Considering Visual Variables as a Basis for Information Visualisation

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"Communication is too often taken for granted when it should be taken to pieces." (Fiske'91)

Abstract

The purpose of this report is to discuss Bertin's concepts about visual variables [Bertin 67/83], which are no longer readily available since they are out of print. Bertin introduced the idea of visual variables as part of his extensive analysis of cartography in the creation of what he terms data graphics as part of his Semiology of Graphics [Bertin 67/83]. In this report these concepts are discussed in terms of computational information visualisation instead of printed cartography. The discussion will centre on how these visual variables can be used in the creation of visual representations for the purpose of information visualisation.

1. Introduction

Information can come in many forms from the concrete to the conceptual and the abstract. If this information is to be capable of communicating to or informing people, it must be represented in a manner that is understandable. This creation of a visual representation from the information is a significant part in the process of creating an information visualisation. Since the information that is being represented may not have any obvious visual manifestation this process of creating a mapping from the information to the visual representation can be non-trivial. In approaching this problem there are sources from many fields of study that have the potential of providing useful advice. These include cognitive science (Ware 2000), information design (Tufte 1983, 1987, 1990), linguistics (Horn 2000), comics (McCloud 1993 2000), film (Dondis) and cartography (Bertin 1967/83).

2. The Importance of Representation

Creating or changing representations in general, or visual representations in particular, is very significant in regards to issues of comprehension and interpretability of the information that is represented.

For this discussion the term representation is used as defined by Marr (1982) to mean a formal system by which the information or data can be specified. Defined in this way a given representation provides specific information about the data and differing representations may more readily reveal differing aspects of the data. To explain the significance of changes in representation Marr's example is paralleled. Arabic, Roman and binary representations can be provided for the concept of the number thirty-four, giving 34, XXXIV, and 100010 respectively. In this example, Arabic numerals reveal information about powers of ten while binary representations reveal information about powers of two. The information about powers of ten is available in all three of these representations, however the degree of accessibility varies considerably. This indicates that choice of representation is of fundamental importance if the information or data that we start with is to be capable of informing others.

The visualisation process involves several representational mappings. Information or data has initially been observed, gathered or generated in some manner and perhaps stored for later use. This in itself involves the creation of a representation. Each time a representation is created a process of abstraction has been used. The act of abstracting is taken to mean to summarise, or to state the essence of the information concerned. Most abstractions are either more or less than a direct transformations in that the new representation was arrived at through more than simply a change of form without alteration of quantity or value of the information. That is, in creating a new representation certain aspects of the information are brought to the fore and others are perhaps obscured or even omitted. It is this process of abstraction in the creation of a new representation that selects which aspects of the data are to be the most accessible. In creating visualisations the first information or data representation will not often have a visual form; therefore a second process of abstraction may be required to create a visual representation.

In a given representation, information may be present but hard to find. Useful representations allow people to find relevant information and allow people to compute desired conclusions. Computations may be difficult or "for free" depending on representations.

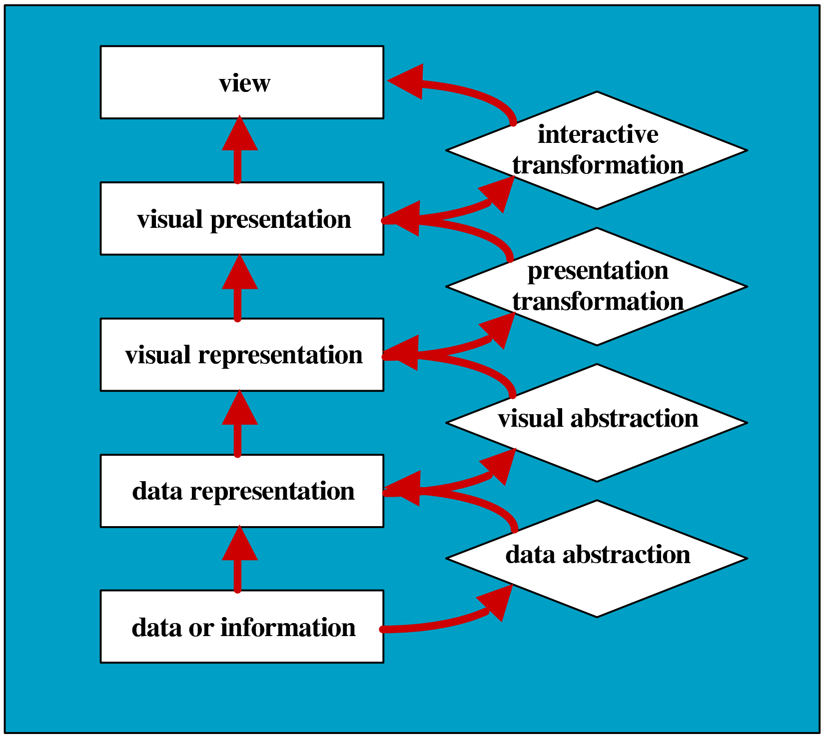


Figure 1: Visualisation pipeline

Choice of representation enables or complicates performance of particular tasks, there are several changes of representation involved in developing a visualisation and that each one of these usually involves a process of abstraction. And the each abstraction effects what information is available for use. The goal of this discussion is to dissect the process, by which a visual representation can be created, increasing consciousness of the process of representational transformations and abstractions. In turn this increased awareness may help in the creation of representations that more appropriately match their tasks.

3. Getting Started

3.1 Basic Units

This is a practical look at how to go about creating a visual mapping that is capable of communicating. Our most familiar mode of communication is with words. Words are composed of sounds or phonemes and these phonemes are constructed from the letters, usually one or two letters make a phoneme. Note that the letters are meaningless in themselves, as are the phonemes [Sausure]. It is not until phonemes are grouped together to form words that they have meaning.

The first question in this discussion is: are there corresponding basic visual units? There is still considerable debate on this subject with the majority opinion being negative. However; Jacques Bertin [1967/83] developed a practical approach for his data graphics that is based on the opinion that there is a basic visual unit and that there are a describable ways of changing this basic unit. What then is the most basic visual unit one make on a blank piece of paper? One can make a mark.

Bertin [1967/83] defines a mark as something that is visible and can be used in cartography to show relationships within sets of data. He names the different ways that a mark can be varied as visual variables. The next question is how can one vary this mark in a manner that is meaningful? Marks can be varied by where we place them on the page and by their visual characteristics such as size, shape, value, orientation, colour and texture.

3.2 Disclaimer

Bertin prefaced his work with the following disclaimer. He states that in developing this approach he was considering the creation of data graphics, on white paper, that are printable with readily available means. That he wanted the data to be visible at a glance and that he is considering normal book reading conditions. This includes normal and constant lighting, and reading distance of up to an arm's length. It is important to also preface this report with such a disclaimer.

One of the principle reasons for writing this report is to make Bertin's concept of visual variables, which is unfortunately now out of print, available to students of information visualisation. However, this is not simply a reiteration of Bertin's concepts, there are several notable differences. Here, these concepts are discussed as they pertain to information visualisations that are created for and presented on computational displays. Also, Bertin classifies visual variables by what he terms perceptual level of organisation. Applying Bertin notions to information visualisation has led to re-phrasing the classification in terms of visual interpretation tasks. One reason for this shift is that it supports a practical emphasis and application. Another reason is that in the approximately thirty years since Bertin first published, research into perceptual capabilities has advanced considerably and has also been considered in terms of information visualisation [Ware90]. This consideration in terms of visual interpretation tasks has led to some variance in the concepts, particularly the definition of the associative interpretation tasks

As the computer emerges as a medium in its own right, it is important to improve our understanding of the capabilities of computational presentation space. For example, before using a new tool, even one as simple as a pencil or a brush, an artist will test it to gain knowledge of the characteristic range of marks that can be made. Just as an artist benefits from knowledge of the tools they are using, a person creating an information visualisation for a computer will benefit from a fuller understanding of the possible representation choices. However, this is not meant to be definitive description of computational visual representation space but is merely a practical first pass. In comparison to printing computational display is a relatively new medium. Readily available computational displays vary considerably from those of printing and, what is more, are in a state of flux. For example, a typical computational display is backlit and has poor comparatively poor resolution (currently up to 1600 x 1200) in contrast to printing. Also new physical displays are arising on a regular basis as well as new software capabilities. These will continue to change what it is possible to display visually. For instance on a computational display one can to consider; movement (speed, frequency, onset, style), the quasi 3D display (depth, occlusion, aerial perspective, binocular disparity, stereo viewing), illumination, transparency and three readily available colour channels (either red, green and blue or hue, saturation and value).

