The language of graphics
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CHAPTER 2

Graphic Syntax

It seems appropriate to start our exploration of ‘graphic syntax’ with a look at ‘syntax’ in language. Let us first note that meaning depends on structure.

“Part of what a sentence means depends upon its separate words, and part depends on how those words are arranged.”

Minsky (1985, p. 266)

In a similar way, part of what a graphic representation means depends upon the graphic objects that it contains, and part depends on how those graphic objects are arranged.

“No matter what their form or purpose, all graphics consist of elements arranged in space. Both the characteristics of the elements and their spatial arrangement are used to communicate.”

Tversky (in press)

Several authors have proposed to apply a notion of ‘grammar’ or ‘syntax’ to spatial arrangement in graphic representations.

“Although we can distinguish between sentences and diagrams, in that amongst other things the former have a one-dimensional, one-directional scheme to order their elements, and the latter have the potential to utilize fully two (or even three) dimensions, both make use of a grammar to establish their meaning.”

Richards (1984, p. 10/2-10/3)

“Spatial parsing is the process of recovering the underlying syntactic structure of a visual communication object from its spatial arrangement.”

Lakin (1987, p. 684)
"A grammar is the set of rules for combining symbols, whether the symbols are words or pictures."

Horton (1994, p. 124)

"The spatial syntax of a visual language refers to the system of visual grammar rules that govern the spatial arrangement of components within a visual representation."

Engelhardt et al. (1996, p. 2)

All of these quotes refer directly or indirectly to spatial arrangement. However, in addition to spatial relations, structure and meaning in graphic representations may also involve attribute-based relations. Attribute-based relations may for example involve the relative sizes of graphic objects, or varying degrees of brightness (see the discussion of visual attributes in 2.4). The concept of ‘graphic relations’ can serve as a superordinate concept that includes spatial relations as well as attribute-based relations. In summary, we can take the originally language-related quote from Minsky on the previous page, and adapt it for graphic representations, saying that:

Part of what a graphic representation means depends upon the graphic objects that it contains, and part depends on the graphic relations that those graphic objects are involved in.

The decomposition of graphic representations into graphic objects and the graphic relations they are involved in, lies at the core of this chapter (2). In the first section (2.1), we will provide an overview of our approach to graphic syntax and its recursive nature. We will then briefly explore graphic space (2.2), which is the substrate of all spatial relations within graphic representations. After that we will take a brief look at graphic objects (2.3) and their visual attributes (2.4). By far the longest section is the last one (2.5), in which we will explore the various types of basic and composite syntactic structures into which graphic objects can be arranged within a graphic space.
2.1 Overview of Graphic Syntax

Richards justly cautions us that “Whilst certain parallels between the grammatical structure of language and the graphical structure of diagrams may be useful, particularly for providing descriptive terms, care must be taken not push too far such similarities as there may be.” (Richards 1984, p. 3/2). Having been warned about the endeavor, we have nevertheless taken up the challenge.

In this section we will provide an overview of the proposed approach to syntactic composition and decomposition in graphic representations. First let us briefly consider the principle of compositionality of meaning, as it is referred to in the field of formal linguistics.

“[...] the semantics must specify the interpretation of an infinite number of expressions, but in a finite manner. The obvious way to proceed, then, is to let the definition of the semantics parallel the finite, recursive definition of the syntax. This method ensures that to every syntactic rule which allows us to construct a certain type of expression out of one or more simpler ones a semantic rule corresponds, which states how the interpretation of the newly formed expression is to be obtained from the interpretations of its component parts. Succinctly put, [...] the interpretation of a complex expression is a function of the interpretations of its parts. This is the principle of compositionality of meaning, also referred to as ‘Frege’s principle’.”

