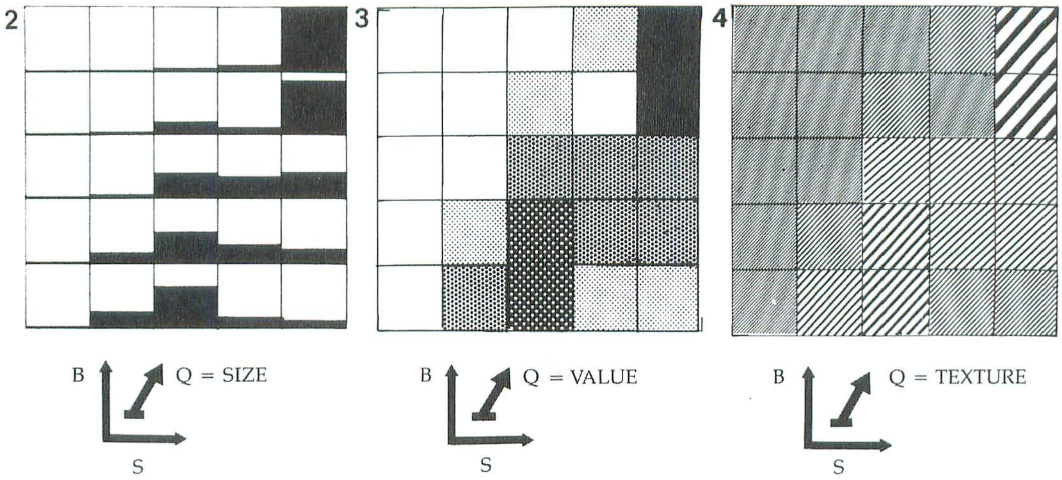
– categories of **SHAPE**, since a mark with a constant size can nonetheless have an infinite number of different shapes (figure 7).

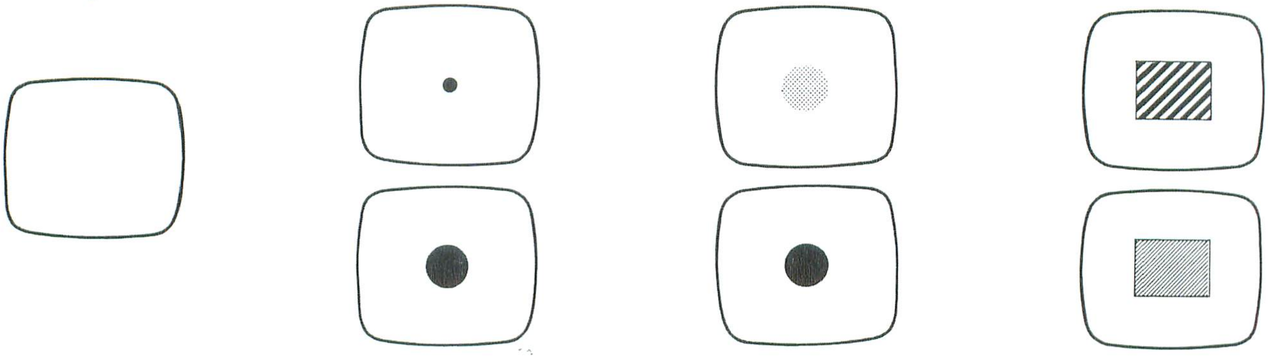
7 Thus any retinal variable can be used in the representation of any component. But it is obvious that each variable is not suited to every component. It is the notion of level of organization which provides the key to solving this problem.

1

1	1	4	10	84
1	3	16	9	71
1	5	32	29	33
1	14	42	24	20
1	21	53	14	11







8 9 10 11

PLANAR DIMENSIONS AND "RETINAL" VARIABLES

The use of retinal visual variables is not required by cartography alone. It is necessary in all graphic problems involving three or more components, when the two dimensions of the plane are already being utilized.

Consider the information: amount of salaries, distributed according to branches of the economy and size of enterprise.

INVARIANT —*amount of salaries distributed by enterprises*

COMPONENTS —≠ *five branches of the economy (commerce, energy, transportation, industry, service)*
—Q *(salaries) in % per branch of the economy, according to*
—O *five, business enterprise size-categories (0, 1–5, 6–100, 101–500, more than 500 employees)*

The quantities are given in figure 1. As in the map of Brittany (figure 1, page 60), the two dimensions of the plane are utilized; the branches on one axis, the size of the enterprises on the other. Retinal variables must be called upon once again to represent the quantities, as illustrated in figures 2–7. In order to choose the best representation, we must determine what distinguishes the planar dimensions from these variables and what characterizes the different retinal variables.