While Bertin's basic idea translates well from data graphics to computational visualisation, there are several distinctions and in all probability more distinctions or at least more precise characterisation of these distinctions will develop with use.

3.3 Marks

A mark can be a point, a line, an area and, on a computational display, a surface and a volume. Once a mark has been made and that mark is used to represent something other than itself it is frequently referred to as a sign.

Points

Points theoretically have no size. Symbolically they represent a mathematically dimensionless location. That is, a point represents the concept of location (x, y, z) independently from the size and shape that it manifests. Points of course will have such things as size, shape and colour in order that they can be perceived but they still symbolically stand for a dimensionless point. Points operate in a 1D, 2D, or 3D space. Marks that indicate points can vary in all visual variables. "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." [page 44 Bertin 67/83]

Lines

Lines have length but no theoretical width. Symbolically they can represent such things as a boundary, a connection, a separation and an edge. Similarly to points, lines manifest visually with some thickness in order that they may be seen. But they stand for the location of the line. A change in the visual characteristics of the line such as, thickness (size), texture, or colour does not change the meaning of the line. Changing its location will change its meaning. Lines operate in a 2D or 3D space. “A line signifies a phenomenon on the plane which has measurable length but no area. This signification is independent of the width and characteristic of the mark which renders it visible.” [page 44 Bertin 67/83]

Areas

An area on the other hand has length and width. Changing these properties changes the meaning of the area. For instance, if an area represents a country, decreasing the size of the area on the map would signify decreasing the size of the country. Areas operate in a 2D space. An area can change in position, colour, value, or texture but not in size, shape or orientation without making the area itself have a different meaning. “An area signifies something … [in the presentation] that has measurable size. This signification applies to the entire area covered by the visible mark.” [page 44 Bertin 67/83]

Surfaces

Surfaces are similar to areas in that they have length and breadth but they exist in a 3D space and have no theoretical thickness. They can represent such things as connections, volume separations and volume edges. A surface can change in colour, value, or texture and size in thickness only without changing its meaning. Other changes in position, size, shape or orientation will give the surface a different meaning. A plane is a flat surface.

Volumes

Volumes have length, width and depth. Their size is their meaning. They exist in a 3D space. A volume can change in position, colour, value, or texture but not in size, shape or orientation without making the volume itself have a different meaning. Similarly to an area, a volume signifies something that has measurable size. This signification applies to the entire volume covered by the visible mark.

4. The Visual Variables

In this section I will introduce Bertin’s visual variables, discuss briefly some differences caused by computational display and augment them minimally according to these differences. These are briefly introduced and illustrated in Table 1.

In computational presentation the addition of **motion** as a visual variable is important. Changing a marks motion is a new visual variable available for computational presentation. There are many changes on motion that are possible. These include direction, speed, frequency, rhythm, flicker, trails, and style. For further discussion of the use of motion in information visualisation see Bartram [1998].

5. Characteristics of Visual Variables

Considerable power in creating different visual representations comes from choosing which visual variable would be most appropriate to represent each aspect of the information. The ability to make these choices can be greatly enhanced by understanding how a change in a particular visual variable is likely to affect the performance of a particular task. This is Bertin’s list of visual variable characteristics.

The first four, selective, associative, quantitative and order, are visual interpretation tasks. They allow us to classify visual variables according to whether changes in a given variable enable the performance of these different types of visual interpretation tasks. The last characteristic in this list, length, addresses the issue of how many changes in a particular visual variable can be used effectively.

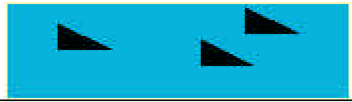
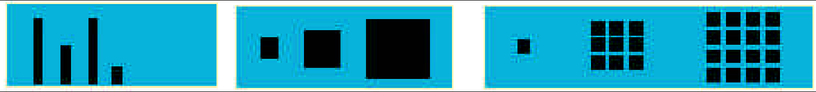
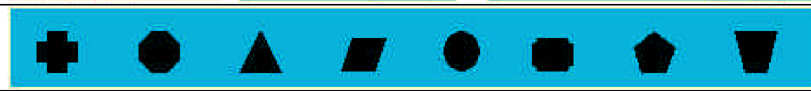
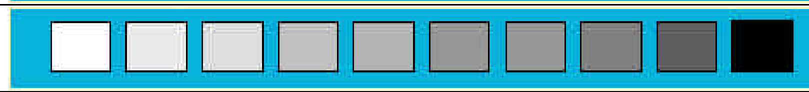
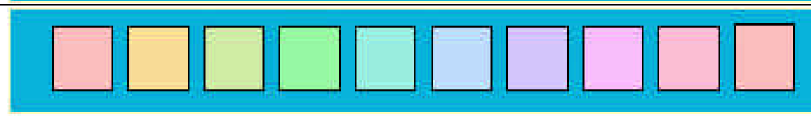
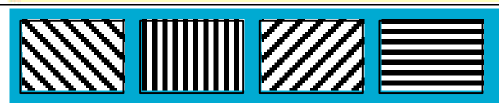
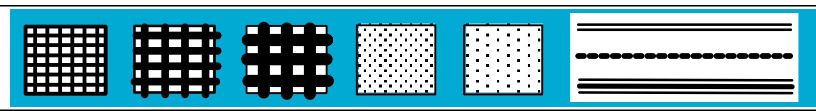
Bertin’s Original Visual Variables	
Position changes in the x, y location	
Size change in length, area or repetition	
Shape infinite number of shapes	
Value changes from light to dark	
Colour changes in hue at a given value	
Orientation changes in alignment	
Texture variation in ‘grain’	

Table 1: These are Bertin's visual variables

5.1 Selective. A visual variable is said to be selective if a mark changed in this variable alone makes it easier to select that changed mark from all the other marks. This task is about the selection of an individual mark as distinct from other marks. The question to be asked is: Is change in this visual variable alone enough to allow us to select it from a group?

5.2 Associative. A visual variable is said to be associative if marks that are like in other ways can be grouped according to a change in this visual variable. This means that several marks can be grouped across changes in other visual variables. For example all yellow marks can be thought of as a group even if they are in different locations or have different shapes. The question to be asked is: Is a change in this visual variable enough to allow us to perceive them as a group? Bertin uses the term associative differently (see page 48 in [Bertin 67/83]).

5.3 Quantitative. A visual variable is said to be quantitative if the relationship between two marks differing in this visual variable can be seen as numerical. For instance, one line can be seen as being four times as long as another line. These are not necessarily precise numerical readings but are often read as ratios of one mark to another. For instance, one line can be seen as being four times as long as another line. The question to be asked is: Is there a numerical reading obtainable from changes in this visual variable?

5.4 Order. A visual variable is said to be ordered if changes in this visual variable support ordered readings. That is a change in an ordered visual variable will automatically be read as either more or less. For instance a change in value will been seen as either less dark or more light. The question to be asked is: Are changes in this variable perceived as ordered?