Gamut (1991, p.140)

A recursive definition of syntax seems appropriate also for graphic representations, in order to account for the fact that a collection of graphic objects, arranged in some spatial structure, often functions as a single graphic object within a spatial structure at a higher level. This phenomenon of nesting is discussed in section 2.1 and further in subsection 2.5.4. In order to achieve a recursive definition of syntax we will refer to a graphic representation as a graphic object, and we will also refer to its graphic constituents as graphic objects. The main principles of the proposed approach to graphic syntax can be summarized as follows:
A graphic representation is a **graphic object**. 

A graphic object may be:
- an **elementary graphic object**, or
- a **composite graphic object**, consisting of:
  - a **graphic space** that is occupied by it, and
  - a set of **graphic objects**, which are contained within that graphic space, and
  - a set of **graphic relations** in which these graphic objects are involved.

**Syntactic decomposition** of a graphic representation:

![Diagram](image)

**FIGURE 2-01**: The proposed syntactic decomposition of graphic representations. A graphic object may itself be a composite graphic object, thus this decomposition can be applied recursively.
Recursive application of the proposed syntactic decomposition:

**FIGURE 2-02:** An illustration of the recursive nature of the proposed decomposition.
We can summarize:

A composite graphic object is a graphic object that consists of a graphic space, a set of graphic objects that are contained in this graphic space, and a set of graphic relations in which these contained graphic objects are involved.

Since a graphic object may itself be a composite graphic object, this analysis applies recursively. This means that a complex graphic representation can be regarded as a nesting of simpler graphic representations. The graphic objects at the lowest level of decomposition are referred to as elementary graphic objects.

Formulating the approach the other way around, regarding composition instead of decomposition, we can state that in order to make a composite graphic object, we make use of a graphic space, of graphic objects that we place in that graphic space, and of graphic relations that we let these graphic objects participate in. Graphic relations may be object-to-space relations or object-to-object relations, both of these will be discussed in section 2.5.

According to the ‘compositionality of graphic meaning’, the semantic analysis of the meaning of a graphic representation parallels the syntactic analysis of its structure.

The interpretation of a graphic object may be:

- an interpretation of it as an elementary graphic object, or
- an interpretation of it as a composite graphic object, constructed from:
  - the interpretations of the graphic objects that are part of it, and
  - the interpretations of the graphic relations in which these graphic objects are involved, which may partly be based on the interpretation of the graphic space in which they are arranged.

In this way the interpretation of a complex graphic representation (a composite graphic object) may be derived through several nested levels of interpreting constituting graphic objects, and interpreting the ways in which these are combined (their graphic relations).

As an illustration of the proposed approach, let us take a look at figure 2.03. Like all of the boxed example figures in this thesis, figure 2.03 comes with a standardized figure caption, in which the figure is analyzed in terms of the specific concepts that are explained in Chapters 2, 3 and 4 (e.g. ‘integral metric space, shared-axis multipanel, metaphoric correspondence’, etc.).
In contrast to this standardized analysis in the caption of figure 2-03, the analysis given in the text here below is of a slightly different character: it does not contain the specific terminology from the chapters to come, but it serves to illustrate the general syntactic approach outlined above, emphasizing its recursive nature.

At the first level of syntactic decomposition we can regard figure 2-03 as a graphic space containing two sub-objects: a complex map-object and a legend-object (note that while the legend-object could be positioned anywhere with regard to the map-object, the chart-objects are anchored at one layer deeper, within the map-object). The graphic relation between the map-object and the legend-object is one of superimposition, which is one of the possible basic object-to-object relations.

At the second level of decomposition, let us choose the map-object for further analysis. The graphic space of the map is a meaningful space (every spatial position carries meaning, regardless of the presence or absence of graphic objects). Graphic sub-objects that participate in object-to-space relations are the surface locators that mark the vegetation zones (in the original these have different colors), the point locators that mark the positions of the cities, the line locators that mark the rivers, and the grid lines that mark longitude and latitude. Graphic sub-objects that participate in object-to-object relations are all the label-objects that are attached to the objects mentioned above. These include the longitude- and latitude-labels that are attached to the grid lines, the names of the cities that are attached to the city-dots, and the chart-objects, which are complex label-objects that are also attached to the city-dots.