When the planar dimensions represent two components of the information, they constitute an image, whose organization and basic form are established once and for all. They lend the plane a meaning which translates into quantities, categories, time (in diagrams), or space (in maps). They also define the field of vision. Beyond its frame the plane once again becomes a sheet of paper; it no longer has a meaning or else it changes in meaning to support another image. Visual "scanning" is thus involved; the reader perceives the planar dimensions through the intermediary of eye movement. Overall perception of the plane depends on "muscular" reactions of the optic system.

The retinal variables are inscribed "above" the plane and are independent from it. The eye can perceive their variation without requiring movement.

One could thus imagine a frame (figure 8) in which two

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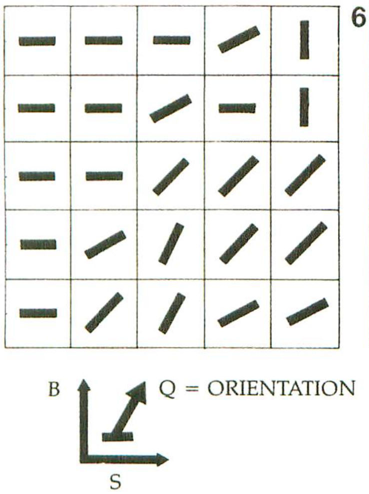

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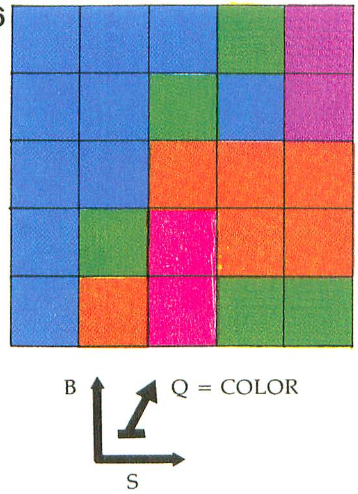

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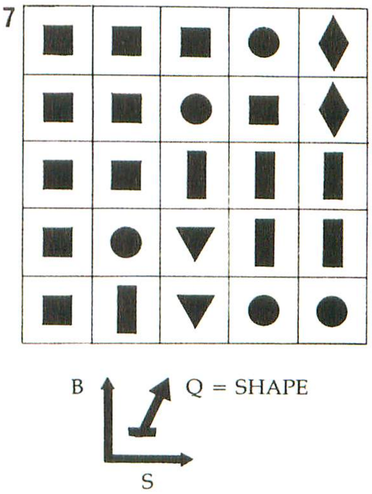

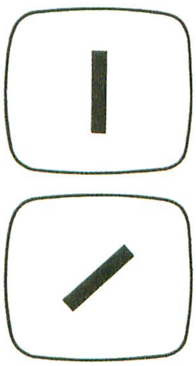

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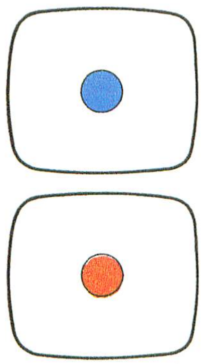

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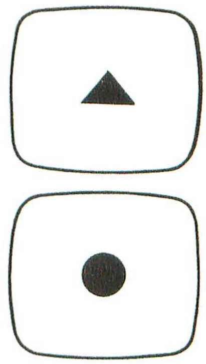

14

different examples of each variable would appear successively, in the same place. This is shown in figures 9–14. No muscular movement is required in order to distinguish between the two examples. These variables rely upon other visual reactions in which scanning does not seem to intervene in a significant manner.

In order to distinguish them from "muscular" responses, we will speak here of "retinal" responses and consequently of retinal variables.

On the scale of ordinary perceptions, which alone interest us here, the retinal variables are physiologically different from the planar dimensions. However, with a very large point, for example, there exists a limit beyond which it is no longer visible as a point. Perception must then call upon "muscular" movement, and the point becomes meaningless in terms of the retinal perception designated by the legend (and reinforced by the other signs). We will now examine the perceptual properties of each of these retinal variables.