5.5 Length. Length is a slightly different kind of characteristic. The length of a visual variable is the number of changes that can be used and still retain the task supporting characteristics that are usually associated with this visual variable. For, example how many changes in value (shades of grey) can still be recognised with confidence as separate. The question to be asked is: across how many changes in this visual variable are distinctions recognisable?

6. Discussing the Characteristics of Each Visual Variable

6.1 Position

A mark on a printed page changes in position when it is moved up or down or to the left or to the right. In print, position changes are changes in the x, y location of the mark. On a computational display, if the representation space is 2D this remains the same, if it is 3D, there are three positional variables, x, y, and z.

While printed graphics are 2D, computational visualisations are created in a computer's quasi 3D-display space. The displays commonly in use at this point are neither completely 2D nor actually 3D. They are 2D in that they present everything on a flat 2D surface. They are 3D in that we can use mathematics to enable us to create displays that appear 3D but in fact they are still always projected onto a 2D screen. The amount of 3D effect can vary from very little as in windows that both exist in multiple over-lapping layers and still seem to be all on the same surface, to as 3D as immerse and stereo viewing can support.

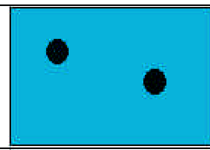
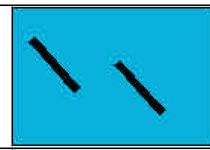
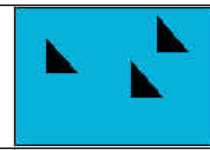
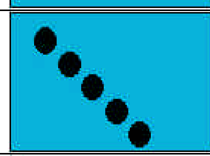
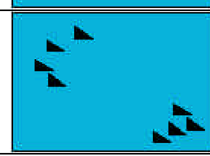
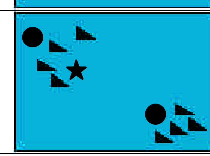
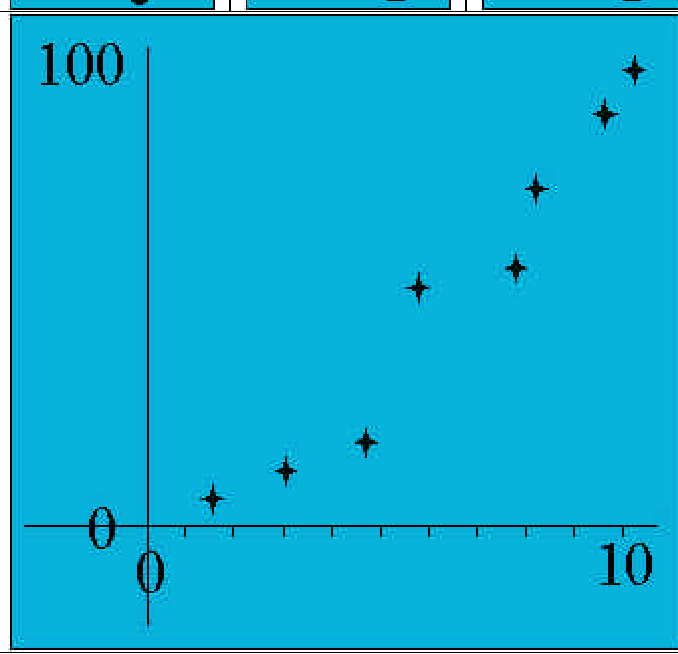
Visual Variable: Position				
✓	selective			
✓	associative			
✓	quantitative			
✓	order			
✓	length			

Table 2: Visual variable position and interpretation tasks

Position: Selective. Marks that are the same in all respects except for position can easily being distinguished and interpreted as different. In Table 2, row 1, columns 3, 4 and 5 show, respectively, circular, linear and triangular marks that differ only in position. They are all selectable based on viewing their location. For instance, if asked to select the lower most mark from Table 2, row1, column 5, you can do so readily by simply looking at it. A change in this visual variable alone is sufficient to allow us to select it from a group.

Position: Associative. Changes in positional visual variables can be used to create groups of marks that can be interpreted as belonging together. Table 2, row 2 shows three examples of this. Table 2, row 2, column 3 shows a diagonal row of circles that are clearly positioned to indicate that they are to be considered as a group. Table 2, row 2, column 4 shows distinct groups of triangles. Here the use of position visually separates these marks into two groups in spite of the fact that all that marks are the same shape and colour. Table 2, row 2, column 5 also shows two groups. In these two groups some of the marks have differing shapes however, the use of position clearly groups them. If asked for the group in the top left corner one can readily see which marks to include. This illustrates that several marks can be grouped by position across changes in other visual variables.

Position: Quantitative. Position is frequently used to indicate a numerical value. The graph in Table 2 that spans rows 3, 4 and 5 and columns 3, 4 and 5 illustrates this. Depending on the care taken with the visual presentation and the incorporation of viewing cues relatively precise numerical readings are obtainable. For example, the small marks on the x-axis greatly aid the ease of retrieving a numerical reading in the x direction. However, numerical readings in the y direction are also obtainable. Definitely the relationship between two marks differing in position can be interpreted as numerical.

Position: Order. Changes in position are readily orderable. This holds true for both up-down interpretations and left-right interpretations. The ordered interpretation of all the marks in the graph in Table 2 rows 3, 4 and 5 and columns 3, 4 and 5 will be consistent.

Position: Length. The positional variables have exceptional length in that a considerable number of changes in position are still perceived as distinct and therefore will still retain the task supporting characteristics that are usually associated with position. While theoretically infinite in that one can theoretically always place a new mark in between two existing marks, practically in computational presentation space the length of the positional visual variables is dependent on the resolution of the display.

Position is the most versatile and most powerful visual variable and, fortunately, there is a positional visual variable for each dimension of the presentation. However, while both of the planar positional variables fully support all of the four of the visual interpretation tasks, this does not seem to be entirely the case for the three positional variables in 3D presentations. For more complete discussion of this issue see [Ware97; Ware00].

6.2 Size

Changing a mark or sign's size is achieved by changes in length, area, volume or by repetition of a number of equal signs. (Table 1, row 2). Only points, lines or planes and be changed in size without causing a change in the interpretation of the sign. A change in size is a change in the dimensions of the sign. For instance, a sign that represents a point in the presentation can be made larger according to needs for visibility while still representing that point.

Size: Selective. A change is size is selective since if a sign is changed in size alone it will become distinct and therefore selectable from the other signs. In Table 3 row 1, it is a simple interpretation task to select either the smaller or the larger sign. Signs that are the same in all respects except for size can easily being distinguished and interpreted as different.

Size: Associative. Changes in size can be used to create groups of signs that can be interpreted as belonging together. Table 3 row 2 shows three examples of this. Here the use of size visually separates these signs into two groups, a group of smaller signs and a group of larger signs. A change in size alone is sufficient to allow us to perceive signs of similar size as belonging to a group.

Size: Quantitative. Size can sometimes be used to indicate a numerical value. However, numerical readings interpreted from changes in size alone are usually approximate and often less the ideally accurate. Table 3 row 3 illustrates this. If the change is size is achieved through repetition of like marks, numerical readings are more readily obtainable. However, if changes in size are achieved by changes in area or volume, they are much more difficult to interpret. A size change that is achieved by a change in one dimension only can be more amenable to comparative numerical interpretations. Use of changes in size when the intention is to make information about comparative numerical values readily available can be problematical. Therefore this use of the visual variable size should be done with caution.

