Semiology of Graphics

Diagrams Networks Maps

JACQUES BERTIN

TRANSLATED BY

William J. Berg

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Howard Wainer, Technical Editor

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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 atemporal 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.

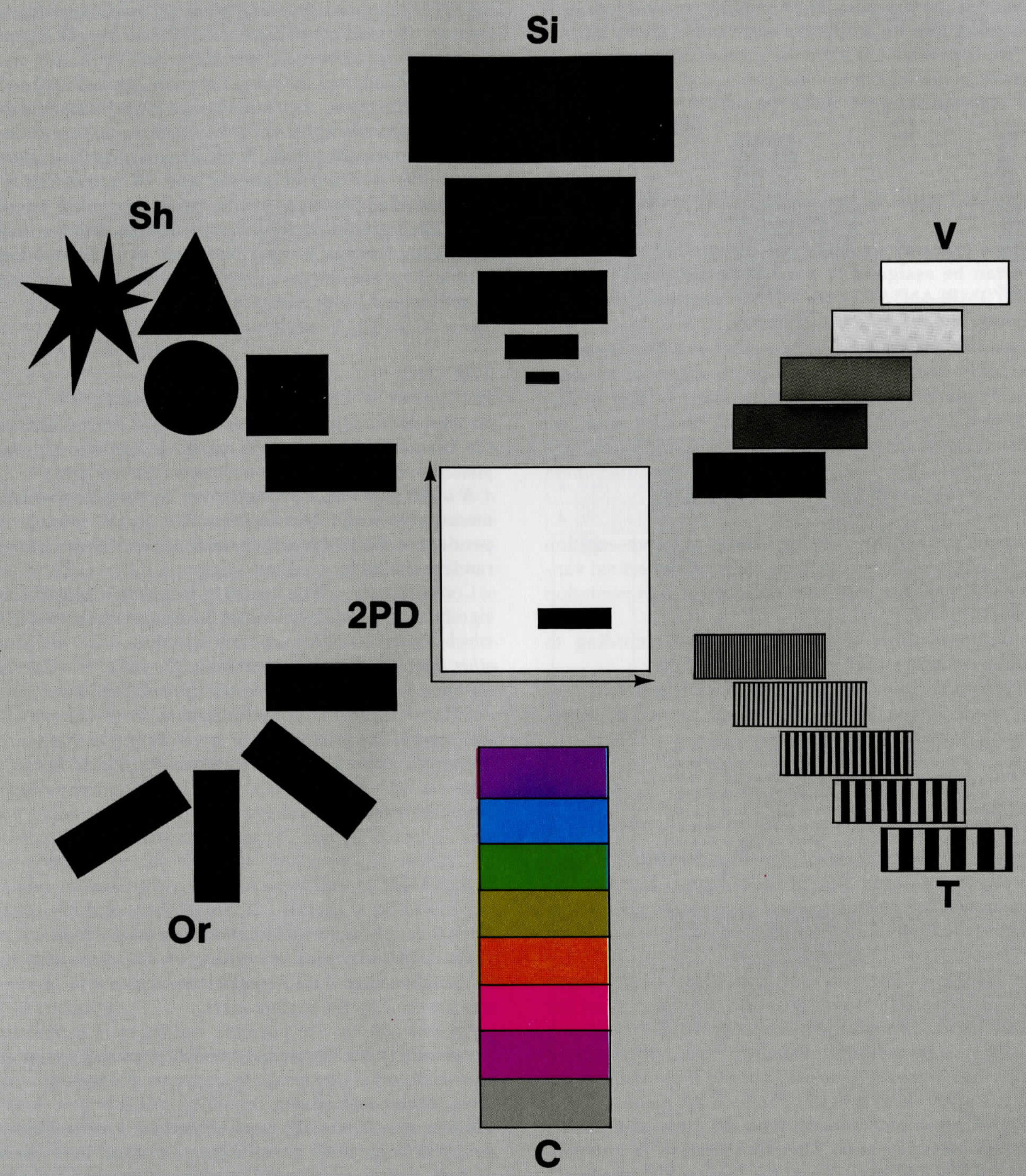
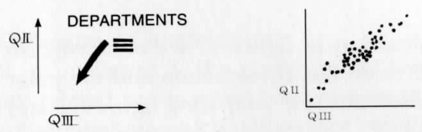
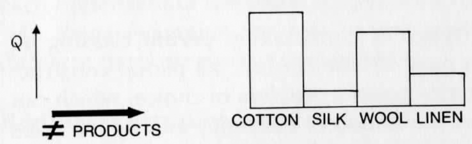
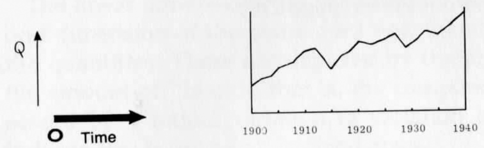
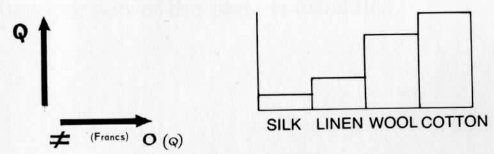
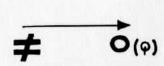
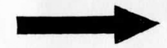
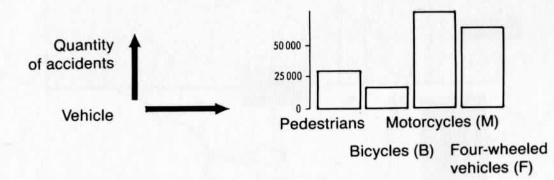
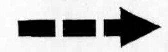
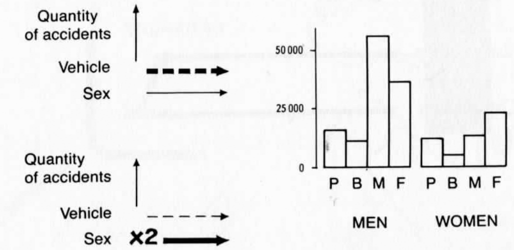
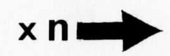
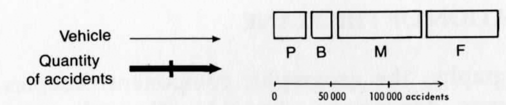
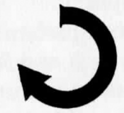
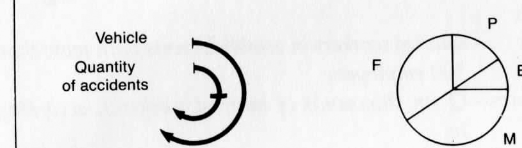
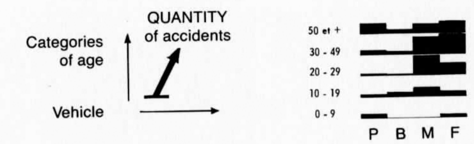
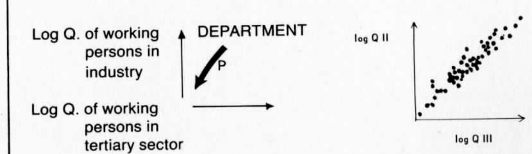


TABLE OF LEVELS AND IMPOSITIONS

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)	

C. The Retinal Variables

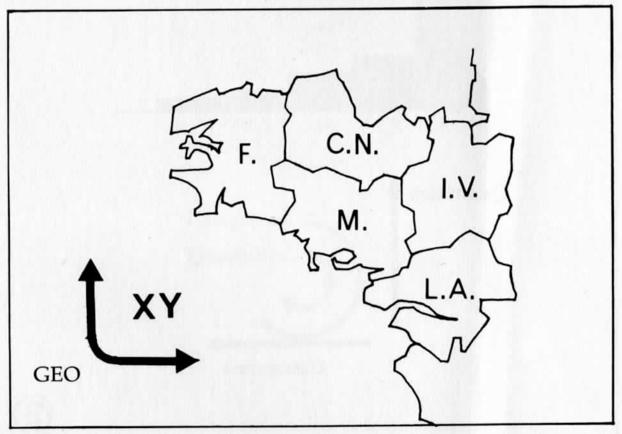
With the introduction of a third component into the information (or a second component in cartography), the graphic representation must utilize the retinal variables.

THE VISUAL VARIATIONS AVAILABLE "ABOVE" THE PLANE

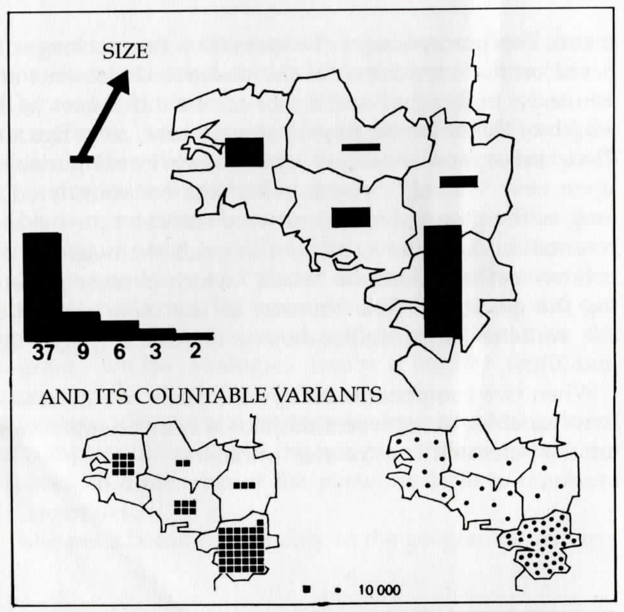
Experimental psychology defines depth perception as the result of multiple factors:

—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:

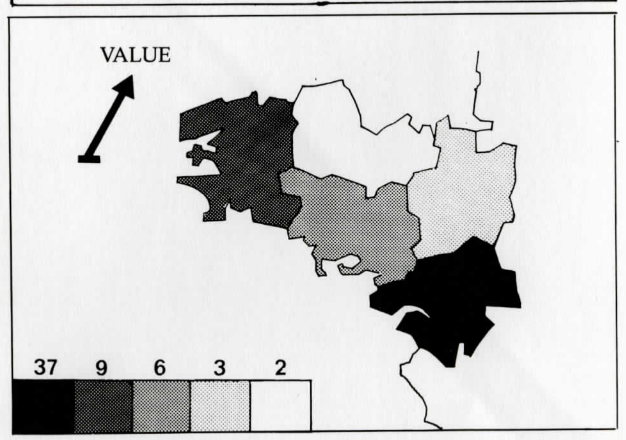


1



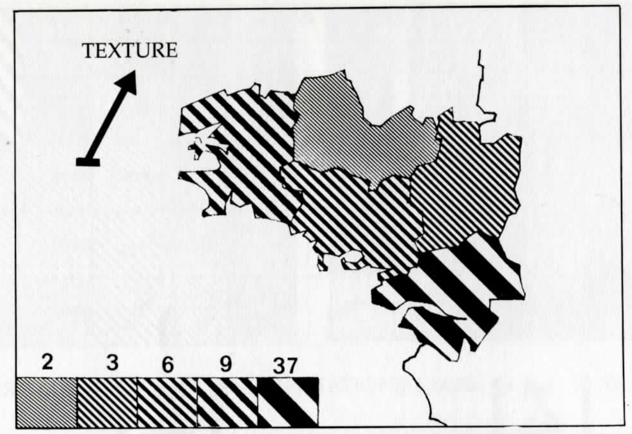
2

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



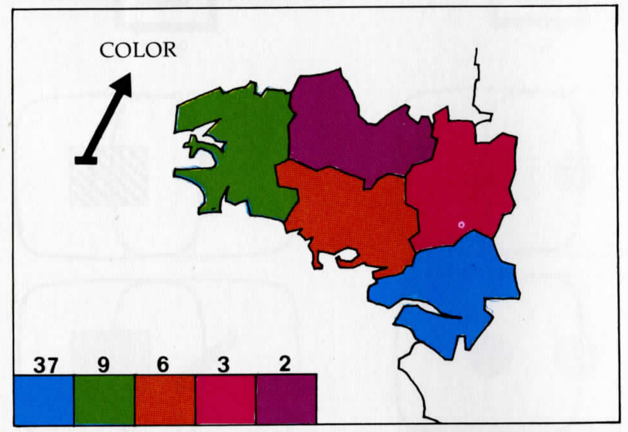
3

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



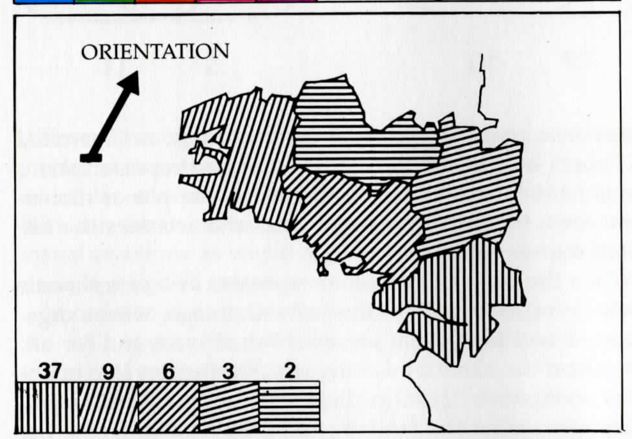
4

—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)



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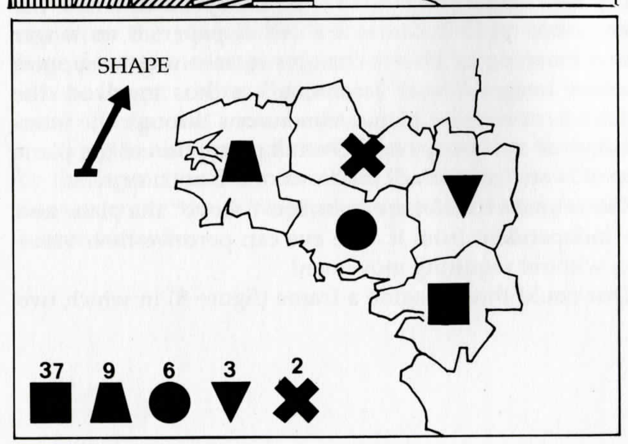
—categories of **ORIENTATION,** various orientations of a line or line pattern, ranging from the vertical to the horizontal in a distinct direction (figure 6)



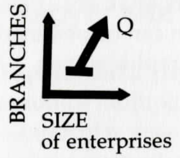
7

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



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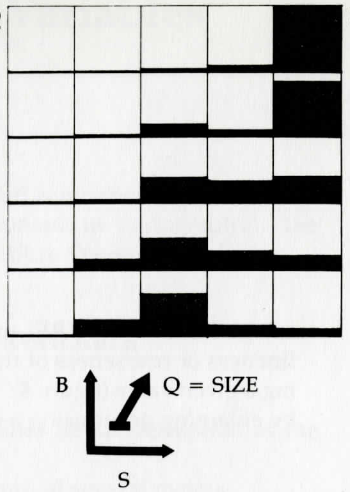

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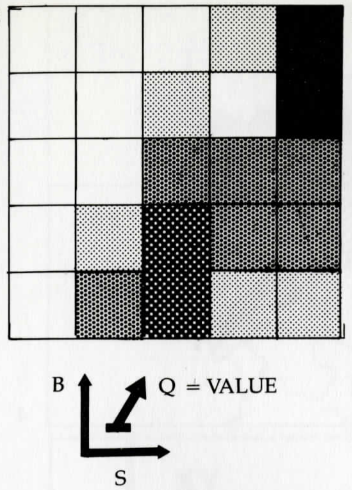

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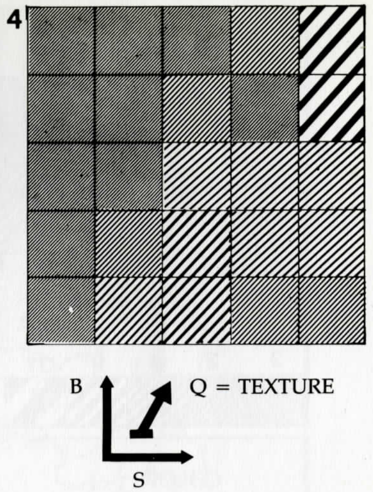