At the third level of decomposition, let us choose one of the chart-objects for further analysis. The graphic space occupied by such a chart-object can be regarded as containing two sub-objects: a line chart and a bar chart. The graphic relation between these two charts is a lineup, which is one of the possible basic object-to-object relations.

At the fourth level of decomposition, let us choose one of the bar charts for further analysis. The graphic space of the bar chart is a meaningful space. Graphic sub-objects that participate in object-to-space relations are the metric bars of the bar chart and the grid lines. Graphic sub-objects that participate in object-to-object relations are the label-objects that are attached to the grid lines.

In the course of this recursive application of the proposed syntactic decomposition, we have mentioned many different roles that graphic objects may play within a graphic representation: ‘surface locators’, ‘point locators’, ‘line locators’, ‘grid lines’, ‘label-objects’, and ‘metric bars’. All of these are examples of what we will refer to as different syntactic roles of graphic objects. An inventory and discussion of such different syntactic roles is provided in subsection 2.5.3.
COMMENT: This figure serves to illustrate the recursive nature of the proposed syntactic decomposition (e.g. the bars in the little bar charts are 'graphic objects within graphic objects'). The figures in the next sections will serve to illustrate the very basic structural principles from which composite graphic structures such as this one can be constructed.
Continued caption for figure 2-03:
SYNTAX OF SPATIAL STRUCTURE (2.5): At the highest level of decomposition, this is a background-inset display. (The legend-object on the lower left is an inset on the complex map-object; as opposed to the chart-objects, the legend-object does not participate in the geographic spatial positioning of the map-object). The background (the map) consists of an integral metric space that contains various objects: surface locators (marking the vegetation-zones), point locators (marking cities), line locators (marking rivers), and labeled grid lines (marking longitude and latitude). In addition, each point locator (city-dot) has both a simple and a composite label (a name and a chart) attached to it. The composite labels (the charts per city) are graphic multiples of a shared-axis multipanel (here: a two-panel) which consists of two composite metric spaces, one above the other. Both of these composite metric spaces (the single charts) are constructed from two orthogonal metric axes. The horizontal one of these metric axes is their shared axis (representing the course of a year). The upper of the composite metric spaces (the line chart) involves a line locator, grid lines and labels, the lower one (the bar chart) involves a lineup of metric bars, grid lines and labels. The superimposed inset (the legend of the map) consists of a lineup with labels.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The integral metric space of the map involves literal correspondence (physical arrangement on the map stands for physical arrangement in the world), while the metric axes of the charts involve metaphoric correspondence (e.g. graphic space metaphorically stands for time). VISUAL ATTRIBUTES: The shapes of the alphanumeric labels involve arbitrary-conventional correspondence (the shapes of the letters of the alphabet involve convention) while the heights of the bars in the bar chart involve metaphoric correspondence (height metaphorically stands for amount of rain).

TYPE OF GRAPHIC REPRESENTATION (4): A map, with embedded statistical time charts. (Statistical time chart = both a statistical chart and a time chart.)

Note that for the sake of simplicity, we have not discussed attribute-based graphic relations in the example above, such as those created by the colors of the different vegetation zones, or by the sizes of the bars in the bar charts.

In most of the existing literature, syntactic approaches to graphics do not include a notion of recursion. A notable exception is Lakin's (1987) examination of 'formal visual languages'. For the bars in bar chart for example, Lakin offers two parsing rules: One rules states that a list of bars may be a bar plus a list of bars (i.e. a list of bars consists of its first bar, plus the list of the remaining bars). The second rule states that a list of bars may simply be a bar. The first rule can be applied recursively (e.g. applying it twice, we learn that a list of bars may be a bar plus a bar plus a list of bars), with the second rule serving as the 'stop condition' (e.g. applying it to the above, we learn that a list of bars may be a bar plus a bar plus a bar). In this way, "the grammar can
handle bar charts with an arbitrary number of bars” (Lakin 1987, p. 686). Unfortunately, Lakin does not offer a generally applicable framework of graphic syntax that would enable the analysis of a wide range of graphic representations. Such an endeavor is a challenge that we will take up in this thesis.