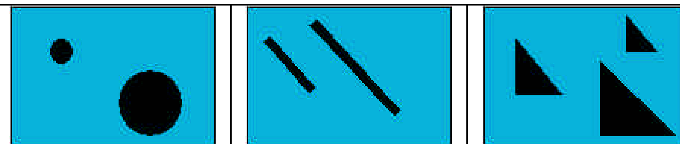
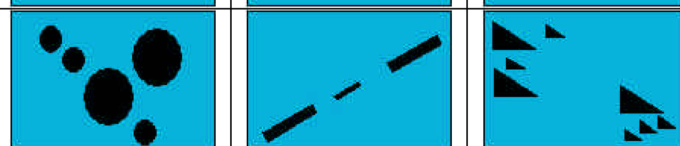
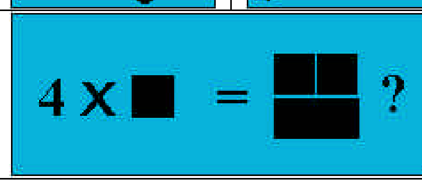
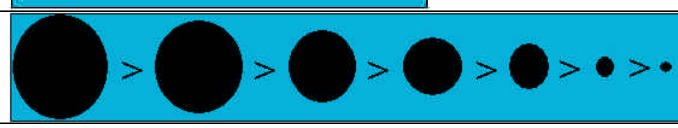
Visual Variable: Size		
✓	selective	
✓	associative	
≃	quantitative	
✓	order	
✓	Length	• theoretically infinite but practically limited • association and selection ~ 5 and distinction ~ 20

Table 3: Visual variable size and interpretation tasks

Size: Order. Changes in size are readily orderable. In fact words such as larger or smaller that express changes in size are amoung the most common ways of indicating order verbally. This is probably due to the ease with which order can be interpreted from changes in size. Table 3 row 4 illustrates this. The interpretation of order achieved through changes in size is consistent across all readings. That is a change in size will automatically be read as either more or less.

Size: Length. While changes is size are theoretically infinite in that one can theoretically always make a minimally larger size, like position this is also limited by the resolution of the display. However, the length of the visual variable size also suffers from a much more practical limitation. To achieve the signification desired, a change in size must be interpretable as change in size. That is the two sizes must be visually distinct. Practically, while it is possible for us to interpret quite small changes in size when they are immediately adjacent, much larger changes in size are needed if it is to remain interpretable across greater distances. Therefore while several changes in size, perhaps in the range of forty to fifty, are usable if they are placed adjacently, only comparatively few, perhaps as limited as in the range of approximately five, are usable if they are to be placed separately in the display.

6.3 Shape

Changing a mark's shape is achieved by any change in outline that does not include a change in size. (Table 1, row 3).

Shape: Selective. A change in shape can be selective. For example, in Table 4 row 1, it is possible to select the circle in column 3, the triangle in column 4 and the square in column 5 as being distinct. However, the simplicity of this interpretation task starts to break as the number and proximity of other signs start to increase. Examine Figure 2. It is not a simple interpretation task to select the shape in the small image on the left from the group of shapes in the image on the right. There are five of them. While changes in shapes are distinguishable, this distinction can often require considerable interpretation effort. Therefore I consider shape as partially selective.

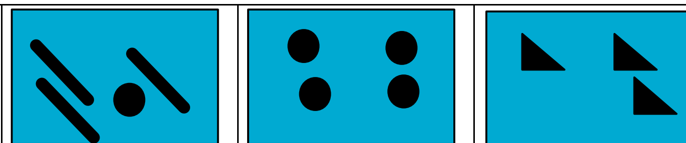
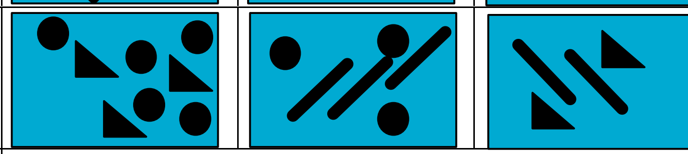
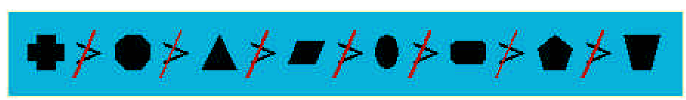
Visual Variable: Shape		
≃	selective	
≃	associative	
≠	quantitative	
≠	order	
✓	length	 theoretically infinite

Table 4: Visual variable shape and interpretation tasks

Shape: Associative. The question is can a change in shape alone be enough to allow us to perceive all the signs with this shape as a group? In Table 4 row 2 there are several examples of small groupings with simple changes in shape. In these small examples, shape is associative. That is, one can interpret the circles in Table row 2 column 4 as a group in spite of the fact that they are not grouped positionally. However, once again if one examines Figure 2, even once one has discovered all instances of a particular shape, it is difficult to interpret them as a group. This is not to say that if, for instance, all the crosses represent the presence of a mine of a map, one can not find another cross and interpret it as signifying that there is a mine at this location. This is a symbolic interpretation. However, a quick visual interpretation of all the mines is not very accessible. Therefore I consider shape as partially associative.

Shape: Quantitative. A change is shape, that is not accompanied by a change in size, does not readily provide a numerical interpretation. Therefore shape is not a quantitative visual variable.

Shape: Order. Signs that change in shape only do not support ordered readings. If they have even approximately the same area, a circle will not be interpreted as more or less than parallelogram. If pressed to order a set of shapes people will order them different according to criteria of their own such as personal preference. Shape is not an ordered visual variable.

Shape: Length. The shape of a sign of a particular area can be varied infinitely.

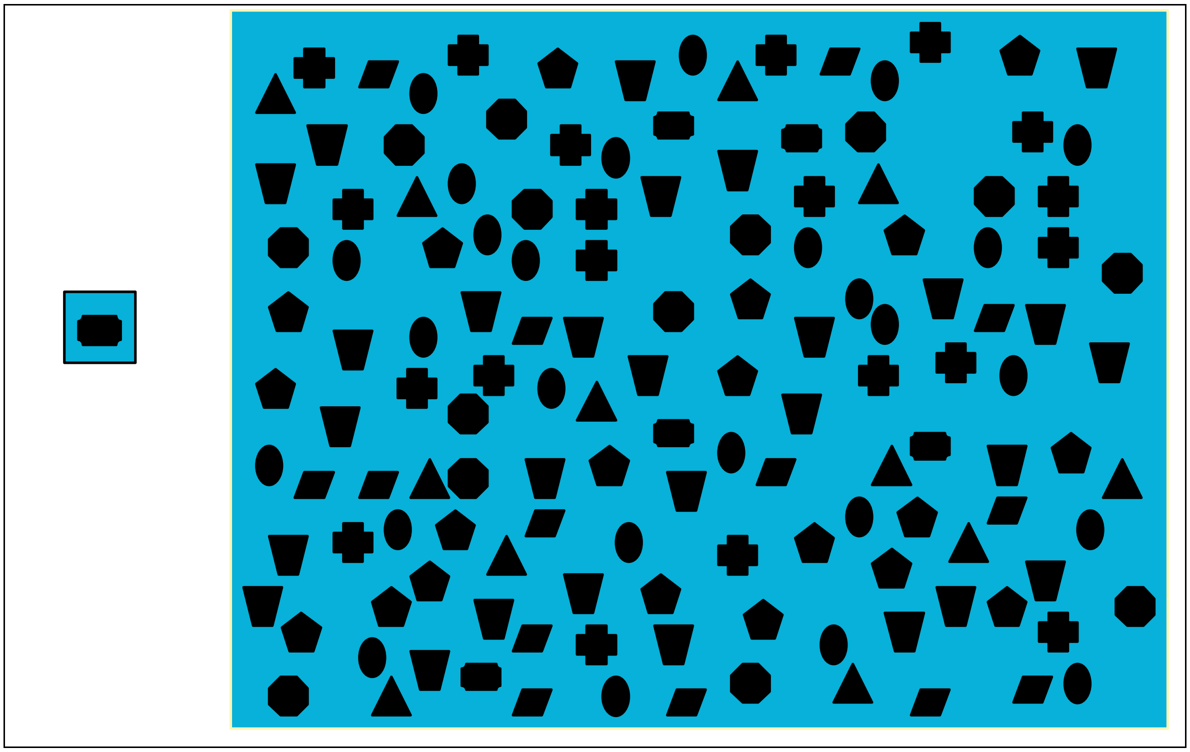


Figure 2: Try the interpretation tasks of selecting the particular shape that is placed on the left hand side and then of associating all examples of this shape as a group

The representational power of shape comes from its infinite length and from symbolic interpretation. A shape can be associated with a meaning and become a sign for that meaning. However, for symbolic meaning to be effective the link between the shape and the intended meaning must be explicit. This symbolic link can be cultural and our alphabets are an excellent example of this. Or this symbolic link can be stated at the time of use for example, in a legend with a map.