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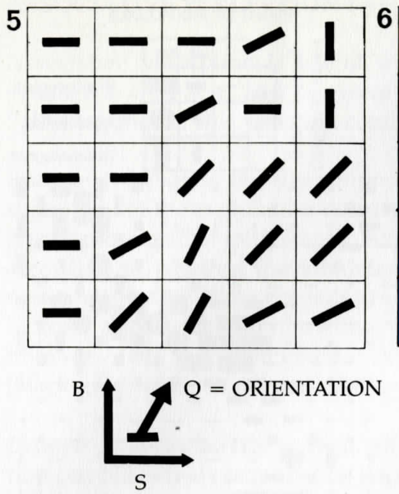

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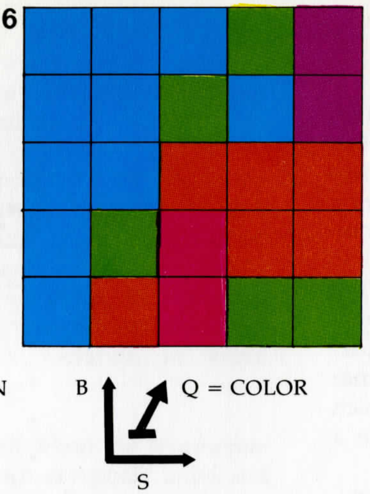

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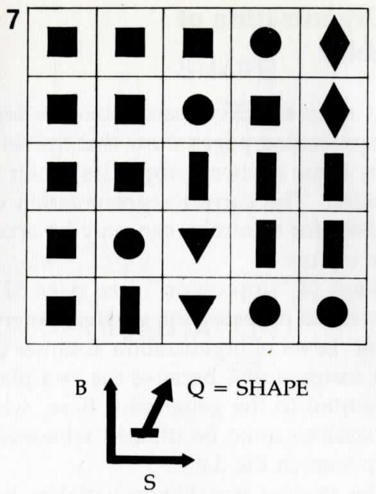

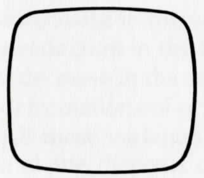

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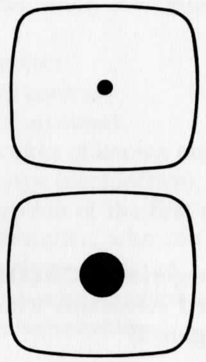

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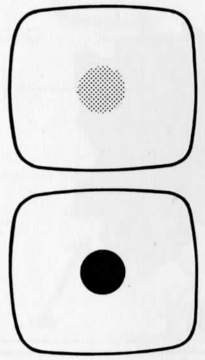

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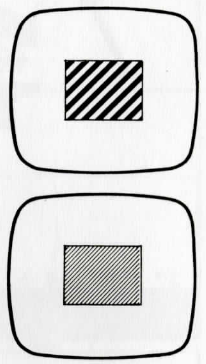

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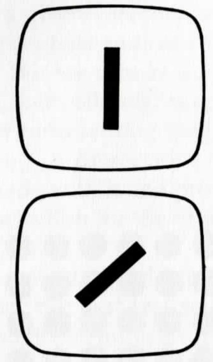

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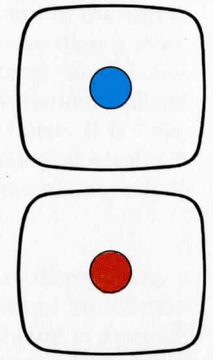

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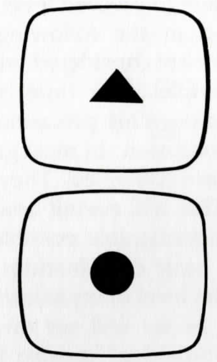


14

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 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.

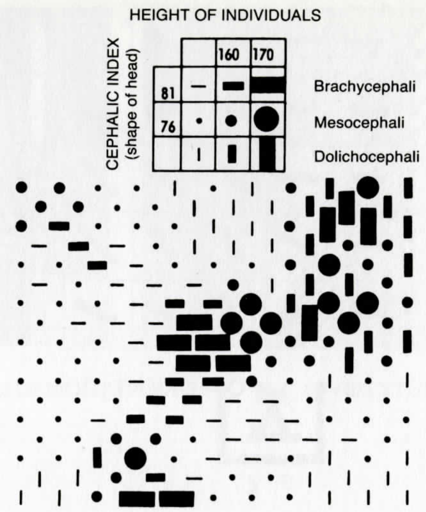
1. The Level of Organization of the Retinal Variables

While the plane is at once selective, associative, ordered, and quantitative, the preceding pages show that the retinal variables possess only some of these properties. Their levels of organization differ. The correct representation of a quantitative component, for example, can only be accomplished by a variation in size.

Along with the notion of "imposition" (see page 52) in diagrams, that of "level" is probably the greatest potential source of graphic error. Level of organization assumes particular importance in cartography, because the two planar dimensions are committed to the geographic base, which means that retinal variables must be utilized whenever a second component appears in the data.

This notion could be studied variable by variable; however, it seems more useful here to proceed level by level.

The visual variables used in the following tests are "pure" variables; that is, they are considered with all other variation excluded. For example, color (hue) variation is considered for one given value. This precaution is indispensable in order to avoid confusion. In most graphic constructions several variables are combined. They must first be examined individually. This will permit analyzing and understanding each of the innumerable possible combinations. There are sixty-three basic combinations for differentiating two point signs! The level of organization of each one of these combinations, as we will see on page 186, corresponds to that of the individual variable having the highest level of organization.



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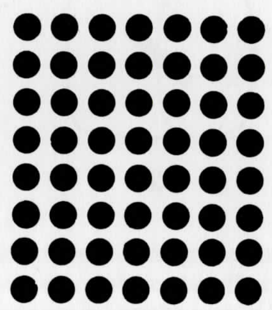

2

ASSOCIATIVE PERCEPTION (≡)

Associative perception is useful when one is seeking to equalize a variation, and to group correspondences with "all categories of this variation combined."

Example 1: What is the distribution of the density of the signs, and of the population density, in a map where each sign represents 500 inhabitants, but where the signs differ according to whether the inhabitants are farmers, herdsmen, or nomads? If the nomads are in black, the herdsmen in gray, and the farmers in white, only the density of the nomads will be perceived. A variation in value (black-gray-white) is not associative.

Example 2: Associativity is required when the representation combines two components, such as cephalic index and height of individuals, as in figure 1. The eye can easily isolate a given category of height by grouping the signs, with all cephalic indices combined. Shape variation is associative. But we cannot immediately isolate all the dolichocephali, with all heights combined. Size variation, utilized here for representing height, is not associative. It is "dissociative." A dissociative variable dominates all combinations made with it and prohibits carrying out an immediate visual selection for the other variables.

Test for associativity. Since it is a question of disregarding a variation, the best test seems to be a series of undifferentiated points forming a uniform area, as shown in figure 2. If the eye can immediately reconstruct the uniformity of the area, in spite of a given visual variation, this variation is associative (≡). If not, it is dissociative (≠).

The tests given in figures 3–8 show that SIZE and VALUE are dissociative, while all the other variables are associative. The same is true for line and area representations.

Visibility

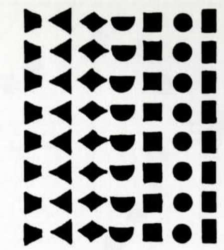
All the signs in figure 2 appear to us with the same power. They have the same visual "weight" or "visibility."

An associative variable does not cause the visibility of the signs to vary.

Signs differentiated by size and value appear to us with different power, and our moving away from the images, for example, would cause the signs to disappear in succession. They do not have the same visibility.

A dissociative variable causes the visibility of the signs to vary.

SHAPE
≡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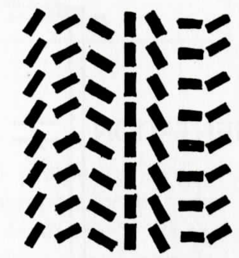
ORIENTATION
≡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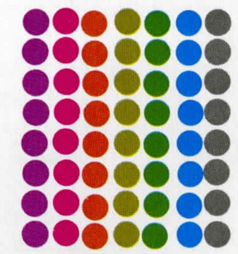
COLOR
≡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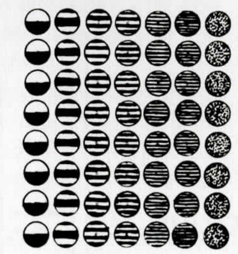
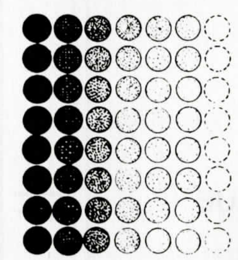
TEXTURE
≡


6

VALUE
≠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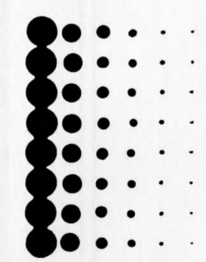
SIZE
≠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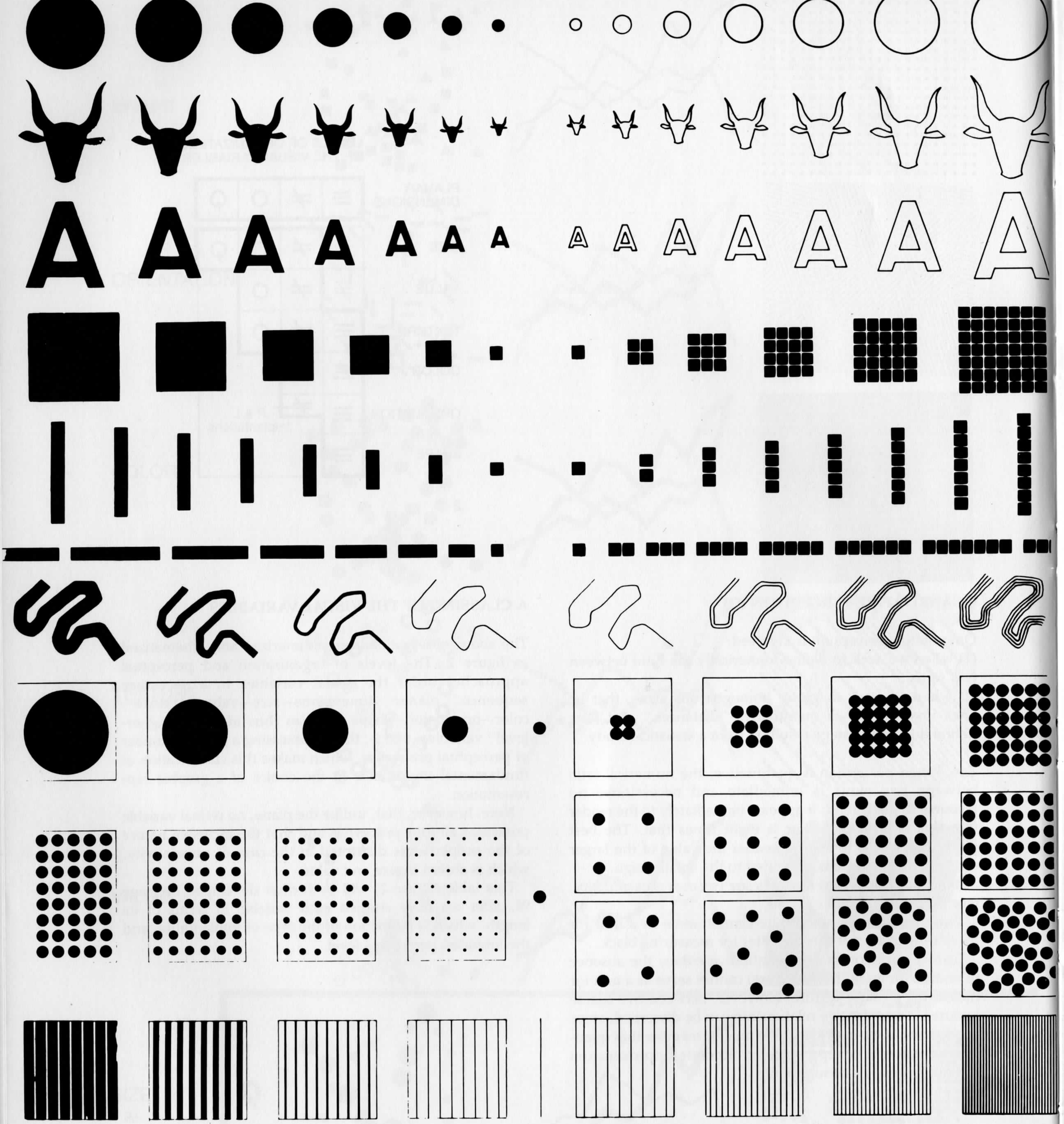


2. Characteristics and Properties of the Retinal Variables

SIZE VARIATION

In point or line representation, any figure can vary in size without varying in position, value, texture, color, orientation, or shape.

It is a variation in the dimensions of the mark (area) which constitutes the perceptual stimulus for size variation.

Implantation

In *point representation,* the figure can assume many forms: It can be geometric or mimetic; it can be a column of proportional height; it can be formed by parts which are joined and countable. The extent of variation is very large in point representation; we can, for example, usefully construct two visible points, one of which has an area 10 000 times larger than that of the other (pages 182 and 363).

In *linear representation,* a line can be made to vary in thickness.

We can also juxtapose countable parallel lines. However, the extent of variation will be limited if the lines converge, as in a highway network.

In *area representation,* the area cannot vary in size. But its constituent points or lines can vary in size and number. Here, the extent of variation is limited by the size of the area involved. However, it is possible to construct several circles or figures which extend beyond the area (page 373).

Length

In quantitative perception and ordered perception, the number of possible steps is unlimited, but on the average the eye will not distinguish more than twenty steps between two points whose areas are in a ratio of 1 to 10. This limit has caused us to propose a "natural series of graduated sizes," indicating the steps which are necessary and sufficient for any quantitative representation (page 369).

Perception

With *selective perception,* size variation is very limited. In the circumstances that occur in an average drawing, it is not advisable to count on more than four or five selective steps (such that one can isolate and precisely define the form constituted by all the points of a given size). *Size variation is dissociative,* and it is not possible to disregard it visually. Any other variable combined with a size variation will be dominated by it, and its length will diminish accordingly. With very small points, color, for example, becomes practically imperceptible.

The combination of size and value. Since value is also dissociative, a size variation will be perceptible only for signs having a dark value. Black or white signs can even deprive the size variation of all of its immediate properties.

PRINCIPAL SOURCES OF CONFUSION IN THE USE OF VALUE VARIATION

Value Is Ordered, and We Cannot Reorder It

In figure 1 (death rates in Paris [number of annual deaths per 1000 inhabitants]), the designer was not careful to order the grays according to the order of the death rates. The figure must be read point by point, and it is only through considerable mental effort that the information can be grasped. Visual evaluation of the image would be erroneous.

When the two orders correspond (figure 2) the image becomes meaningful, and its retention useful.

Value Is Not Quantitative

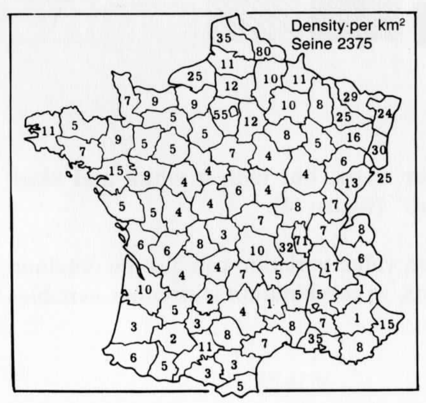
When oil consumption in Europe (1954) is portrayed by a value variation, as in figure 3, only the order in which the consumptions are classed is indicated. Even if it is known that Portugal consumes one million tons, the image by itself permits no evaluation of consumption in the other countries. The reader is dependent upon a legend. Visual means are underemployed.

However, if a size variation is used, ratios are perceptible and evaluations are possible (figure 4).

The population of the various sections of Paris, as represented in figure 5, indicates the order of the sections by population size. However, this image produces an erroneous impression of the concept—population—because an area representation suggests the notion of density. But we can see from figure 6 that the representation of density gives a very different image.