Further on in this chapter we will discuss graphic objects and graphic relations in detail. But first we will now take a look at graphic space, which is the medium in which graphic objects and their graphic relations ‘live’.
2.2 Graphic Space

GRAPHIC SPACE AS A MENTAL CONSTRUCTION

Imagine a standard drawing of a cube. The drawing is perceived as showing a three-dimensional cube, which has right angles at all its corners. However, many lines of the (flat) drawing itself do not actually form right angles with each other. Imagine a topographic map. The map may show a road crossing a river, where we ‘see’ that the river crosses ‘underneath’ the road, while on the (flat) map there actually is no river drawn underneath the ink that indicates the bridge (see visual layers, discussed below). What we see when we look at a graphic representation is a mental construction. It is a result of the mechanisms of human visual perception. These mechanisms involve the principles of perspective and the principles of Gestalt perception.

Throughout this thesis, whenever I talk about the spatial structure of a graphic representation, I will mean the spatial structure that we ‘see’ in the representation, as opposed to the spatial structure into which the marks (e.g. ink, pixels) are arranged on the presentation surface. In other words, our notion of spatial structure will not concern the physical space of the presentation surface, but the two-dimensional or three-dimensional graphic space that is displayed on that presentation surface. See the front cover of this thesis for an example of a three-dimensional graphic space. We have noted above that even a map depicts (an aerial view of) a three-dimensional space, in which a bridge visually occludes the river running ‘beneath’ it.

In the creation of a graphic representation there is the step of projection and rendering, in order to produce the actual ink- or pixel-pattern that will hopefully lead to the mental construction, the ‘mental diagram’ that we want the viewer to see. This step involves the careful application of principles of perspective and principles of Gestalt perception. In this thesis we will not deal with this step of projection and rendering - our concern rather is with the ‘virtual’ or ‘mental’ pictures that we see when looking at graphic representations.

VISUAL LAYERS: A COMMON PHENOMENON IN GRAPHIC SPACE

As mentioned above, even in seemingly two-dimensional graphic representations graphic objects are often perceived as occupying different visual layers, where some graphic objects appear as being superimposed on other graphic objects, partially occluding them. Visual layers lie at the basis of superimposition as one of the possible types of object-to-object relations (discussed in 2.5.1), and background-inset displays, which are superimpositions of composite objects on each other. In other composite spatial structures, a visual layer ‘in front’ may be used to provide elements that are ‘secondary’
to a ‘primary’ spatial structure ‘behind’ it. Labeling for example (discussed in 2.5.1) can be regarded as occupying a visual layer ‘in front’ of the structure that is labeled. Graphic objects that play different syntactic roles (discussed in 2.5.3) may occupy different visual layers: from ‘back’ to ‘front’, a common ordering of graphic objects is a) volume and surface locators, b) line locators, c) point locators and connectors, and d) labels.

In section 3.3 we will distinguish information objects from spatial reference objects and legend objects. Spatial reference objects such as grids tend to occupy a visual layer ‘behind’ the layer of the information objects. Legend objects on the other hand - if they are perceived to occupy a different visual layer - tend to be ‘in front’, serving as an inset in a background-inset display.

The phenomenon of visual layers is often referred to as ‘figure-ground’ perception. It has been noted in various texts on graphic representation. Bowman (1968 p. 18) refers to ‘multi-plane space’. Tufte (1990 pp. 52-65) devotes a chapter to ‘layering and separation’. MacEachren (1995 pp. 120-123) discusses ‘visual levels’. Although they use different terminology, they all mean what we are describing here as visual layers. In the context of maps, which sometimes have superimposed legends, MacEachren (1995 p. 122) points out that layers may exist within layers, giving the example of a road crossing a stream. He suggests that the notion of a continuum of visual layering may be more appropriate than the notion of a limited number of visual layers.