6.4 Value

Changing a mark's value is achieved by changes in darkness or lightness of the mark (Table 1, row 4). This provides a range of shades of grey and is considered as independent of changes in colour. That is the value of a mark will be taken as its relative lightness or darkness alone. The extremes in value, white and black can be approached through changes in any hue, such as red or blue. This use of the term value is consistent with its use in the increasingly common HSV (hue, saturation, and value) breakdown of changes in colour space.

Value: Selective. Marks that change in value can easily being distinguished and interpreted as different. In 5Table , row 1, columns 3, 4 and 5 show, respectively, circular, linear and triangular marks that differ value. They are all selectable based on viewing their value. For instance, if asked to select the grey circle from Table 5 row1, column 3, you can do so readily by simply looking at it. A change in value alone is sufficient to allow us to select it. Note in Figure 3 how value remains selectable when the numbers of surrounding signs increases. It is, for instance, quite possible to select the dark grey sign.

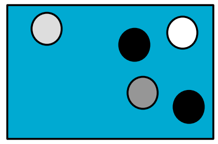
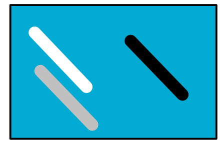
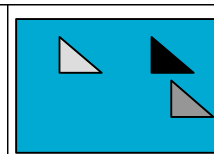
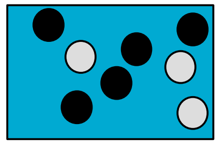
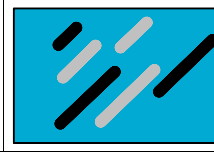
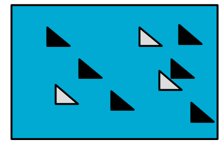
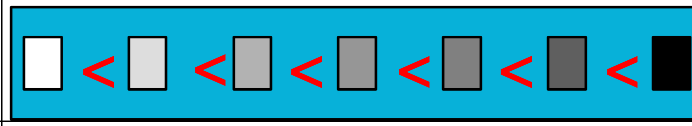
Visual Variable: Value				
✓	selective			
✓	associative			
≠	quantitative			
✓	order			
✓	length	• theoretically infinite but practically limited • association and selection ~ < 7 and distinction ~ 10		

Table 5: Visual variable value and interpretation tasks

Value: Associative. Changes in value are associative since signs that are like in other ways can be grouped according to a change in value (see Table 5, row 2). Also value can be used to group several marks across changes in other visual variables. Note how in Figure 3 this holds true as the number of surrounding signs increases. For example, associating all white signs is readily accessible interpretation task.

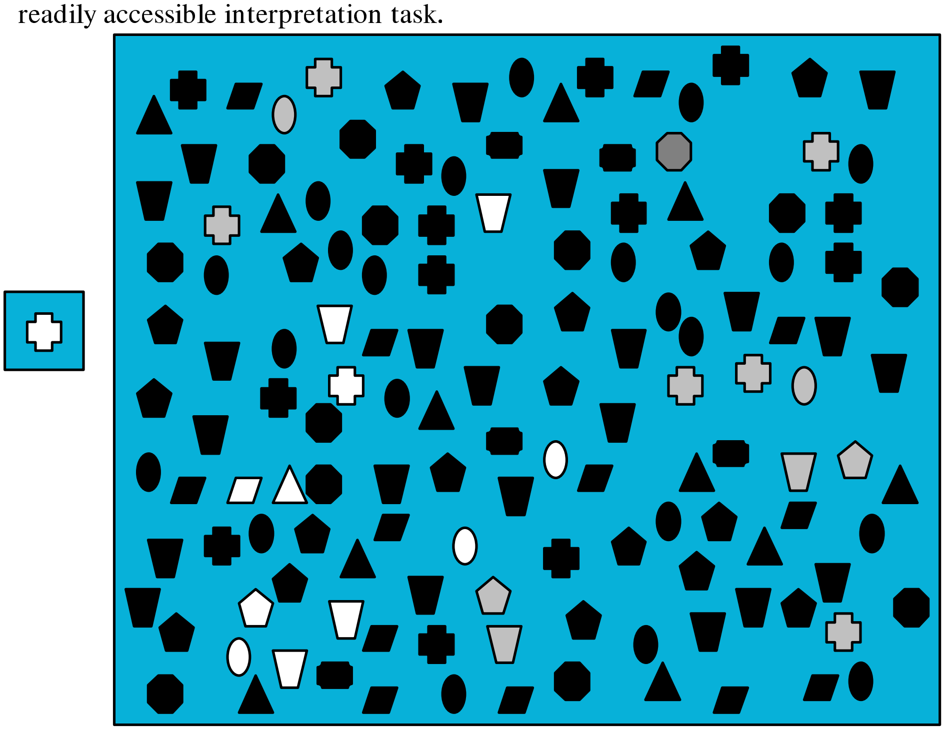


Figure 3: Try the interpretation tasks of selecting a particular value or associating all examples of a particular value as a group

Value: Quantitative. Changes in value do not provide numerical readings since the relationship between two signs differing in value only, is not seen as numerical. For instance, while one grey may be seen as darker or lighter than another grey it will not be seen as say four times as dark as the other grey. Even ratios between shades of grey are not easily visually interpretable. The visual variable value is not quantitative.

Value: Order. Value is ordered since changes in value support ordered readings. That is a change in value will automatically be read as either more or less than the previous value. In fact, changes in value are very powerfully ordered. Significantly so that they will override reading from changes in other visual variables. See the discussion under colour about this.

Value: Length. The number of changes possible in value is theoretically infinite but is practically limited. To retain the facility it provides for selective and associative interpretation tasks it is advisable to limit the length of this variable to six or seven changes that include black and white. If the required reading is between adjacent signs it may be possible to increase this length slightly in that we can interpret changes in shades of grey more readily when there are no visual gaps between.

6.5 Colour

Changing a mark's colour in Bertin's [67/83] terms involves changes in hue without changes in value (Table 1, row 5). On a computational display there are other readily available changes that can loosely be termed changes in colour. These include saturation and transparency. This discussion considers variations in colour that can be achieved at a constant value.