The representation of quantities by value obliges the designer to transform a series of numbers into a series of numerical classes. There are several rules for doing this. But the problem is precisely that there is no single rule; the reader never sees more than a certain choice of steps, among all the possible ones.

The maps in figures 8–11 all represent the same information that is given in figure 7, i.e., the working population in the industrial sector in 1954. Depending on the particular design, each reader will form a different image of the same information. The only image which does not involve a prior choice of class intervals is figure 12, where the quantities are represented by proportional circles.



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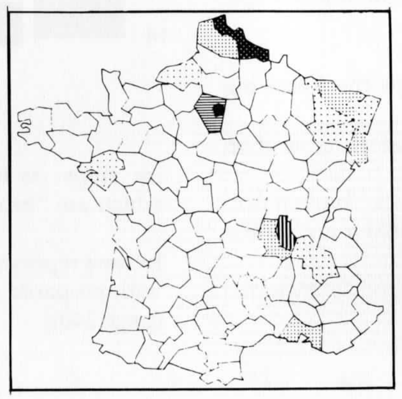
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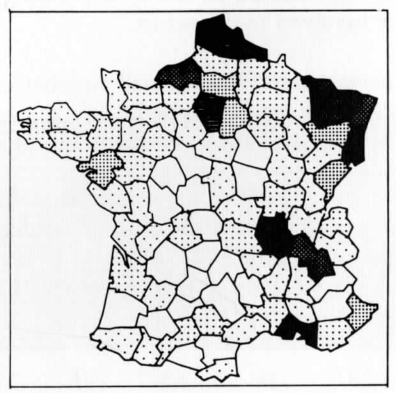
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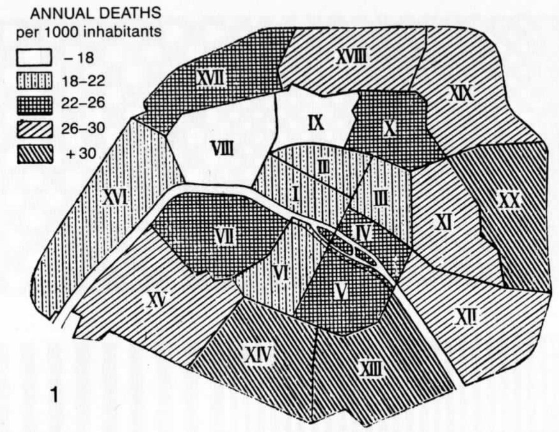

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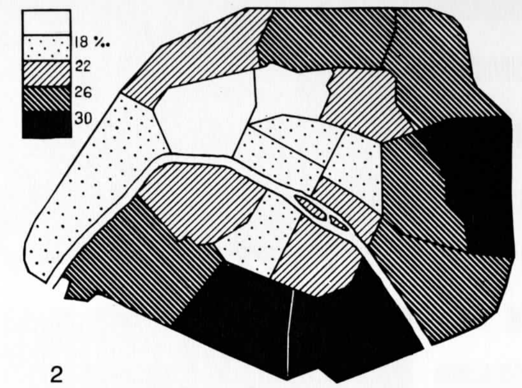

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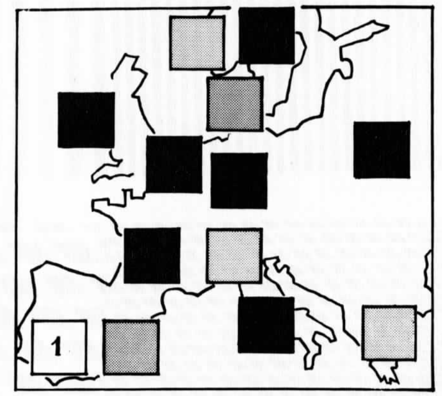

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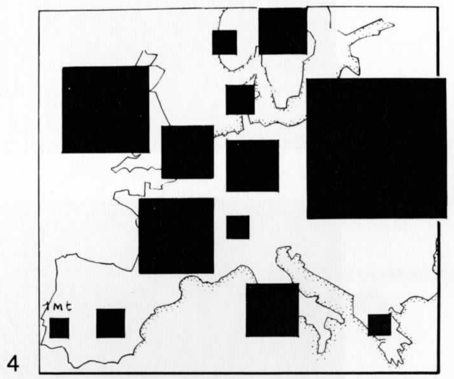

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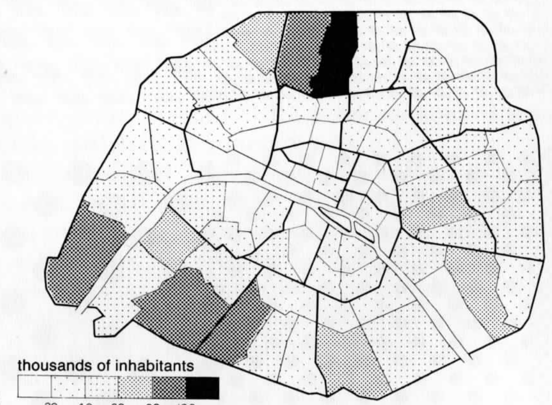

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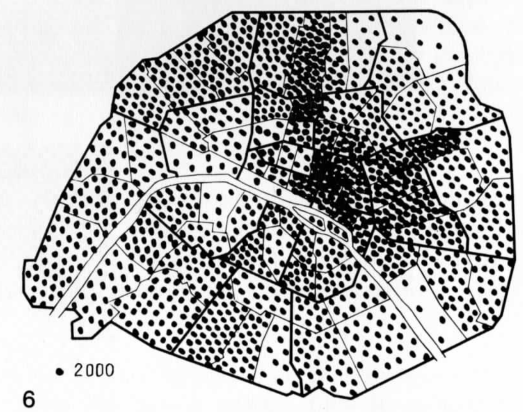

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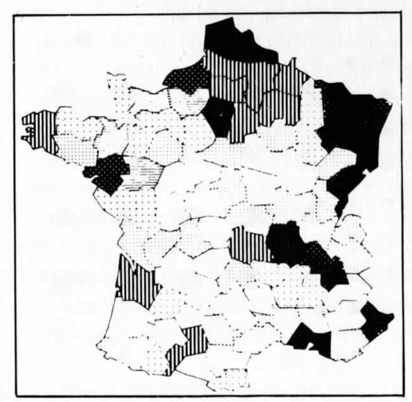
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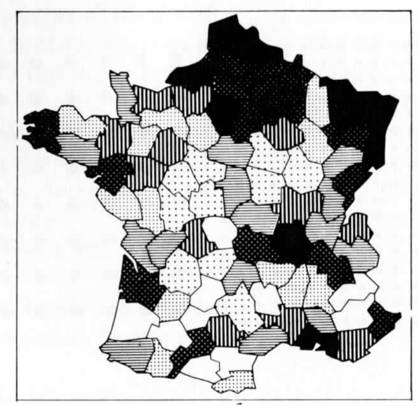
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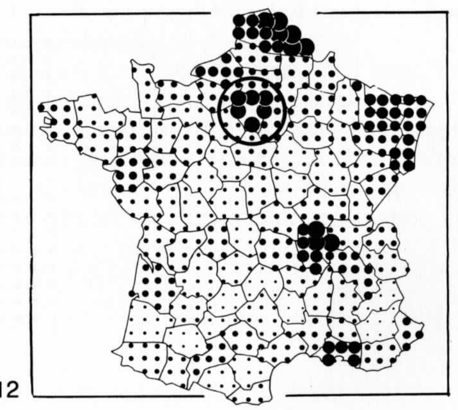
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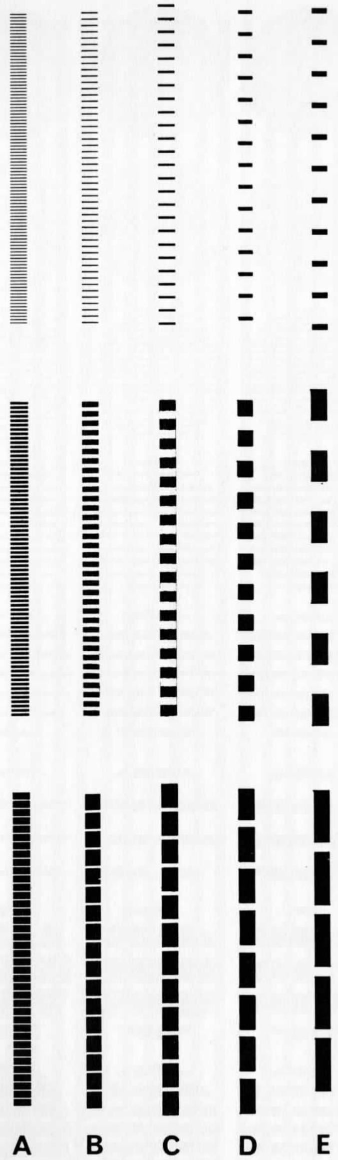

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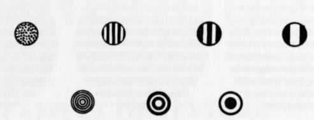

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The Vibratory Effect in Linear Representation

This effect is easy to obtain (see figure 2B, C, and D), and it determines the selectivity of texture in linear representation. (The value variation runs from figure 1 to 3, and the texture variation from A to E.)

The Vibratory Effect in Point Representation

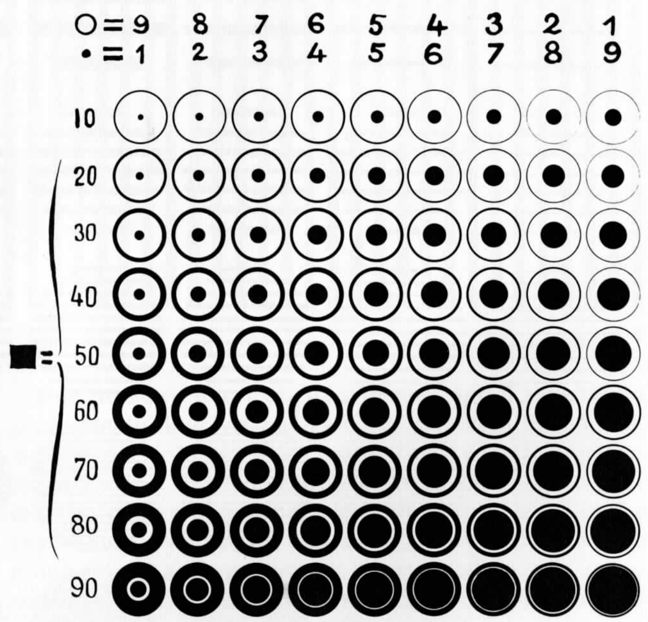
Providing the signs are large enough (larger than 2 mm, approximately), this vibratory effect can be produced in two ways:

(1) by a variation in *internal complexity* within a given shape, as in figures 4 or 5.

But among all the possibilities for construction of figure 5, what sizes of the white ring yield the best vibratory effect?

The table in figure 7 combines variations in the arrangement of the ring (from left to right) and variations in value (from top to bottom). A cyclical construction (figure 8) emphasizes the power of this effect, which dominates the value variation. This construction confirms that it is in values of 50% to 60% and around the designs marked by a cross in figure 8 that the effect is at a maximum.

(2) by a variation in the *external complexity* of a sign, that is, by contrasting the circle, the cross, and the dash (figure 6). In terms of perceptual effect, this variation approaches that of texture. It tends to create, within the limits of the sign, a zone of vibratory confusion and ambiguity. Owing to this effect, the circle, the cross, and the dash are the three *shapes* which, within certain limits, allow for a selective perception. However, these three signs are not visually ordered.



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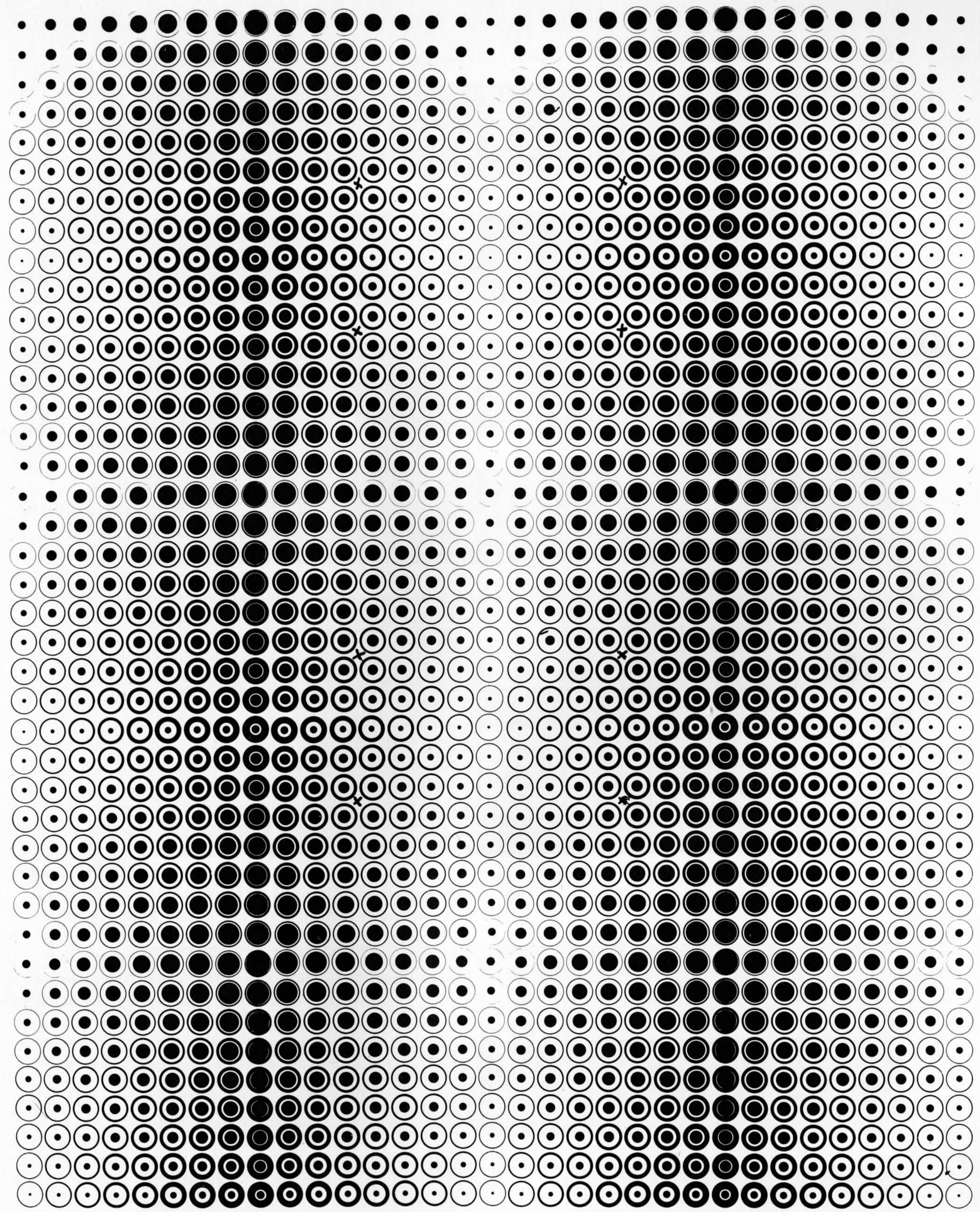
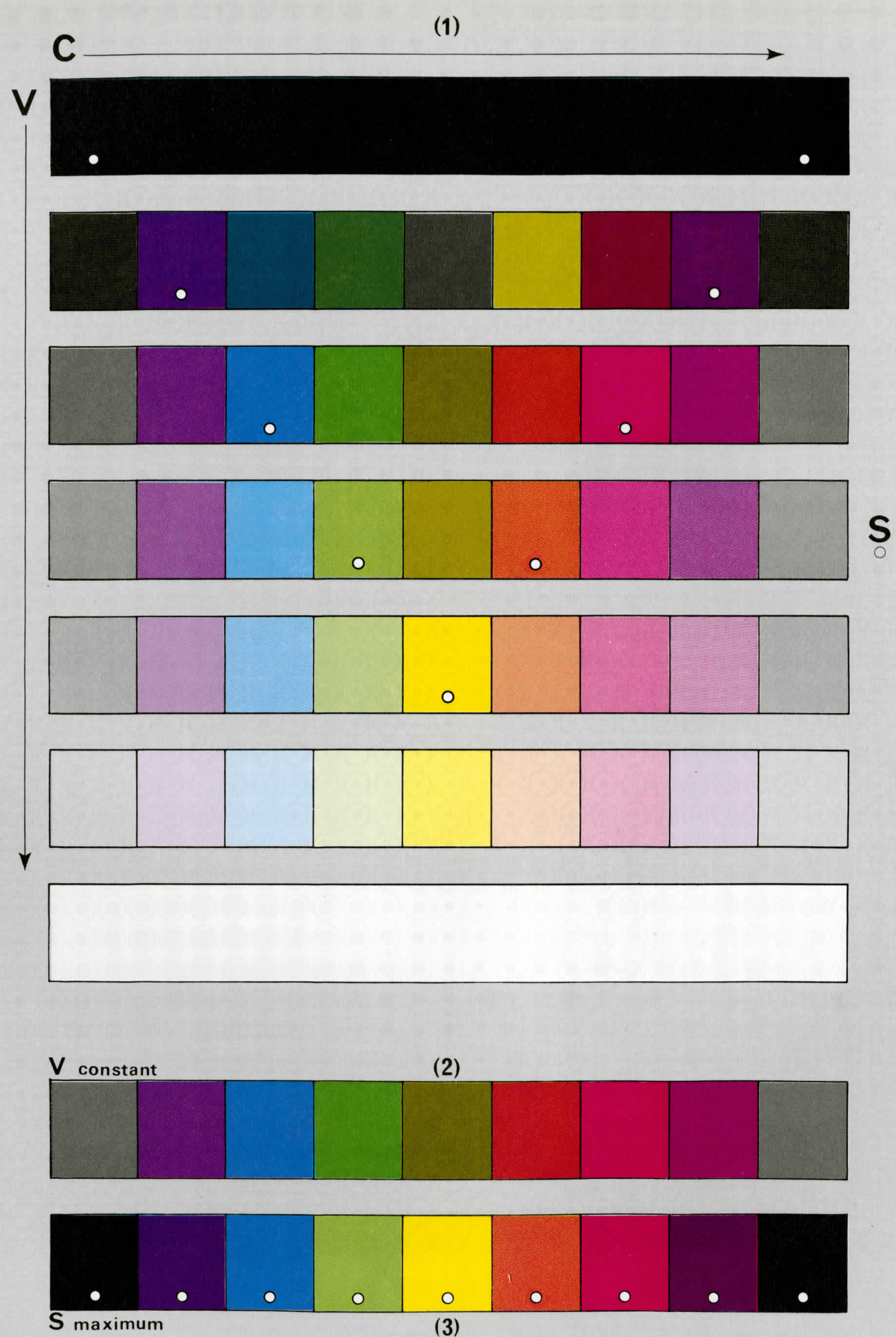