The phenomenon of visual layers of superimposed objects should not be confused with the phenomenon of superimposed metric axes. An example of superimposed metric axes is the clock face, which is a superimposition of two circular metric axes. One circular metric axis is divided into twelve hours, the other is divided into sixty minutes. The clock has two hands, each of which is interpreted according to its ‘own’ axis (hours or minutes). Superimposed metric axes do not necessarily involve visual layers of superimposed objects. The two upper panels of figure 2-46 (illustrating the menstrual cycle) both involve vertical superimposed metric axes, in order to be able to show the curves for two different substances in the same chart. One axis is labeled on the left of the chart, the other axis is labeled on the right of the chart. Wilkinson refers to superimposed axes as “double (or multiple) axes” and says that they “generally should be avoided” (Wilkinson 1999, p. 334). The appropriate alternative design for a chart with superimposed axes would be a shared-axis multipanel (subsection 2.5.4).
THE NOTION OF GRAPHIC OBJECTS

It was noted in section 2.1 that we will regard a graphic representation as a graphic object, and we will also regard the graphic constituents of a graphic representation as graphic objects. This notion of graphic objects incorporates the recursive notion of composite graphic objects and their graphic sub-objects (discussed in section 2.1 and shown in figures 2-01 and 2-02):

A composite graphic object consists of a graphic space that contains a set of graphic sub-objects. A graphic sub-object may be a composite graphic object itself, or it may be an elementary graphic object.

A graphic object is a ‘carrier’ of visual attributes such as size, shape and color. Often a graphic object is equated with its shape, and the shape is regarded as the ‘carrier’ of the other visual attributes (e.g. “a large red square”). Visual attributes are discussed in section 2.4.

ELEMENTARY GRAPHIC OBJECTS

The graphic objects at the most detailed level of a syntactic decomposition are referred to as elementary graphic objects. The level of detail of a syntactic decomposition will usually be chosen such that, with regard to semantics, an elementary graphic object will be a ‘basic-level’ meaningful object (often standing for some concept, entity, or occurrence).

Useful levels of detail for distinguishing meaningful graphic objects depend on the function of the graphic representation in its communicational context and on the goal of the compositional analysis. For example, for the schematic human figure depicted on a bathroom door, it will usually seem appropriate to regard it as an elementary graphic object. Likewise, for a symbol that depicts a knife and a fork, functioning to indicate a restaurant, it will usually seem appropriate to regard it as a single elementary graphic object. For the traffic sign indicating a bike path however - a white pictogram of a bicycle on a circular blue background, it is appropriate to regard it as a composite graphic object consisting of two elementary graphic objects - the pictogram of the bicycle, and the blue circular background. For a map it will usually seem appropriate to regard it as a composite graphic object consisting of many graphic sub-objects. For a complex graphic representation (e.g. a data-rich, multipanel computer visualization) it may be appropriate to decompose it at several levels, into nested, increasingly smaller graphic objects. For example, a legend of a map that is displayed as a box-shaped, superimposed
inset, can be regarded both as a sub-object of the map, and also as a composite object, composed of various sub-objects itself. Figure 2-03 is such an example of a graphic representation in which graphic objects can be distinguished at several levels of detail.

This notion of elementary graphic objects corresponds to Richards’ notion of ‘significant elements’. Significant elements are “the smallest meaningful components” (Richards 2002, p. 93), and “the primary units of analysis” (Richards 1984, pp. 1/9, 3/13). Richards justly points out that it depends on the intentions (assumed intentions, I would say) of the graphic representation whether a particular collection of marks should be regarded as one single element or as several separate elements (Richards 1984, p. 3/14, 3/25, and 2002, p.88).