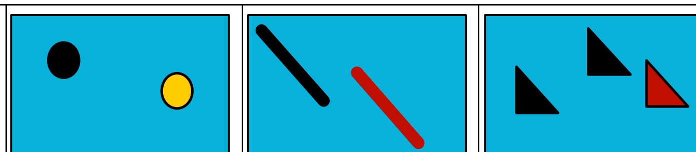
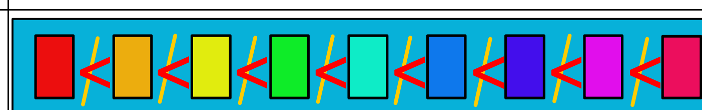
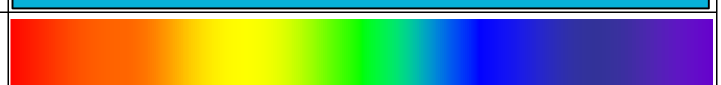
Visual Variable: Colour		
✓	selective	
✓	associative	
≠	quantitative	
≠	order	
✓	length	 • theoretically infinite but practically limited • association and selection ~ < 7 and distinction ~ 10

Table 6: Visual variable colour and interpretation tasks

Colour: Selective. Colour is selective since a mark changed in colour alone makes it easy to select from all the other marks. Table 6 row 1 illustrates how colour is selectable. Figure 4 shows how this selectivity does not break down as the number of marks increases. Colour appears to be particularly selectable for pure and saturated hues.

Colour: Associative. Colour is associative since marks that are like in other ways can be grouped according to a change in colour. Also marks of one colour can be grouped across changes in other visual variables. For example all red triangles in Table 6a row 3 can be thought of as group even if they are in different locations.

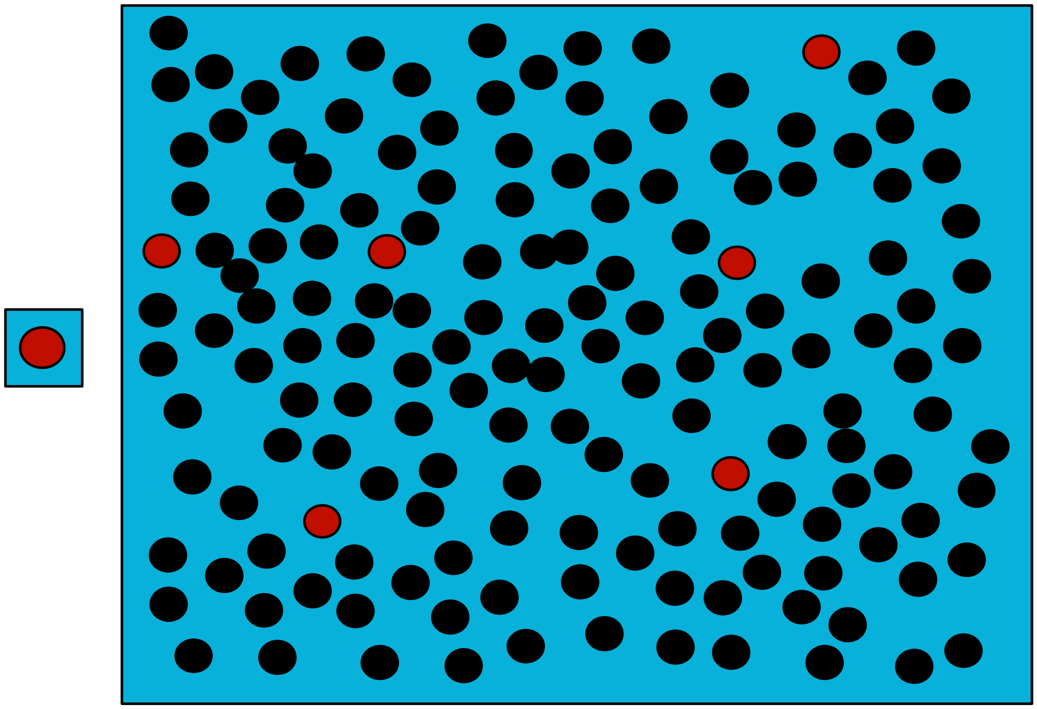


Figure 4: Try the interpretation task of associating all examples of a red as a group

Colour: Quantitative. Colour is not quantitative since the relationship between two marks differing in colour will not be read numerically. For instance, red is not seen as being four times as coloured as blue. There is no numerical reading obtainable from changes in colour.

Colour: Order. Colour is not ordered since changes in colour do not easily lend themselves to readings of greater or lesser. For instance changing a colour from red to green will not been seen having either less colour or more colour. However, it is often said that the rainbow provides an ordered reading for colour. This ordering does not hold up in printed graphics and therefore seems unwise to use in computational visualisation. See the discussion below on colour ordering and the rainbow scale

Colour: Length. Similarly to value, the number of changes possible in colour is theoretically infinite but is practically limited. To retain the facility that it provides for selective and associative interpretation tasks it is advisable to limit the length of this variable to six or seven changes. If the required reading is between adjacent signs it may be possible to increase this length slightly in that we can interpret changes hue more readily when there are no visual gaps between.

Colour Ordering and the Rainbow Scale

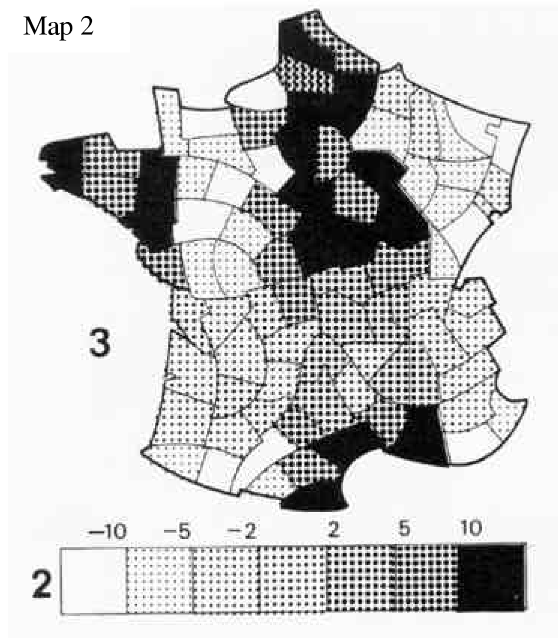
The following example very clearly illustrates several of the points that have been made. It shows what is meant by a visual reading or an easy interpretation at the same time as it illustrates how colour is not ordered and that value dominates colour readings. You can find these maps more extensively discussed on page 86 and 87 in Bertin's book [67/83].

Consider the information given in numbers in map 1. One can see that there are two north-south stripes of negative numbers, one at the eastern border and one along the Atlantic excluding