COLOR VARIATION

The use of color cannot be understood unless the notion of color (hue) is distinguished in a rigorous and definitive manner from the notion of value. They are two different sensations, which, by nature, overlap. We have already defined what we mean by value variation.

COLOR variation is simply the perceptible difference which can be perceived between uniform areas having the same value.

In the double-entry table (figure 1), which represents the color–value combination, it is clear that we can pass through the entire series of colors without changing in value (from left to right), just as we can pass through the entire series of values within each color (from top to bottom).

Each of the boxes in figure 1 is a TONE. A tone placed on a sheet of paper is therefore defined by two parameters: color (hue)* with the categories violet, blue, green, yellow, orange, red, purple, gray (or neutral tint);† and value, defined by the percentage of black in the corresponding gray.

Color Saturation

In order to construct the entire series of values, it is necessary, no matter what the color chosen, to add some white in order to obtain light values, or some black in order to obtain dark values. For each color, there is a central value which does not require the addition of white or black. In this privileged value the color, being neither "washed out" with white (desaturated), not "soiled" by black (darkened), appears as most brilliant. This is the "pure tone" in painting, printing, and colorimetrics. It is the "saturated tone" in experimental psychology.

White corresponds to the addition of all other colors, black to the diminution of all reflecting power. The saturated tone corresponds then to a color involving no mixture with other colors, that is, to a very thin band on the color spectrum.

Value and Saturation

The saturated color is marked by a dot in figure 1 opposite. Note that the pure yellow is in row 5, the pure green and orange in row 4, the blue and the red in row 3, the violet and the purple in row 2.

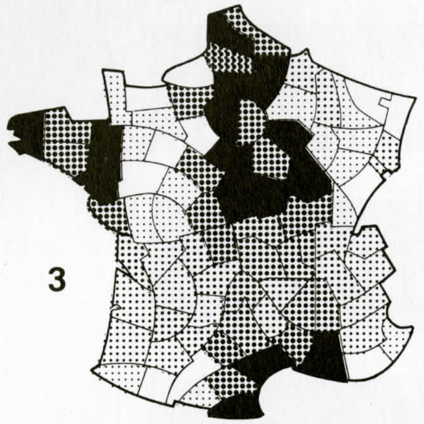
The saturated tone is not of constant value (figure 2), but varies in value according to the color (figure 3).

It is this fact that leads to many of the main problems raised by the use of color. In graphic representation its ramifications are numerous.

TERMINOLOGY

*The word "tint" is too loaded with ambiguity in common language to help us in defining the notion of color. Indeed, we often speak of light or dark tints (value variation), warm or cool tints (color variation), flat or textured tints (texture variation).

†Color variation is the visual sensation resulting from a difference between uniform areas. Thus gray constitutes a color variation in relation to any other color. Conversely, a monochrome drawing in red contains no color variation. (It can be photographed in black and white without loss of information.)



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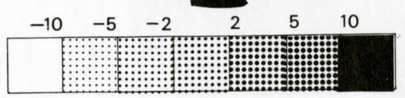

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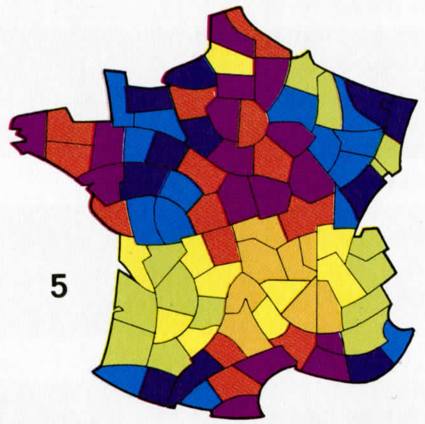

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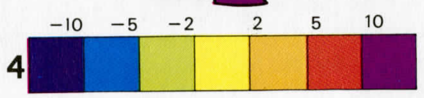

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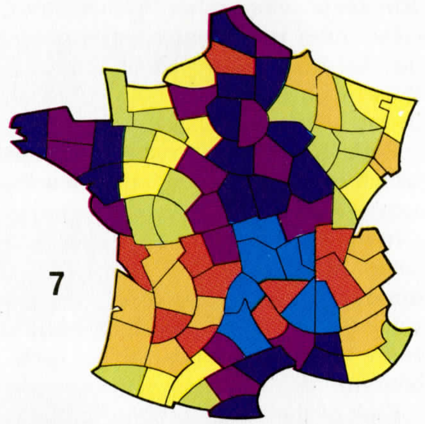

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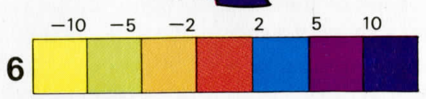

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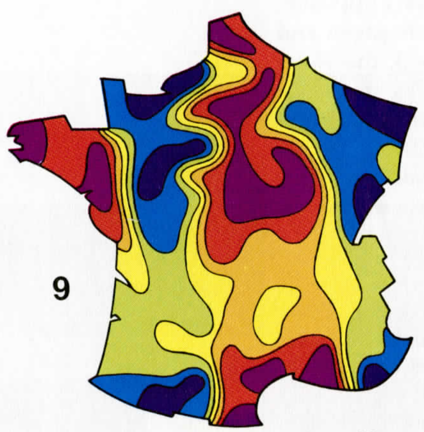

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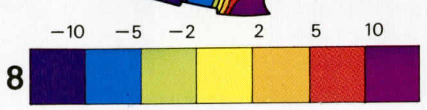

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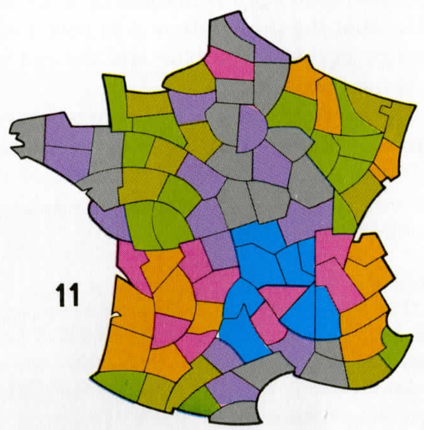

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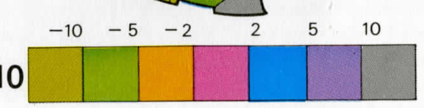

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AT EQUAL SATURATION (MAXIMUM SATURATION)

The Series of Pure Tones Combines Color and Value

If we retain only the pure tones, which is natural since these are the most brilliant, we simultaneously construct a color variation and a value variation. This is the color spectrum represented in figure 4.

Each of the Two Regions of the Spectrum, on Either Side of Yellow, Produces an Ordered Series

The lightest color, near the center of the spectrum, is yellow. But for all the other levels of value the eye encounters two different colors. The order of the values does not correspond with that of the spectral scale.

Immediate Visual Perception Will Follow the Order of the Values and Combine the Two Extremities of the Spectrum

Let us consider the information in figure 1. Represented by a value series (figure 2), it produces the map in figure 3, which is a "North-South" image. Represented by the color spectrum (figure 4), it produces the "East-West" image in figure 5, which is a misrepresentation of the information. Note that it is impossible to disregard this orientation. The eye seems to combine the two extremities of the spectrum into the same perceptual unit, which then contrasts with the unit formed by the central colors. This is because the central colors are "light," whereas the extreme colors are "darker."

Value Perception Dominates Color Perception

In figure 5, blue and red are immediately perceived as similar, rather than different. If this is true, then a legend ordering the colors according to their value (figure 6) will produce an image corresponding to the correct distribution of the information, as we saw in figure 3. This is confirmed by figure 7.

Thus the combination of the "cool" series with the "warm" series is a source of visual confusion in the representation of an ordered component.

Such a combination is only possible with isarithms, where colors which are not adjacent on the spectral scale are never brought together on the plane. The total image is then based on a "warm-light-cool" series (figure 8). The resultant map (figure 9) indeed captures the "North-South" distribution of the information displayed in figures 3 and 7.

AT EQUAL VALUE

Color Variation Is Not Ordered

A color variation without value variation (figure 10) will produce a flat, meaningless image (figure 11). What is properly called color variation is only selective and associative; it cannot be used to represent an ordered component.

The Choice of Selective Colors Differs According to Value

At a given value, that is, on a horizontal row in figure 1 on page 84, there are only two saturated colors (and a single one for row 5). The farther one gets horizontally from a saturation point, the more the other colors, "soiled" by black or "washed out" with white, tend to fuse into grayness.

Selectivity Is at a Maximum Near the Saturated Color and Diminishes as One Moves Away from It

As a result, with *light values,* steps should be chosen around yellow, that is, from green to orange; blue, violet, purple, and red at light value are grayish and not very selective.

Medium values offer the greatest number of selective color steps. The two saturated colors—blue and red—are diametrically opposed on the color circle, and the "grayish" sectors are reduced to a minimum.

When *dark values* are being used, the best colors for making the marks stand out well run from blue to red (through violet and purple). Dark green, dark yellow, and dark orange are dull and not highly differentiated.

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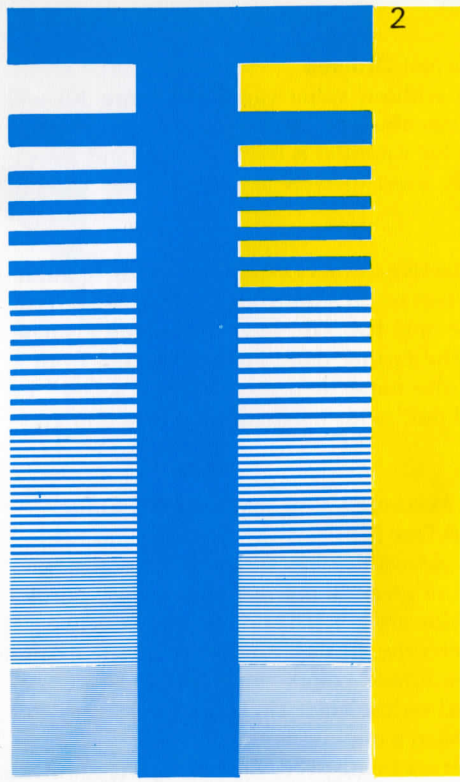

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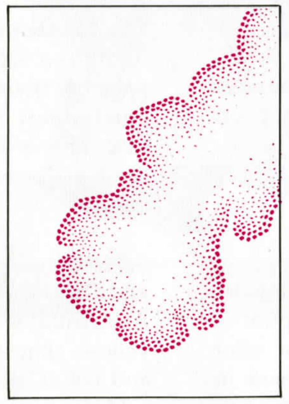

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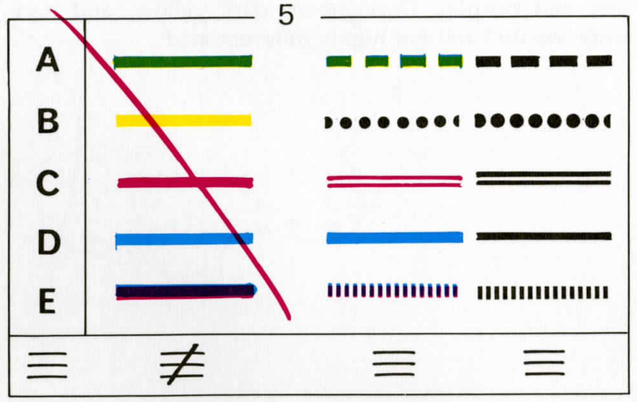

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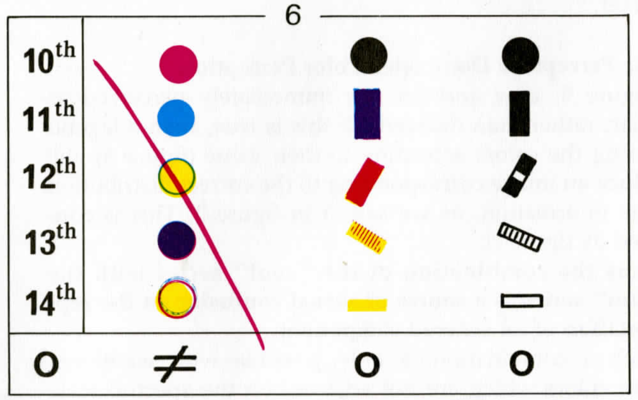

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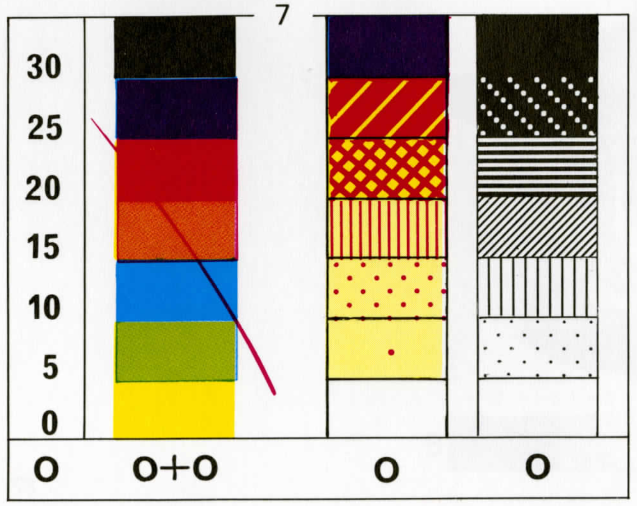

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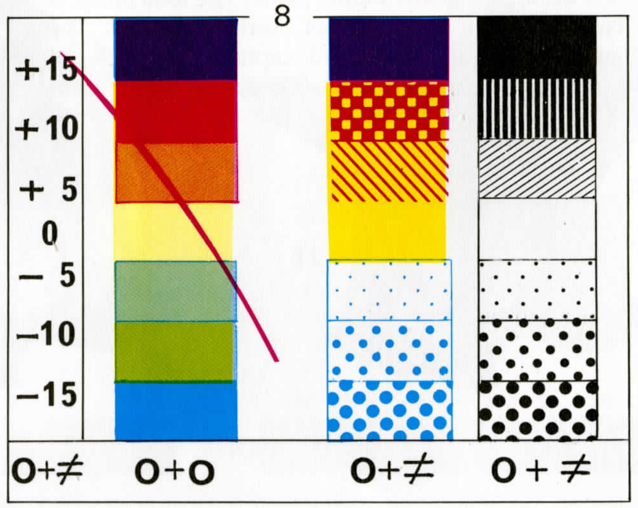

THE SIZE OF THE MARKS AND COLOR "FUSION"

No color sensation is perfectly pure. Nature mixes colors, and the problem is to separate them in space. In order to obtain a color sensation, that is, a perceptible color difference, there must be an area covered with a *uniform color* (similar over the entire area) and contrasting with another area (of *another uniform color*). Obviously, the smaller the areas the more one approaches a natural mixture, and the less the problem is resolved. Any effort at coloration is a struggle against natural mixture, against color "fusion."