If we would really want to pursue the comparison to a linguistic analysis, we could regard the proposed notion of elementary graphic objects in graphic representations as corresponding to the notion of morphemes in language. Morphemes are the smallest meaningful components of speech. The word ‘sleepwalking’ for example consists of three morphemes, ‘sleep’, ‘walk’, and ‘-ing’. Graphic objects could be regarded as corresponding to constituents in a linguistic analysis, which can be distinguished at various nested levels. In the subsection on object-to-object relations, we will see that even the linguistic distinction between free morphemes and bound morphemes could possibly be made in graphic representations. Free morphemes are morphemes that can occur by themselves (e.g. ‘sleep’, ‘walk’). Bound morphemes are morphemes that are always attached to other morphemes (e.g. ‘-ing’). In graphic representations, more specifically in composite symbols, content objects (e.g. a drawing of a cigarette) could be regarded as corresponding to free morphemes, while modifier objects (e.g. a red cross over the cigarette) could be regarded as corresponding to bound morphemes (see the discussion of composite symbols in subsection 2.5.1). Concerning this issue of a possible linguistic counterpart of elementary graphic objects, I might disagree with Richards here. In his characterization of ‘significant elements’, Richards states that “if we are going to use linguistics as a model, then what is needed for present purposes is not the pictorial equivalent of a phoneme or morpheme but something closer to a noun phrase” (Richards 1984, p. 3/13).
2.4 Visual Attributes

"The nature of the pigments provides the basis for sensations of light and color; that is, brightness, hue and saturation. The geometrical demarcation of these qualities provide the physical basis for perception of areas and their shapes. Altogether, these factors constitute the vocabulary of the language of vision [...]" (p.16).
"Positions, directions and differences in size, shape, brightness, color and texture are measured and assimilated by the eye." (p. 20)

Gyorgy Kepes (1944)

In the quotes above, Gyorgy Kepes lists the visual ‘factors’ that were later proposed by Jacques Bertin (1967/1983), and subsequently picked up by many authors on graphic representation: position, direction (referred to by Bertin as orientation), and differences in size, shape, brightness, color and texture. We will refer to these ‘factors’ as visual attributes.

A visual attribute is a visually perceivable attribute of a graphic object.

Visual attributes have been discussed thoroughly in the existing literature. In this section we will therefore confine ourselves to providing a brief general inventory of visual attributes.

For convenience, I propose to divide visual attributes into two groups, which I will call spatial attributes and area-fill attributes. In Bertin’s illustration, reproduced here as figure 2-05, what I will regard as area-fill attributes are the two attributes shown on the right - value (V) and grain (T), and the attribute shown at the bottom - color (C). The remaining attributes - orientation, shape, size, and the two spatial dimensions of the plane, fall in my category of spatial attributes.

If we would regard every point of a graphic object as being anchored to its location in graphic space, then varying a spatial attribute of the object would alter this anchoring (at least for some points), while varying an area-fill attribute of the object would not alter this anchoring.
COMMENT: The figure shows Bertin’s set of “visual variables” that can be used in graphic representations: size (Si), value (V), grain (T), color (C), orientation (Or), shape (Sh), and the two spatial dimensions of the plane (2PD).
Spatial visual attributes, according to the definition given above, are spatial position, size, shape, and orientation. In this framework spatial position is treated separately, in the context of syntactic structures (2.5). Size is a versatile attribute. Variations of the size of a graphic object may be homogeneous in all directions, or they may be restricted to the height, length or width of the graphic object. Two special cases of the use of size are proportional division (which is about the sizes of sub-objects) and proportional repetition (which is about the sizes of composite objects). Proportional division is discussed further down in this section, and proportional repetition is discussed in subsection 2.5.1. A shape may be regarded both as a visual attribute and as a graphic object - a graphic object is often equated with its shape, which is regarded as the ‘carrier’ of the other visual attributes.