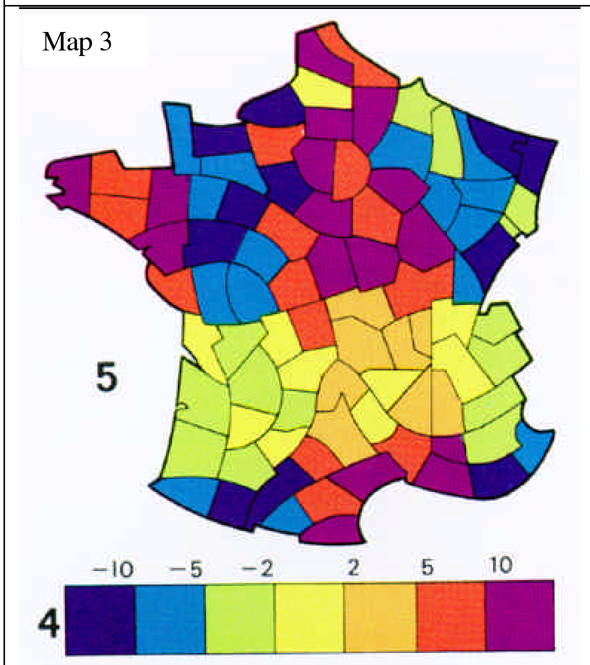
Rainbow Scale Considerations

Map 1

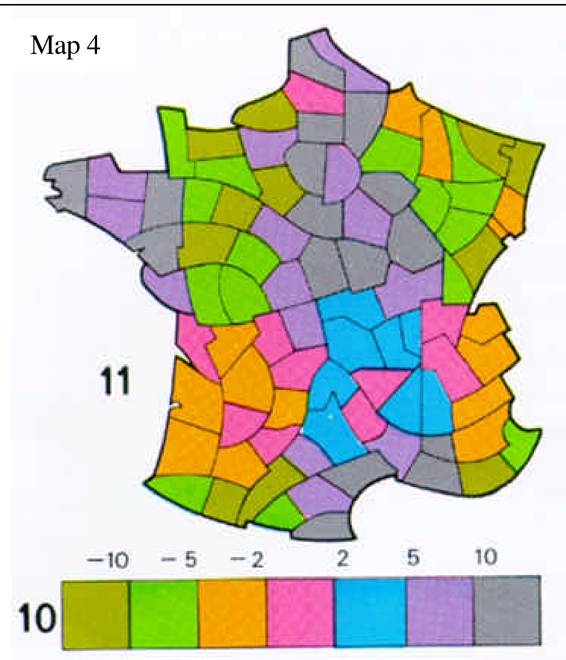
Map 2



Map 3



Map 4



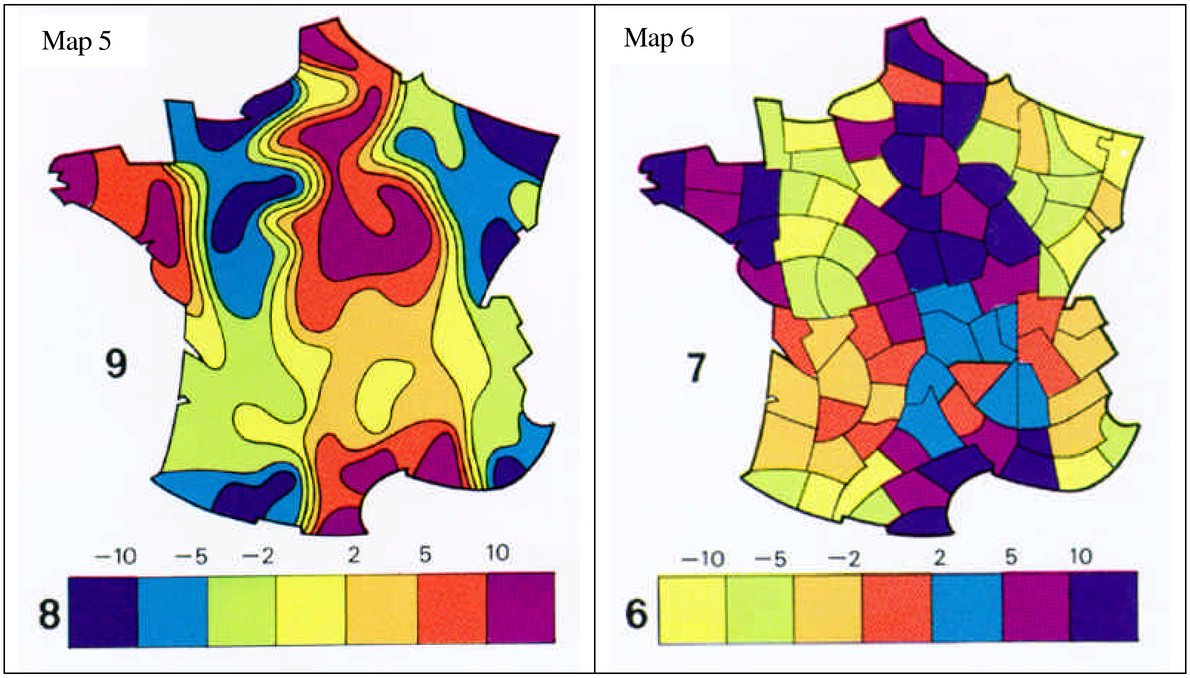


Table 7: A series of maps that illustrates difficulties that arise with use of the rainbow scale

Brittany. Map 2 represents these numbers as changes in value and the result gives a quick north-south reading, providing an easy interpretation of the information in the numbers.

Map 3 uses colour and the rainbow scale. However, this use of colour obscures the data. In fact, in map 3 it appears that the primary patterns in the data have an east-west reading. This is actually incorrect. The immediate visual interpretation follows changes in value instead of the changes in hue. The colours at each end of the rainbow scale (indigo and violet) are dark colours and the eye naturally groups them. Map 4 shows an attempt to retain the use of colour and retrieve an accurate data interpretation. Here the colours have been adjusted so that they are all of the same value (this may not be perfectly true because of colour constancy problems). This attempt at a solution provides a flat reading where distinctions between colours are not as clear. However, it does minimise the east-west reading of the full rainbow scale.

The solution provided in map 5 does use the rainbow scale and provides the correct north-south reading. However, this is done through use of more data. In this map the data values in between the high and low data values are also indicated. Access to increase resolution in the data is not always a possibility. Map 6 provides a relatively simple but effective solution by reordering the colour so their changes in value are aligned with changes in the data.

6.6 Orientation

The orientation of a mark the represents a point can be changed in that it be drawn in an infinite number of different orientations. Changing the orientation of an area or line can be achieved by changing in angle in which a pattern is applied (Table , row 6). These changes in alignment are discernible in 2D presentations such as printed graphics and 2D computational displays. The first limitation is that even in printed 2D graphics the shape of this mark must be distinct in terms of sections of its contour or must be longer in one direction than it is wide. This limitation becomes more acute in a computational display were orientation of lines may already be used to depict perspective. Because of this if one is using 3D computational display then using orientation is problematic.

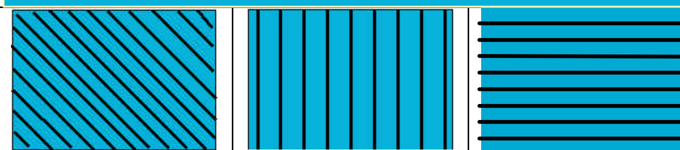
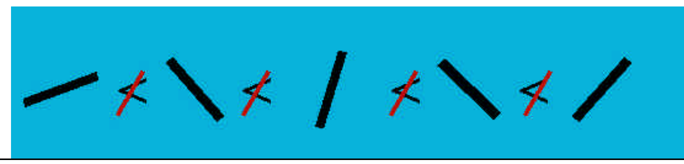
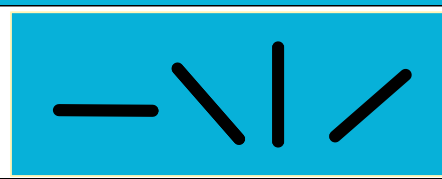
Visual Variable: Orientation		
✓	Selective	
✓	associative	
≠	Quantitative	
≠	Order	
✓	Length	

Table 8: Visual variable orientation and interpretation tasks

Orientation: Selective. Orientation can be selective if the display does not use perspective and if the shape or pattern whose orientation is to be changed has a linear aspect. The answer for this visual variable is that under favourable circumstances orientation can be selective.

Orientation: Associative. As with selection, orientation can be associative if the display is does not use perspective and if the shape or pattern whose orientation is to be changed has linear aspect. The answer for this visual variable is that under favourable circumstances orientation can be associative. While these limitations generally apply, marks and objects that are either vertical or horizontal are quite readily seen as groups.

Orientation: Quantitative. Numerical values, quantities or ratios are not associated with changes in orientation. Changes in angles are used to represent numbers in pie charts. While we do interpret large differences in angle, it has been shown that these numerical interpretations are more difficult when represented as angles instead of length [Ware 2000].

Orientation: Order. There seems to be some notion of order if the changes in orientation are progressive. That is if the changes in orientation are either decreasing or increasing some sense of ordering is provided. On the other hand if they are organised randomly then this sense of order seems to dissipate. Generally it is better to assume that orientation will not be interpreted as ordered.