The smaller the mark, the less distinguishable are the colors; the length of a color variation is thus a function of the size of the marks.

The marks must be at least 1.5 mm in diameter to usefully support even a very few color variations. On the other hand, it is easy to see a difference between any two colors, no matter how similar, when they are applied over a large area. For very large areas, perceiving a million different separable tones is conceivable.

Color Fusion Permits Us to Create New Colors from Given Colors

Once the problem of separation is more or less resolved, by the use of colored pigments, it is easy to move in the other direction and mix the colors. The eye naturally mixes separate colors, all the more easily when spatial separation is reduced by the arrangement of the marks.

A blue and a white produce, at certain points, a blue, and a light blue, and a white (figure 1). From one area to another, we progressively see the blue becoming altered, the white becoming colored. A blue and a yellow produce, at a certain point, a green (figure 2). This visual property is the basis for:

(1) trichromatic representation. From "primary" blue (cyan), yellow, and red (magenta), virtually the entire spectrum can be reconstructed in a manner sufficient for most common problems (figure 3).

(2) trichromatic analysis. The three primary colors can be used to represent three ordered components. The multiple combinations of the components can then be studied and any regions of the plane corresponding to similar or neighboring combinations can be discovered. They will have the same tone. This is trichromatic analysis (figure 3).

(3) the spatial division which transforms the color of a mark according to the sharpness of its boundaries. Blurred edges favor fusion. The most common graphic application is an arrangement of graded points; it extends its coloration well beyond the last point (figure 4).

PRINCIPAL SOURCES OF CONFUSION IN THE USE OF COLOR

The Colors of the Spectrum Are Dissociative (≠)

The series of pure tones varies in value and, as such, is dissociative.

Yellow is a light color, very near to white. Consequently, line B of figure 5 is not very visible.

In linear (or point) representation, light colors should be avoided. Black can replace them, and the series will have sufficient visibility. Furthermore, it is necessary here and in the following examples to ensure that a black and white photograph of a color graphic would still be comprehensible (see page 90). This is achieved by combining color with other visual variables (shape, texture, and orientation). Finally, we note that in all these examples (figures 5–8), a monochrome legend is, practically speaking, as efficient as color.

Color Is Selective (≠); It Is Not Ordered

The series of points in column 2 of figure 6 is supposed to represent an order of centuries, but it would not produce an ordered image. This result could only be obtained by a series of values from one of the scales of the spectrum (here the "warm" scale), preferably combined with orientation (column 3, figure 6).

The Eye Mixes the Two Scales of the Spectrum in a Single Series of Values

In figures 7 and 8, it is not the order of the component which the eye will reconstruct, but the order of the values. This will lead to the confusion observed in figure 5 on page 86.

In figure 7 the component is homogeneous. We can go from white to black either by the "warm" scale or the "cool" one, each excluding the other.

In figure 8 the component is a dual one, differentiating a positive series from a negative one. The solution consists of representing the positive series by the "warm" scale, with quite fine screens (fine texture), and the negative series by a variation in the size of highly visible points (coarse texture) rendered in a single color borrowed from the "cool" scale (green or, preferably, blue).

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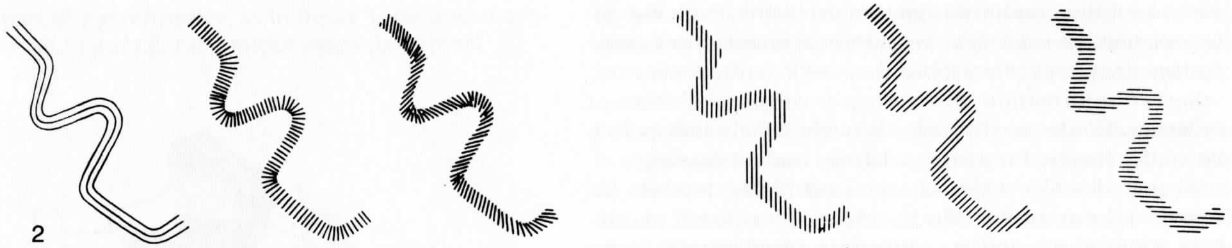

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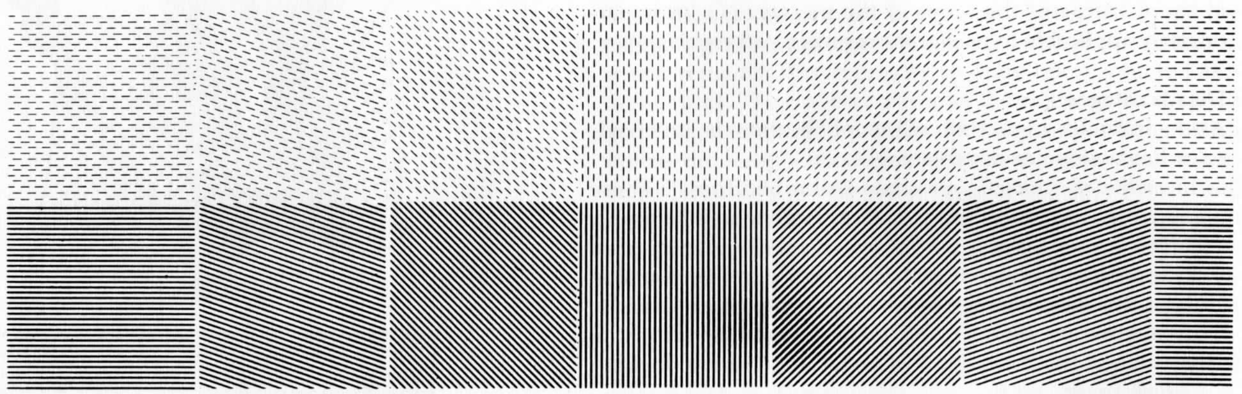

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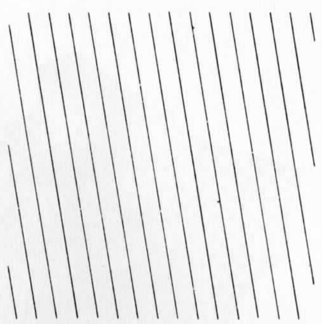

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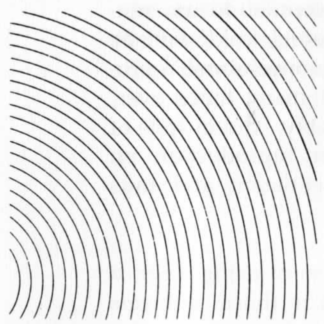

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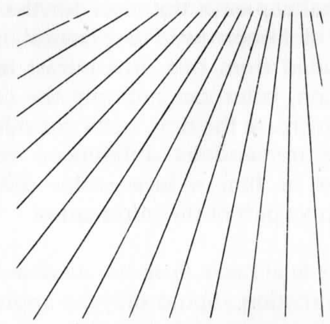

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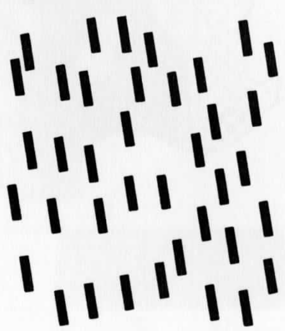

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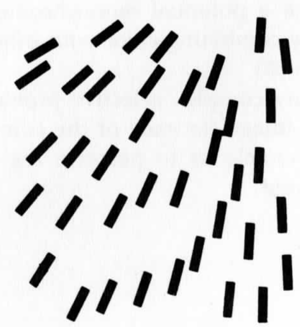

9

ORIENTATION VARIATION

In point representation, a mark can assume an infinite number of different orientations without changing the position of its center. However, we are sensitive to such a variation only when the mark has a linear aspect (figure 1). (The ratio height/base must be at least 4/1.) Furthermore, for this variation to be meaningful, we must be able to detect categories of orientation (figure 2); this obliges the designer to limit the number of categories in order to distinguish among them. Parallelism among the signs in a meaningful orientation is thus of fundamental importance, and we can further state that:

it is the difference in angle between fields created by several parallel signs which constitutes the perceptible "stimulus" for orientation variation.

Parallel circular systems (figure 5) and their rectilinear counterparts (figures 4 and 6) also involve variations in orientation. They create well-defined fields in area representation as well as in point representation (note that the centers of the corresponding signs are the same in figures 7, 8, and 9).

Implantations

Since shape variation is not selective, it is clear that, in *point representation, orientation is the only available variation which can differentiate signs of equal visibility* (see 323). (Color is another possibility, but this cannot always be used for reasons mentioned earlier. Texture too is possible, but it has limited length and is difficult to construct.)

It is preferable to restrict oneself to four orientations (figure 10), constructing the oblique lines at 30 degrees and 60 degrees rather than at 45 degrees. Five orientations are possible, but selectivity diminishes. Note that all the oblique signs tend to form a family in contrast to the orthogonal signs.

Linear signs can vary in shape (figure 11). If we study a drawing of oriented signs, the axis of perception being as distant as possible from the perpendicular to the plane of the paper (figure 12), all the signs parallel to this axis stand out and isolate themselves from the other signs.

In *linear representation* we must limit ourselves to two orientations: the axis of the line and its perpendicular. Selectivity is reduced but still exists.

In *area representation* variation in orientation is the easiest to construct, but it is at the same time the least selective (figure 3). It can only be used at the inventory stage or in combination with a selective variable.

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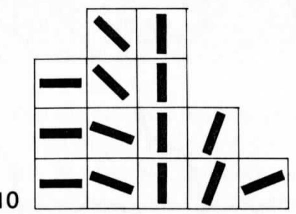

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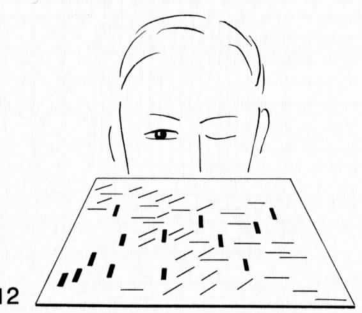

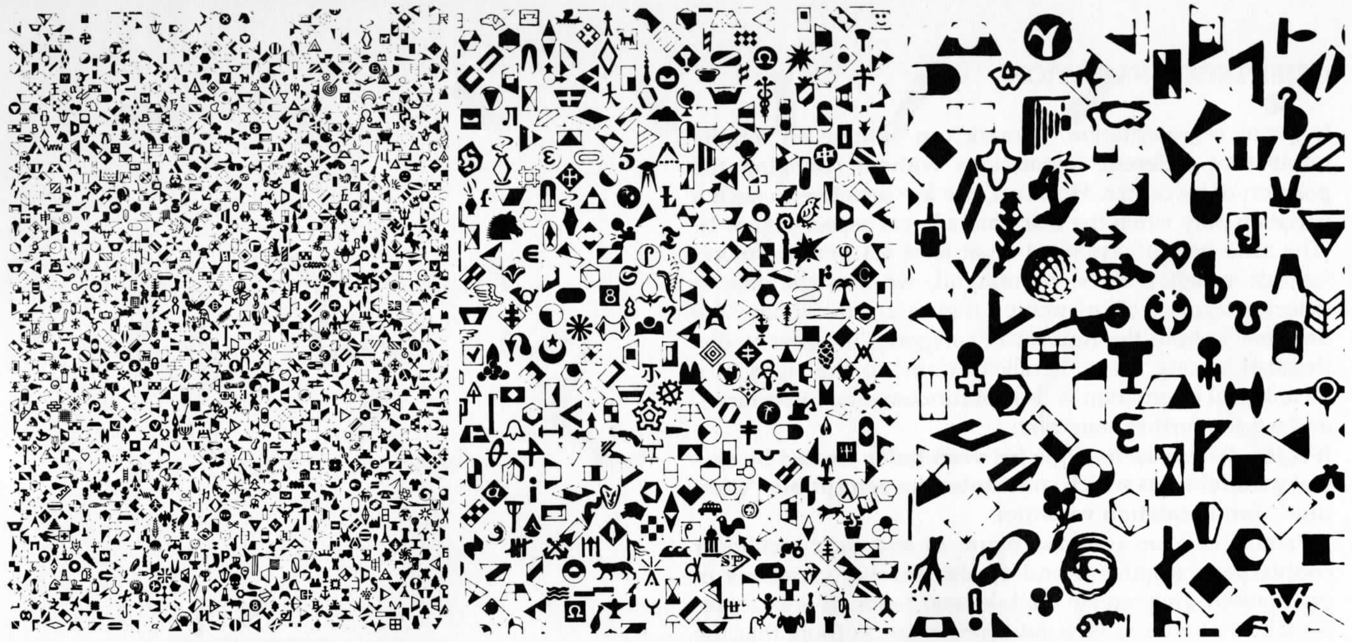

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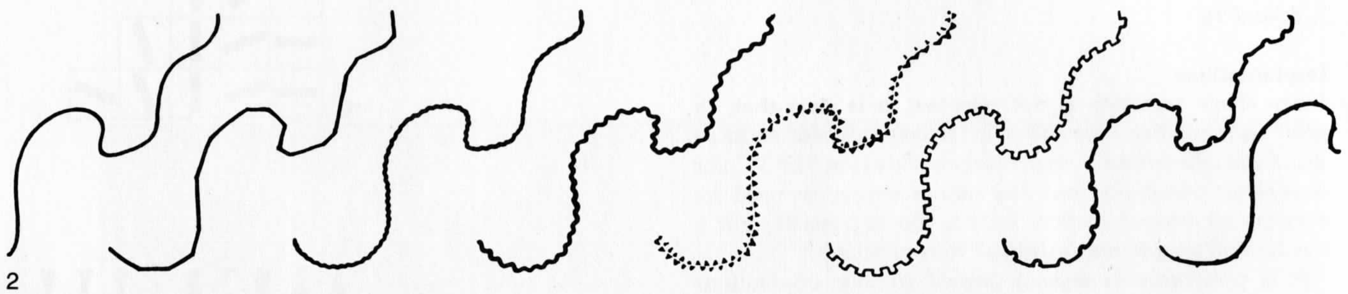