Area-fill attributes can be divided into color attributes and texture attributes. Color attributes are usually subdivided into hue, saturation, and brightness. Bertin’s ‘value’ refers to brightness (light versus dark). Bertin’s ‘color’ refers to “the repertoire of colored sensations which can be produced at equal value” (Bertin 1983, p. 61). Later authors have split Bertin’s ‘color’ into hue and saturation. Texture attributes have become almost obsolete these days, through the wide-spread possibility of using color instead. Texture attributes can be subdivided with regard to the spatial attributes (defined above as including size, shape, and orientation) of the involved texture elements (e.g. hatch lines). This means that we can distinguish size of texture elements, shape of texture elements, and orientation of texture elements. There has been some slight confusion regarding Bertin’s treatment of texture. What Bertin means with the French term ‘grain’ is “the fineness or coarseness of the constituents of an area” (Bertin 1983, p. 61), which is our size of texture elements. Another appropriate term may be ‘granularity’ (Wil-
kinson 1999, p. 118). However, Bertin’s French ‘grain’ was translated with the broader and therefore somewhat misleading term ‘texture’ in the 1981 and 1983 translations of his work, which Bertin enormously regrets now (Daru’s interview with Bertin, 2000). In his more recent English publications Bertin translates his French ‘grain’ with the English ‘grain’ (Bertin 2000). For a discussion of different approaches to texture attributes see MacEachren 1995 (p. 272-275).

Intended as additions to the set of visual attributes listed above, MacEachren has proposed clarity attributes, for example transparency of fill and crispness (or ‘fuzziness’) of edges (MacEachren 1995, pp. 275-279 and 2001, p. 28). Transparency and crispness can be suitable for the graphic representation of uncertain information. Both transparency and crispness are also mentioned by Wilkinson, although Wilkinson uses the term ‘optics’ for MacEachren’s ‘clarity’ and the term ‘blur’ for MacEachren’s ‘crispness’ (Wilkinson 1999, pp. 132, 162). Regarding our dichotomy, transparency of fill is clearly not a spatial but an area-fill attribute. Crispness of edges however may fall outside this distinction.

We will return to the set of visual attributes in section 3.4, where we will make some brief remarks about the matching of different types of information to the appropriate graphic means for representing them.

A SPECIAL CASE OF USING SIZE: PROPORTIONAL DIVISION

A common way to graphically represent percentages of some total quantity is the proportional division of a graphic object. In a proportional division the total surface or volume of a graphic object is divided into sub-objects, and the relative sizes of these sub-objects are subject to interpretation. Proportional division is common along both circular and rectilinear dimensions. A pie chart, like the one shown in figure 2-04, involves a proportional division along a circular dimension. A stacked bar like those shown in figure 2-26 (illustrating offshore dumping of radioactive waste) involves a proportional division along a rectilinear dimension.
2.4 Visual attributes

FIGURE 2-06: ‘Disposition of a family income of $900 - $1000’.
SOURCE: Brinton 1914, p. 6.
COMMENT: This figure serves to illustrate proportional division.

SYNTAX OF SPATIAL STRUCTURE (2.5): A proportional division of a composite graphic object along a circular axis. The segments contain graphic sub-objects and labels.

TYPE OF CORRESPONDENCE (3.1): VISUAL ATTRIBUTES: The proportional sizes of the pie slices can be regarded as involving metaphoric correspondence (the size of a pie slice does not stand for some physical size but for a percentage of the total of financial expenses). The shapes of the contained pictorial objects can be regarded as involving literal and metonymic correspondences.

TYPE OF GRAPHIC REPRESENTATION (4): A statistical chart.

Having discussed graphic space, graphic objects and visual attributes, we will now turn to a main theme of this thesis: syntactic structures in graphic representations.
# 2.5 Syntactic Structures

In this section we will explore the syntactic structures of graphic representations.

The **syntactic structure** of a composite graphic object is a set of **graphic relations** in which its constituent graphic objects are involved.

Together, *graphic space* (section 2.2), the *graphic objects* contained in it (section 2.3), and their *visual attributes* (section 2.4), could be regarded as the 'ingredients' of graphic representations. *Graphic relations* are the ways in which these 'ingredients' are combined into syntactic structures (usually meaningful ones). In this section we will first examine syntactic structures consisting of object-to-object relations (section 2.5.1), and then syntactic structures consisting of object-to-space relations (section 2.5.2). After making an inventory of the **syntactic roles** that graphic objects may play within a syntactic structure (section 2.5.3), we will finally discuss some specific aspects of composite syntactic structures (section 2.5.4).