Orientation: Length. While variations in orientation theoretically infinite, practically it may be wise to limit its use to four variations, vertical, horizontal and two opposing diagonals.

6.7 Discussing Grain, Pattern and Texture

Bertin defines texture to be "texture variation is the sensation resulting from a series of photographic reductions of a pattern of marks" [page 79, 67/83]. This definition fits more closely with what I think of as grain. In fact [page 11, 67/83] contains a translator's note saying that in French, Bertin uses the word grain. A change in grain is achieved by increasing the number of marks without changing the value. Defined in this manner a texture variation is a variation in granularity without a change in pattern or value or hue. For clarity in the rest of this discussion I will use the word grain where Bertin's translator used texture. I will use the word pattern to mean repetitive use of shape (the use of marks upon marks) and keep the word texture for the apparent surface quality of the material like wood or marble. Therefore, when considering how pattern affects the visual interpretative tasks, one can turn to the discussion under the visual variable shape. The discussion that follows on grain parallels Bertin's discussion on texture. After that I will look briefly at texture as a surface quality.

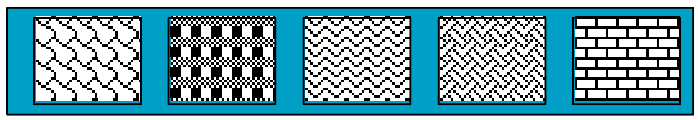
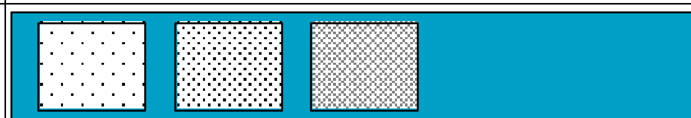
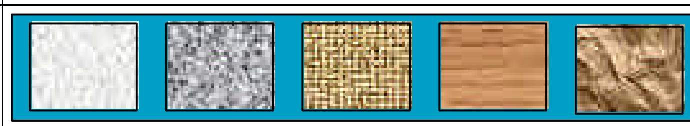
Pattern	repetitive use of shape variations	
Grain	varying granularity	
texture	a characteristic of the material	

Table 9: Variations in pattern, grain and texture.

6.8 Grain

Any colour or value except the extremes, black and white, can support variations in grain.

Grain: Selective. A grain can be selective; in fact, changes in grain can be very noticeable sometimes to the point of being visually irritating. Bertin suggests the careful use of this vibratory effect can provide powerful emphasis, stressing that it is the designers responsibility to ensure that this effect is not over done. [Tufte87] has several examples that over use this effect and definitely interfere with general readability.

Grain: Associative. Grain is minimally associative but as with selectivity the irritating effect can counteract the usefulness of this. For instance, in Table 10, row 2 the crosshatched bars can be grouped.

Grain: Quantitative. Grain is does not support numerical interpretations.

Grain: Order. Grain is not ordered expect if the changes in grain are often accompanied by changes in value.

Grain: Length. The larger the mark the more length there is for grain. Its use is dependent the size of the point and on the thickness of the line. Across approximately five changes in grain the interpretation tasks of selection and association are still effective.

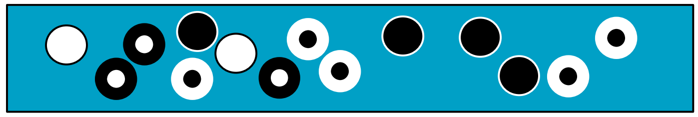
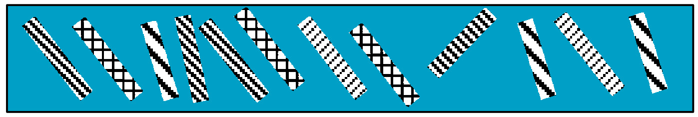
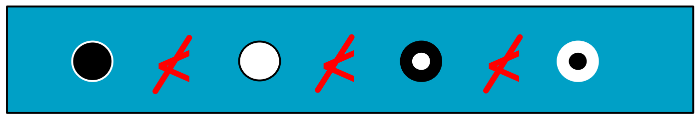
Visual Variable: Grain		
✓	Selective	
✓	associative	
≰	quantitative	
≰	order	
✓	Length	• theoretically infinite but practically limited association and selection ~ < 5

Table 10: Visual variable grain and interpretation tasks. This is discussed as texture in Bertin's book

6.9 Pattern

When considering how pattern affects the visual interpretative tasks, one can turn to the discussion under the visual variable shape.

6.10 Texture

Changing a mark's texture is achieved by any change in the apparent surface quality of the mark (Table 11). Note the careful distinction between pattern, which is the use of marks upon marks, grain as just discussed and the use of texture. Texture can be considered to be a surface property of the material of the mark.

Texture: Selective. Texture is selective since a mark changed in texture alone makes it possible to select the changed mark from all the other marks. Table 11, row 1, a change in texture from sand to grass to bricks is readily distinguishable.

Texture: Associative. Texture is associative since marks that are like in other ways such as shape can be grouped if they have the same texture. With texture this grouping can go further. Objects can be grouped by texture type. For instance, in Table 11 row 2, all floral textures can be thought of as a group.

Texture: Quantitative. There is no numerical interpretation of texture.

Texture: Order. Are changes in this texture are not perceived as ordered unless they are associated with changes in value.

Texture: Length. The visual variable texture has considerable length. There are not only many different textures there are many types of different textures.

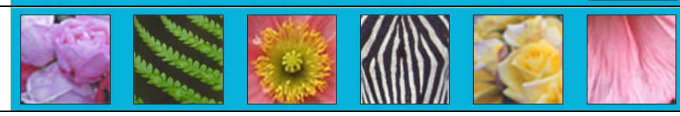
Visual Variable: Texture		
✓	selective	
✓	associative	
≠	quantitative	
≠	order	
✓	Length	• theoretically infinite

Table 11: Visual variable texture and interpretation tasks

6.11 Motion

In the physical world we are very sensitive to motion and can detect changes in motion even in out peripheral field of vision. In printed graphics use of motion was not a possibility. In computational displays, while it is a possibility, it has been little used in information representation and little investigated. There are many aspects to motion that can be changed. These include: direction, speed, flicker, frequency, rhythm, style, onset, etc. The following is intended to be just preliminary discussion.

Motion: Selective. Since motion is one of our most powerful attention grabbers it is probably selective.

Motion: Associative. Objects moving in unison are grouped effectively. In fact, objects moving in unison may be thought of as being united.

Motion: Quantitative. It is likely that there is no numerical reading obtainable from changes in this motion. However, changes in speed or frequency or other characteristics of motion may prove to be distinguishable in this manner.

Motion: Order. Motion may be ordered. Speed may be one characteristic by which motion can be ordered.

Motion: Length. There are a considerable variety of motions.

Discussion of the Use of Visual Variables on a Computer

This report has discussed Bertin's concepts about visual variables [Bertin 67/83] in context of their use in information visualisation on computational displays. Though the distinctions and variations use of computer brings to this concept has been mentioned; it has not yet been fully investigated. Some of these differences include:

- The addition of surfaces and volumes to types of marks,
- The addition of the third dimension in positional variables,
- The separation of colour into hue, saturation and value. (in this document changes in hue are discussed as changes in colour, changes in value are discussed as changes in value and changes in saturation are not discussed.)

- The visual variable orientation loses much of its usefulness because of its interference with perspective presentations.
- I have left pattern, as did Bertin [Bertin 67/83], to be considered as repetitive variation in shape. This should be re-assessed.
- Since use of texture is so readily available in computational displays, I have reverted to the term Bertin [Bertin 67/83] used in French 'grain' and introduced texture as a change in surface quality.
- I have just touched on the possibilities of motion.
- There are other possibilities such as depth, occlusion, and transparency, which should be addressed.

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