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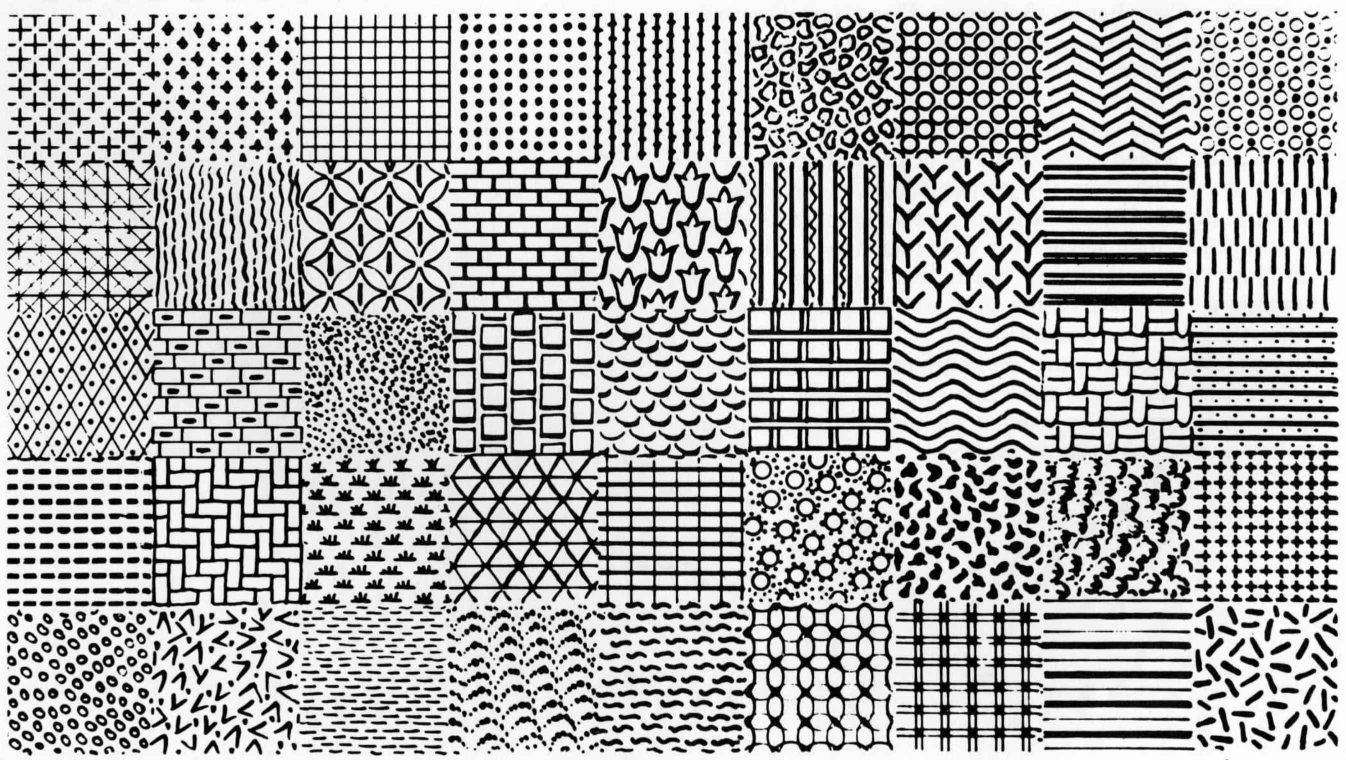


3

SHAPE VARIATION

The World of Shapes Is Infinite

A mark with a constant area can assume an infinite number of different shapes. This variation has *unlimited length,* and it is tempting to abuse it.

Figure 1 contains several hundred different signs. *Three pairs are strictly similar.* In searching for them the reader will notice that the eye focuses only on the mimetic shapes and virtually ignores the geometric ones. An idea, not a figure, creates interest and facilitates retention. Note the difficulty experienced in attempting to study more than one sign at once and in searching for the same sign several moments after observing it. This is because identification of the sign absorbs all the reader's attention, obscuring the position of the sign on the page.

It is the element of "similarity" recognized in the shape which constitutes the stimulus for this variable and confers its principal characteristics upon it:

Shape variation is associative and can be used when the image of the density of the signs, "all shapes combined," is meaningful (page 157 and figure 1, page 322).

Shape variation is not selective. It does not permit answering the question: "Where is a given category (differentiated by shape)?" (See, for example, page 157.) All signs of like shape cannot be grouped at a single glance, since it is necessary to construct an image for each sign in order to identify it. *Shape is not utilizable in problems involving regionalization.*

Shape variation is only applicable for elementary reading. It serves:

(1) to reveal similar elements, and therefore different elements

(2) to facilitate external identification (page 19), through shape symbolism.

Shape and Implantation

In *point representation* (figure 1), when the forms are amorphous, two similar marks are difficult to identify. If they are geometric, we can easily redraw them and construct identifiable marks. Some are highly familiar, such as numbers and letters. They can also be mimetic (persons, animals, objects) and tend to evoke the same concept for the majority of readers. The innumerable "flourishes" which can be added to any sign also enter into this variation. Since selectivity depends on other variables, the designer tempted by shape variation should first draw a dash. By making it vary in value, texture, orientation, or color (if applicable), the designer can obtain a selective series which is generally sufficient for most problems (see figure 1, page 324, and page 325). Shape can be added subsequently, but must not disturb the differentiation just obtained.

In *linear representation* (figure 2), a line can vary in shape and translate different concepts by differences in angularity (page 329).

In *area representation* (figure 3), especially for large areas, which will accommodate large signs, a certain selectivity can be obtained by carefully contrasting points and lines. Optimum selectivity is produced by other variables—size, value, and texture—which come more naturally to the designer (figure 4). Certain patterns have achieved the status of symbols (figure 5).

Shape Symbolism

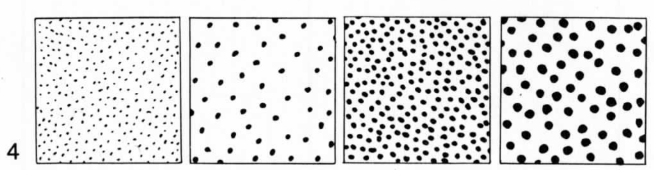
"What is at a given place?" If the visual response is a triangle or a square, the reader must have recourse to the legend. On the other hand, a mimetic shape will often avoid this necessity and resolve the problem of *external identification.* How is this effect obtained?

It should be stated at the outset that the meaning of a shape is never obvious. The signs on page 157 do not enable us to dispense with the legend. Indeed, even the most recognizable shapes can suggest numerous meanings. A horse's head can just as easily correspond to a race track, a stable, a stud farm, a riding school, a bridal path, a horse butcher, a glue factory, a harness factory, a chess game, etc. The cross, "symbol" par excellence, allows students armed with bad maps to imagine New York as garnished with cemeteries: The fine black crosses of the cemeteries and the fine red crosses designating monuments are similar at first glance!

There is no universal shape signification. The meaning of a symbol becomes familiar to us only by habit; through the repetition of a similar situation. A shape can become a symbol only within a restricted domain, rigorously defined and previously familiar to the observer. However, we must recognize that modern information tends to mix different domains and hinder such familiarity!

Thus, creating an efficient code of conventional signs is less a problem of discovering effective shapes than a problem of defining the field in which they are to be used and in which *their meaning will be constant and sufficiently repeated to become established.* Within a given code, the efficiency of the signs will depend less on their evocative capacity than on the visual distances which can be obtained *among the shapes* in order to avoid ambiguity and confusion.

4



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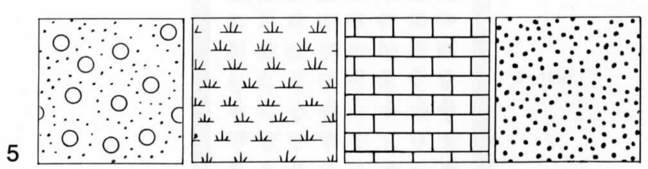

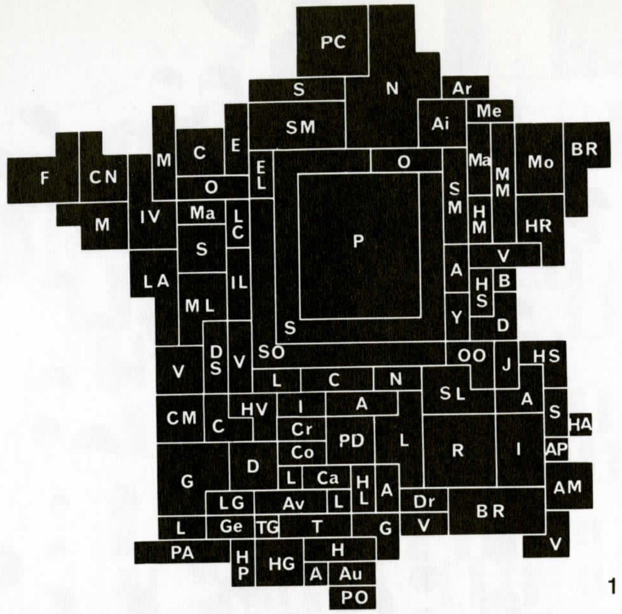

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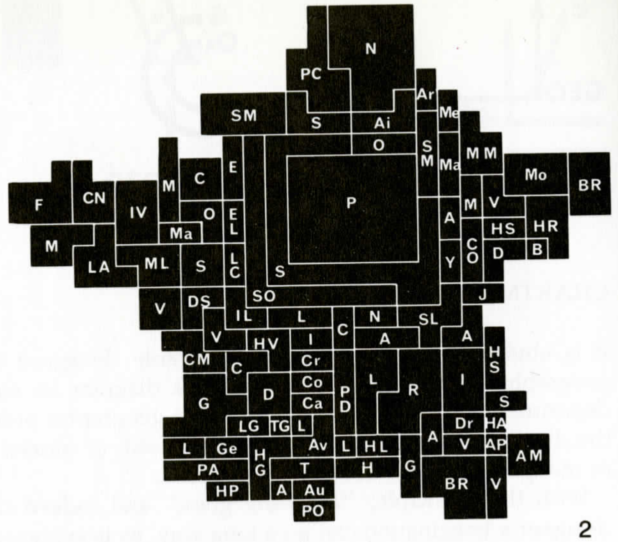


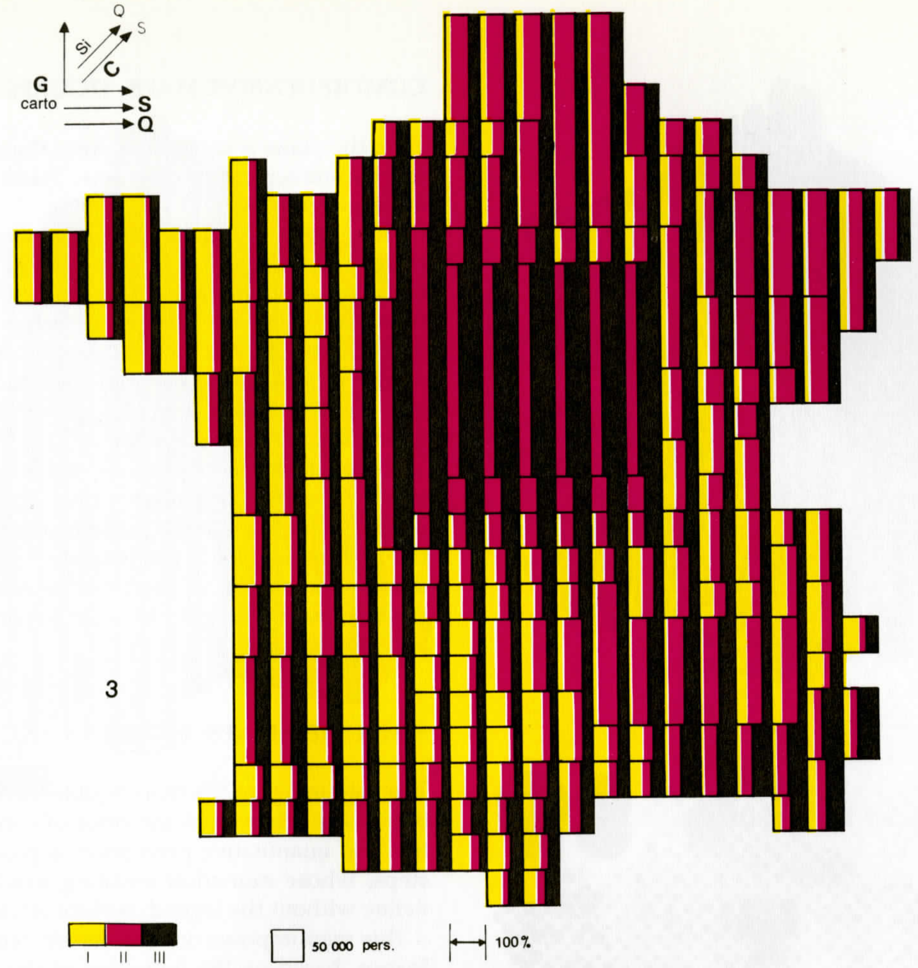
2

CARTOGRAMS

By relating the divisions of the map (departments), not to the actual geographic areas occupied by these departments, but to the total quantities of population per department, we adopt a very different system, THE CARTOGRAM, in which visible space changes its meaning.

The image is spectacular, and the observer is immediately struck by the gigantic proportions of the Parisian population. We evaluate these quantities of population by size differences, as well as by the distortions of geographic space which they entail. But it is precisely these distortions which prohibit the reader from identifying the departments by means of geographic familiarity. Acquired habit has become useless! We must either "read" the name or number of the department (figure 1), that is, return to the elementary level of reading, or else form a new habit of identification. Unfortunately, the principle of construction itself prohibits the forming of such a habit for two reasons!
(1) Each designer will construct a different cartogram from the same information. Thus, figure 2 differs from figure 1 because of the principle of transformation being used. The characteristic "outline" of France has been purposely deformed in figure 2 in order to emphasize the regions where the population is relatively large (Brittany, Nord) or small (the Aquitainian Basin). In figure 1, on the other hand, the designer has attempted to preserve the exterior geographic shape of France by allowing only internal changes.
(2) There are as many components able to serve as the basis for a cartogram as there are imaginable concepts. And for each component the place, and thus the shape and position of a given department, will be different.

One can compare several images based on the same cartogram. However, they will not facilitate geographic identification, which draws a large part of its effectiveness from the constancy of its component shapes. A cartogram, like a map, can accommodate several different retinal variables, as in figure 3, which is similar to figure 3 on page 123, or figure 4, which is similar to figure 5 on page 123. Note that the resemblances among the sectors are hardly visible and, in fact, are overwhelmed by the striking differences in total working population per department.



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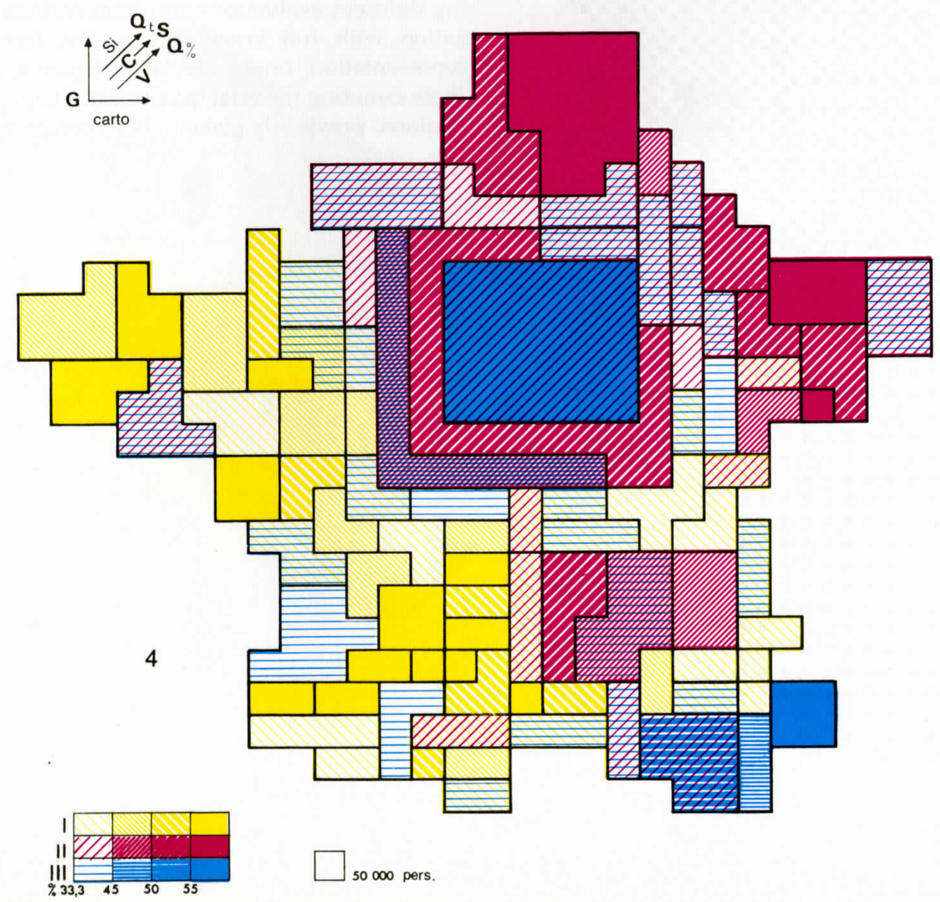

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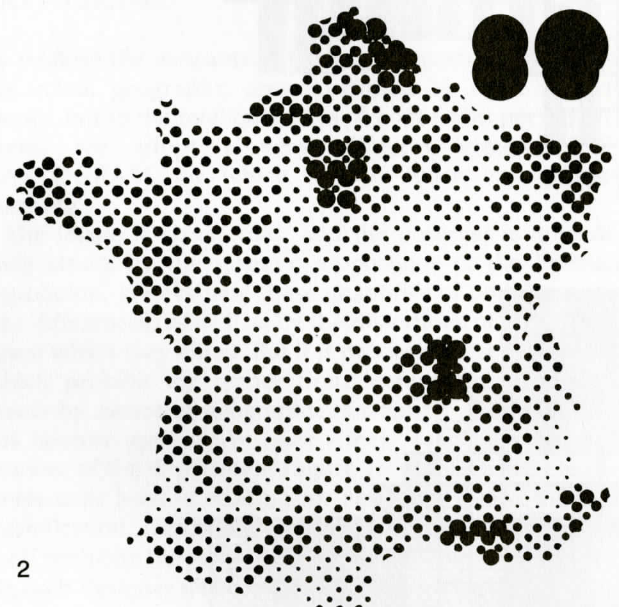


2

COMPREHENSIVE MAPS: FIGURES 3 AND 4

Here the plane is something other than a simple receptacle for two-dimensional diagrams. Furthermore, it is once again geographic.

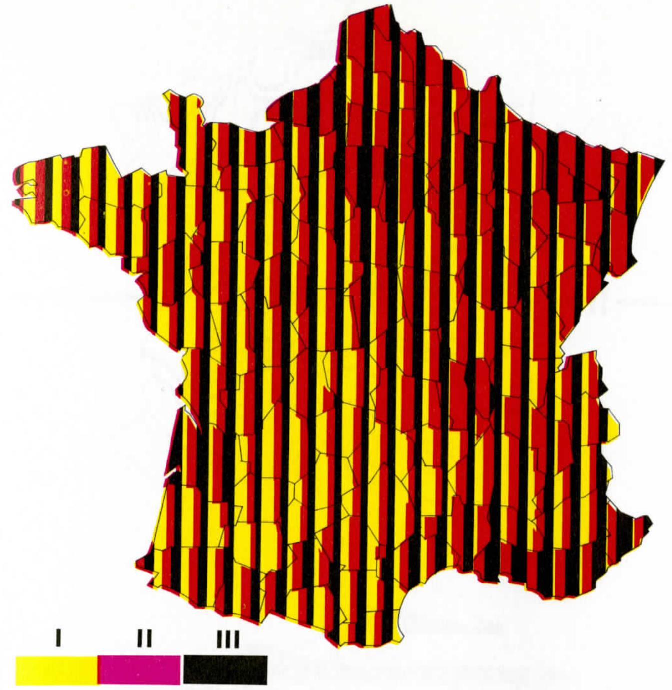
These maps result from the superimposition of three images, one per sector, and the use of a retinal variable to try to differentiate them. This variable is indispensable in figure 3; without it the overall image (figure 1) displays only the totals, which are all equal (100%). In figure 4 the retinal variable is indispensable for differentiating the sectors, but the overall image (figure 2) denotes the absolute quantities, all sectors combined.

These constructions are *comprehensive* and represent the totality of each quantitative series. However, it is still difficult: (1) to obtain a rapid answer to the question, ''What is the distribution for a given sector?''; (2) to compare this distribution to that of the other sectors; and (3) to retain the information visually in order to compare it with external information.

SIMPLIFIED MAPS: FIGURES 5 AND 6

The map in figure 5 is more legible than the previous ones, but this is achieved at the price of considerable *simplification*. No quantitative perception is possible. Four ordered steps, whose numerical meaning would be impossible to define without the legend, replace all the numbers.

This map imposes on us a certain regional perception of France, based on the definition of the steps (which could have been entirely different), and it prohibits us from making different evaluations and from criticizing the regionalization with full knowledge of the facts. To this area representation, one could, as in figure 6, add point signs (here denoting the total quantities). They quantify the populations, previously given only in percentages.



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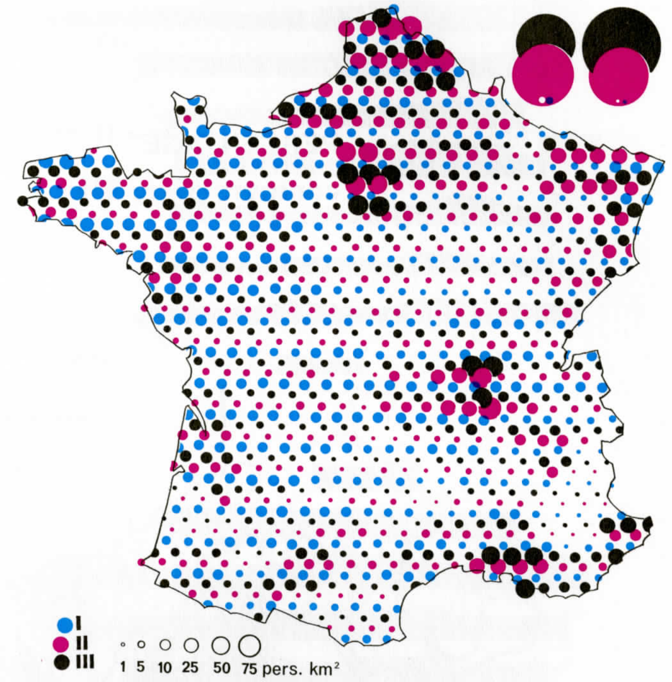

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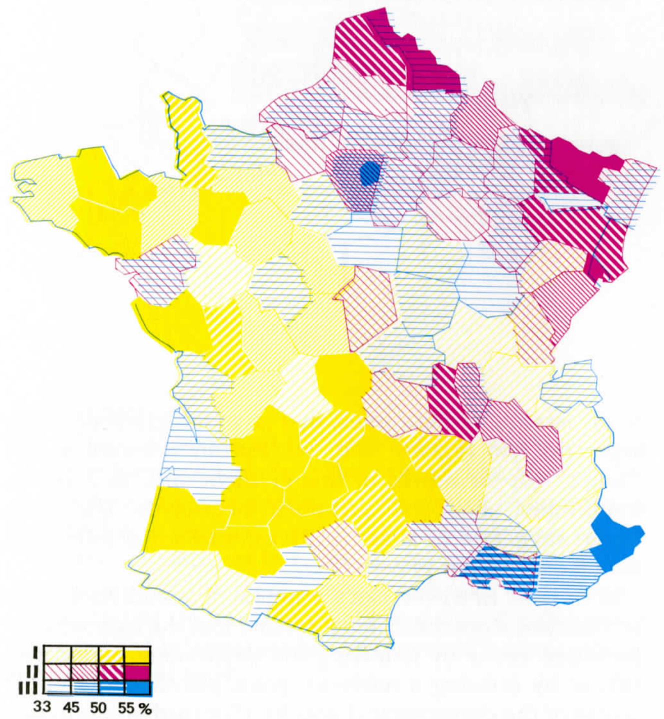

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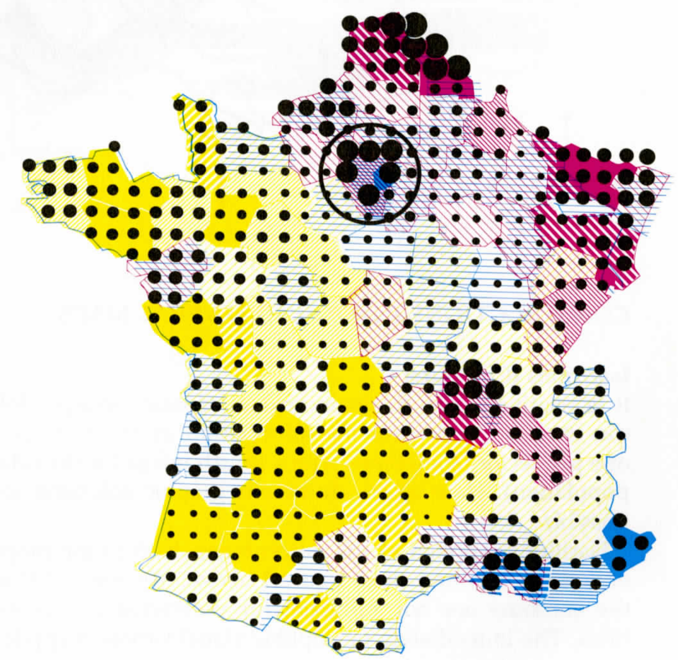

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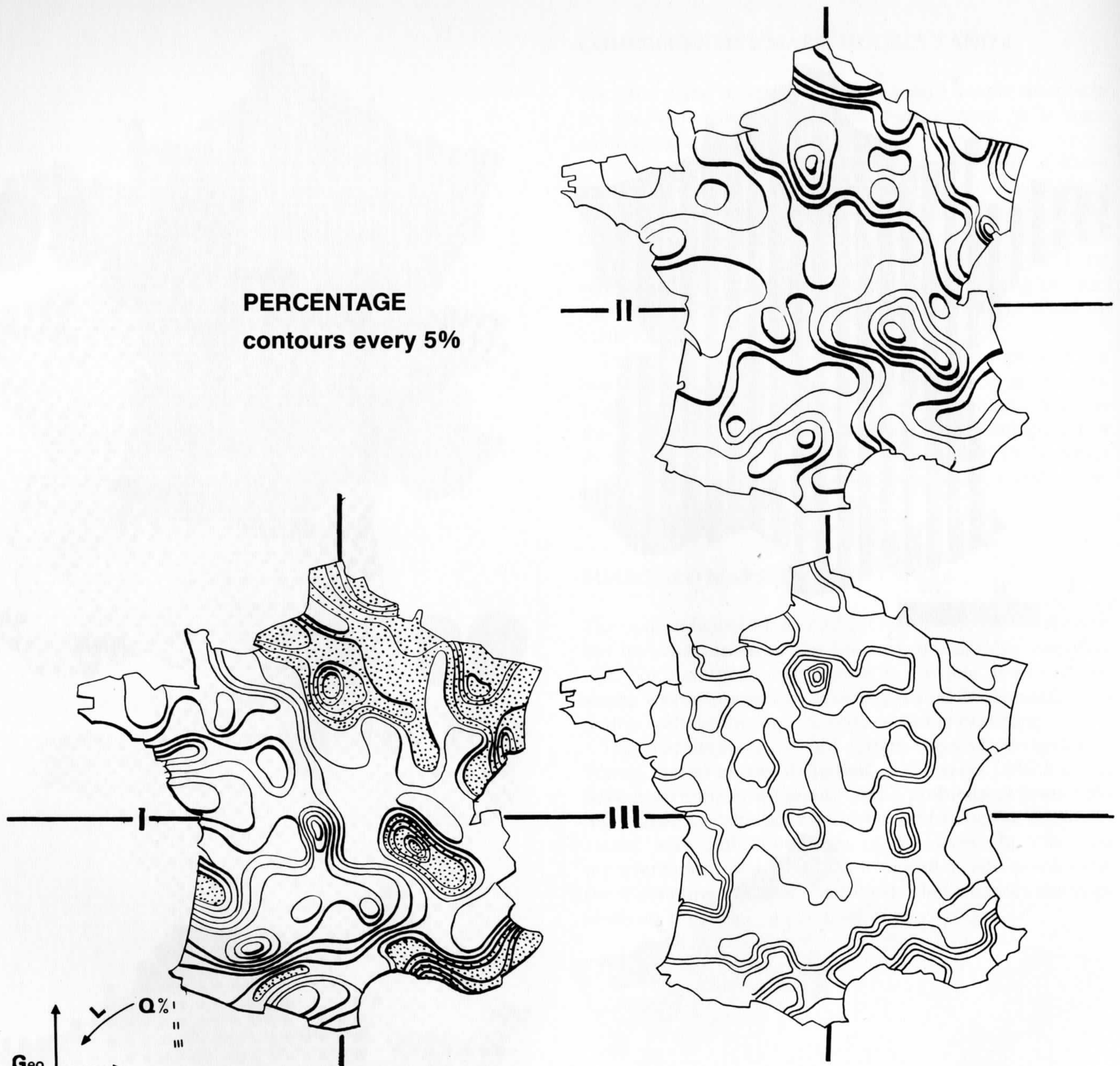


1

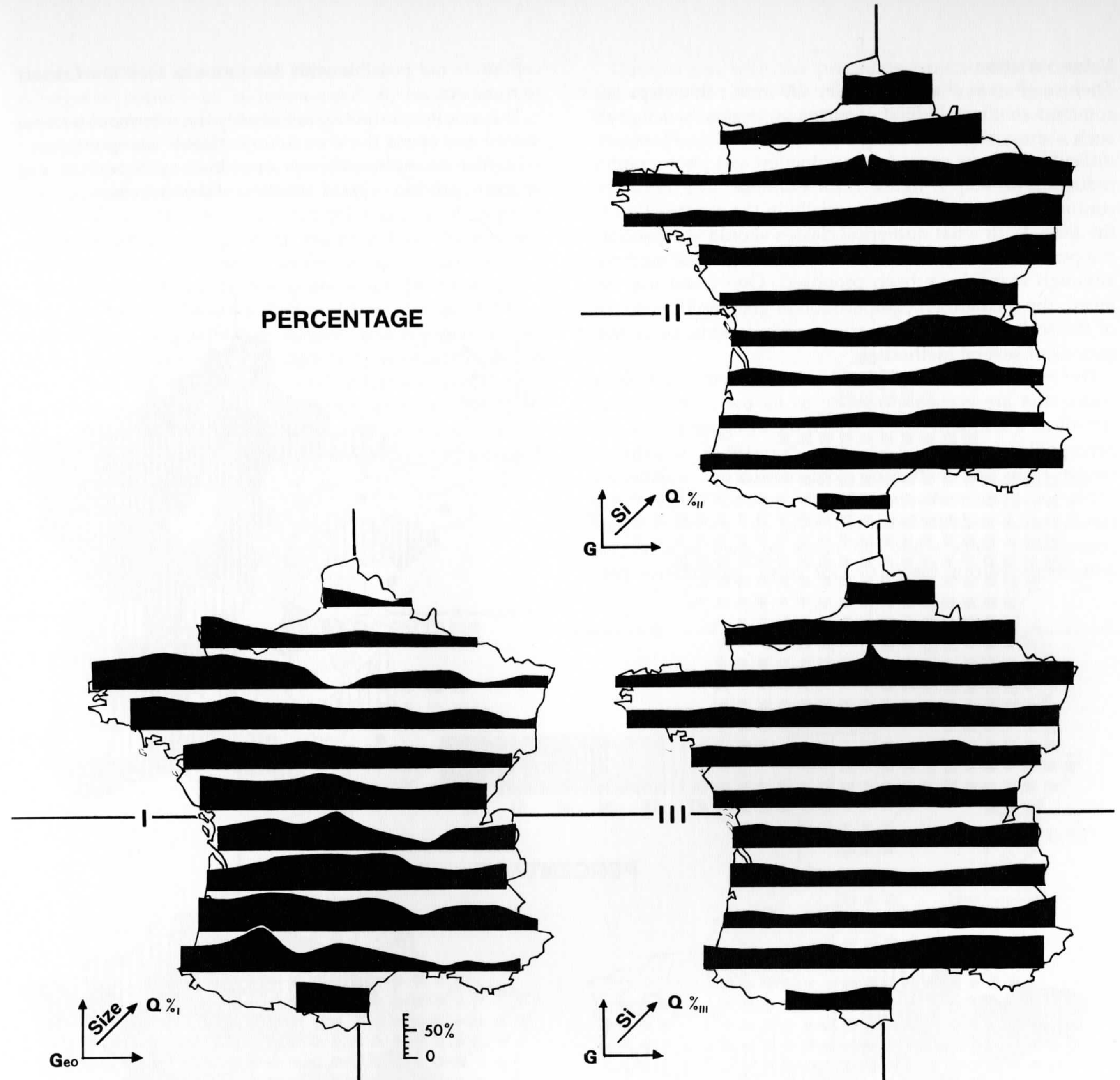
CONSTRUCTIONS INVOLVING SEVERAL MAPS

Isarithms (Contours)

It is relatively easy to retain several separate images. We can therefore represent the information in three images, one per sector (sometimes with a fourth image for the total population). Here again, numerous graphic solutions are possible.

Isarithms, applied to the percentages, lead to the maps of sectors I, II, and III in figure 1 above. We see (III) that the contours are not sufficient for portraying the quantities. The immediately perceptible visual variation applies to the spacing of the curves, that is, to the gradient which separates two regions. But, we remain unaware of the "sense" (up or down) of this gradient and, as a result, uninformed about the quantities themselves. The sense can be suggested by shading (II), especially in combination with a discrete dot pattern (I).

In no case, however, can the notion of quantitative value be obtained from these images. Note that the contours can be traced either by following the department boundaries (III) or by utilizing a reference point placed at the visual center of the department (I and II). (For further discussion of isarithms, see page 385.)



2

Vertical Sections

Isarithms correspond to the sectioning of a volume by a series of horizontal planes. This volume can also be suggested by a series of vertical planes, drawn as sections. If the spacing is planned accordingly, these sections can be "shaded" in black, as in figure 2, and a quantitative perception results: the more black, the greater the quantity. These images are much more efficient than the preceding ones, but the information has lost much of its precision at the department level.

Value Variation

The use of areas characterized by different value steps is a common solution. Indeed, it seems quite easy to construct such a map, while assuring excellent legibility. However, difficult problems occur in reproduction and photographic reduction (in map I, figure 1, for example, step 54 can be confused with black), and especially in the construction of the map. With what numerical classes should we associate the perceptible steps of value? There is no general method, although many have been proposed. One could use the mean, the median, an equipartition of geographic space or of the scale of quantities, various progressions, or combinations of several methods.

The interpretations in figure 1 below, based on different scales that are each appropriate to its own distribution, constitute a standard case in which the designer adapts the perceptible steps to any variation in quantity, whether it ranges from one to two or from one to one million, in order to obtain a diversified and vigorous image. As a result, white and black can represent any numbers whatsoever, and, since white can never be used as a precise unit for measuring black, or vice versa, quantitative perception is not possible with this formula. One must resort to numbers.

This solution reduces considerably the information transmitted and opens the door to unjustifiable interpretations.

In this example, value is combined with texture and shape to produce a good selection of distinct steps.

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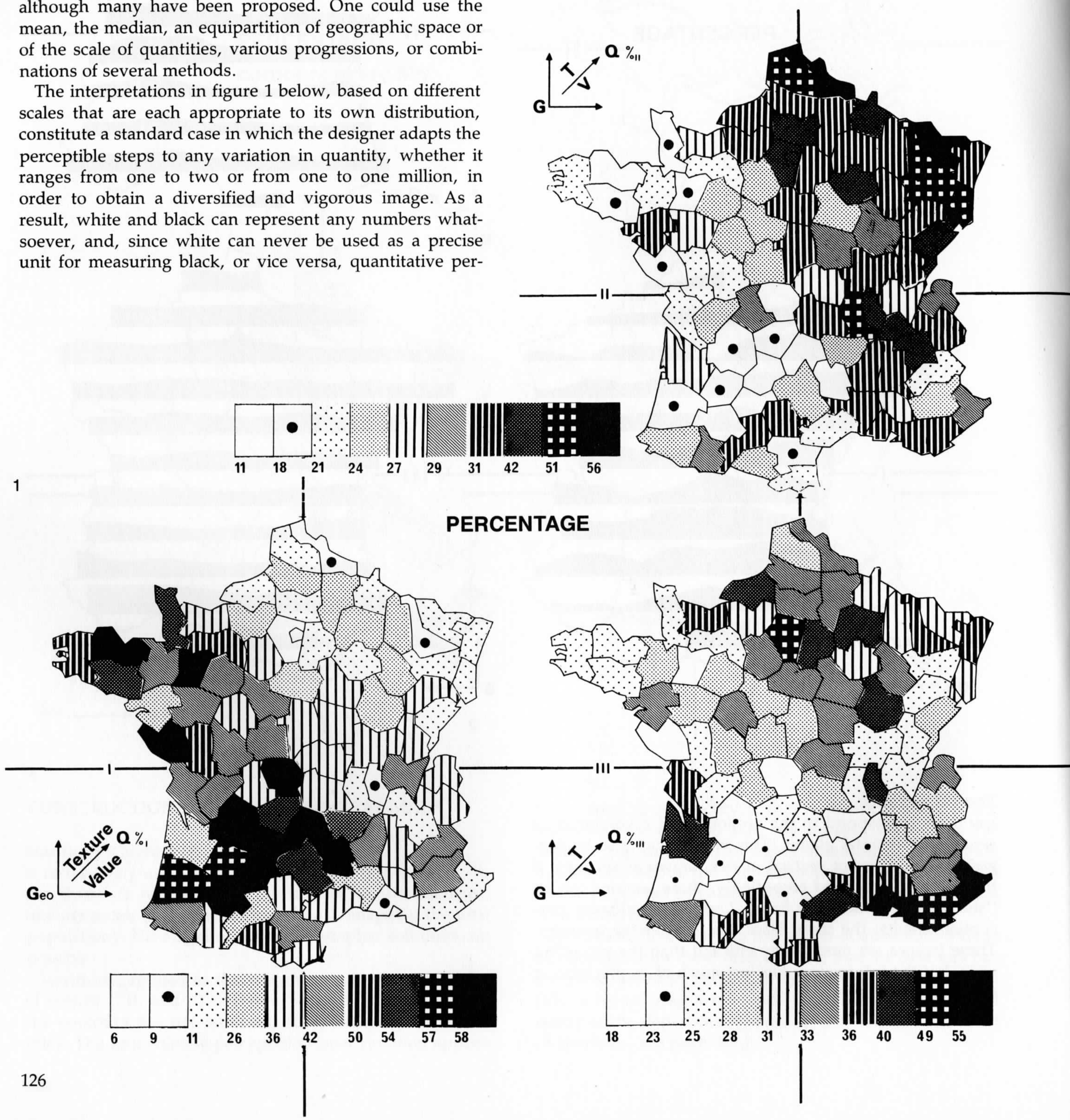


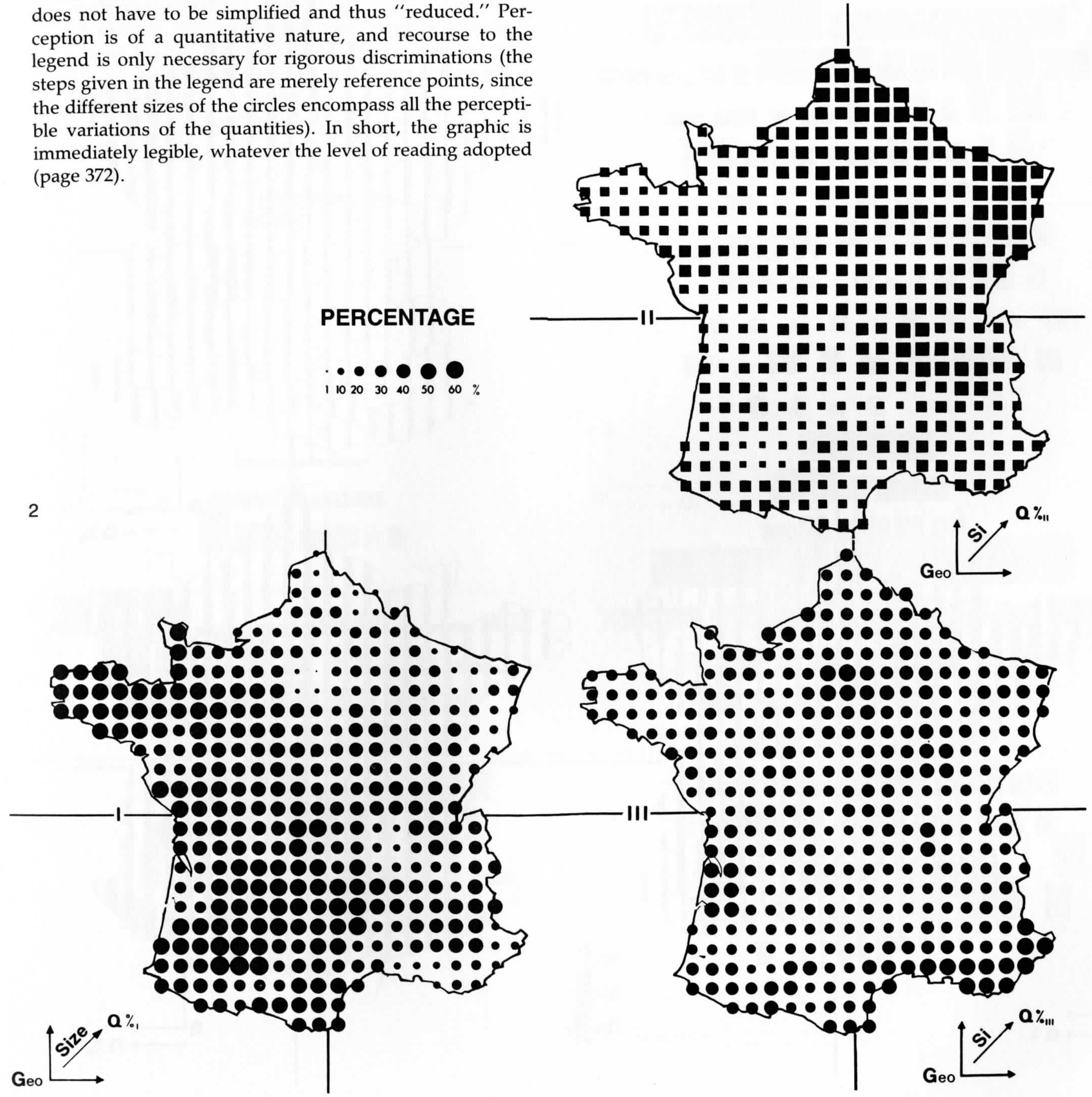
Graduated Sizes in a Regular Pattern

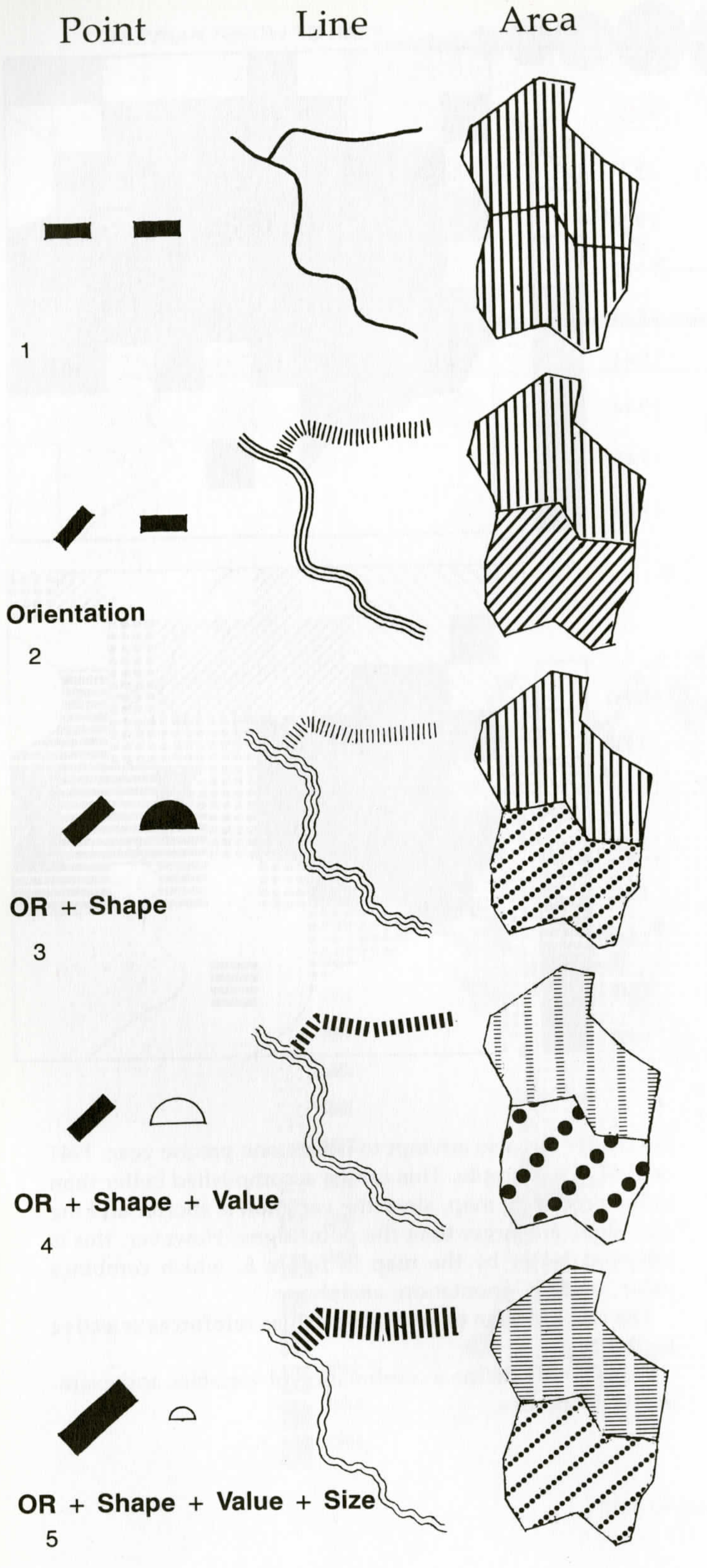
A regular pattern of different-sized circles (figure 2), applied to given areas, proves easy both to construct and to copy (see also page 369). Above all, it is the most rigorous of all graphic solutions for quantitative problems. Since it is capable of espousing all the nuances of the information, it avoids the problem of a prior choice of steps, a major difficulty in the previous example. Here the reader's interpretation is not falsified by the designer's decisions.

The method of construction is universal. The information does not have to be simplified and thus "reduced." Perception is of a quantitative nature, and recourse to the legend is only necessary for rigorous discriminations (the steps given in the legend are merely reference points, since the different sizes of the circles encompass all the perceptible variations of the quantities). In short, the graphic is immediately legible, whatever the level of reading adopted (page 372).

Comparison with the preceding construction illustrates the extent to which the reader can be dependent on the designer when any quantitative information is divided into a limited number of classes, represented by steps of value.

2





COMBINATIONS OF VARIABLES

The pairs of point, line, and area signs, which are similar in figure 1, are differentiated in figure 2 by the use of orientation. In figure 3 they are differentiated by both orientation and shape. This is an orientation-shape combination. The differentiation in figure 4 combines orientation, shape, and value. In figure 5 we utilize orientation, shape, value, and size.*

All the combinations of retinal variables are possible.

The figure on page 185 displays all the combinations which can differentiate two point signs. In group 1 (first row) a single variation separates the two signs of each pair. In the other groups, each pair is differentiated respectively by two, three, four, five, and finally six variations.

When the thirty-two combinations with size are aligned in the same column, one can see that color, for example, or any other variable is represented thirty-two times. Excluding repetitions, there remain sixty-three possible combinations between two signs.

*When value variation, normally obtained by a difference in inks (black, dark gray, light gray inks), is obtained, as here, by a visible line pattern or dot pattern, this will add to the perception of value a perception of texture, which is obviously different from black, which has no texture.