Types of **graphic relations** that graphic objects may be involved in:

<table>
<thead>
<tr>
<th>object-to-space relations</th>
<th>object-to-object relations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>spatial relations</strong> between objects and positions in a meaningful space** (metric space or distorted metric space)</td>
<td><strong>spatial relations</strong> between objects (spatial clustering, separation, lineup, linking, containment, superimposition)</td>
</tr>
<tr>
<td><strong>attribute-based relations</strong> between objects** (relations involving variations in size, color, brightness, shape, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 2-07**: The different types of graphic relations.
“Is twice as high as” and “has the same color as” are examples of attribute-based relations. Attribute-based relations concern the visual attributes that were discussed in the previous section (2.4). In this section we will examine spatial structures. A spatial structure is set of spatial relations in graphic space. Spatial relations may either be object-to-space relations or object-to-object relations (see figure 2-07). A spatial structure that involves neither a meaningful space nor meaningful object-to-object relations is an arbitrary spatial structure: the spatial arrangement of graphic objects is not subject to interpretation.

In the following two subsections we will first examine object-to-object relations, and then object-to-space relations.
2.5.1 Structures involving object-to-object relations

Object-to-object relations are graphic relations between graphic objects. Bertin, MacEachren and other authors have studied attribute-based object-to-object relations (concerning differences in size, color, etc.). We will here concentrate on spatial object-to-object relations, which have received much less attention in the existing literature on graphic representation.

What distinguishes different types of spatial object-to-object relations from each other, are different aspects of the relative spatial arrangement of graphic objects that are subject to interpretation. The basic types of spatial object-to-object relations that we will distinguish in this thesis are: spatial clustering, separation by separators, lineup, linking, containment, and superimposition. We will see that it is quite common for a group of graphic objects to be simultaneously involved in two or more of these basic types of structures. This is possible because syntactic structure in graphic representations may involve several dimensions and aspects. Syntactic structure in linguistics on the other hand involves only one dimension and aspect - linear sequence. This means that in linguistic expressions, a constituent can not simultaneously participate in several syntactic structures (except, of course, in structures at different levels of constituent decomposition). See the discussion of simultaneous combination in subsection 2.5.4.

One way to look at different types of spatial object-to-object relations is to regard them as different types of object-to-object ‘anchoring’. The concept of ‘anchoring’ will be taken up again at the beginning of subsection 2.5.2, and discussed further in subsection 2.5.3.

We will now discuss each of the proposed types of object-to-object relations. At the end of this subsection, we will examine the existing literature in search of notions concerning object-to-object relations.

SPATIAL CLUSTERING

Spatial clustering is the spatial arrangement of a set of graphic objects into two or more groups through the use of within-group proximity versus between-group distance. In other words, a spatial clustering of a set of objects will result in two or more composite objects that contain subsets of the involved objects. These subsets of graphic objects are referred to as clusters. The food pyramid in figure 2-08 for example shows clusters of ocean creatures. Spatial clustering entails the separation of (groups of) graphic objects by empty graphic space, and is in that sense related to the separation of graphic objects by a separator, which is discussed further down in this subsection.
COMMENT: This figure serves to illustrate spatial clustering.
SYNTAX OF SPATIAL STRUCTURE (2.2): An ordered vertical lineup of clusters of graphic objects. Within a cluster, the graphic objects seem to be arranged in a more or less arbitrary spatial structure.
TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: Neither the division of creatures into clusters nor the vertical order of these clusters are meant to be taken literally (as showing a physical structure). Both have a metaphorical function in expressing the 'food pyramid' of the ocean. VISUAL ATTRIBUTES: The shapes of the creatures involve literal correspondence.
TYPE OF GRAPHIC REPRESENTATION (4): A grouping diagram, containing pictures.
A SPECIAL CASE OF SPATIAL CLUSTERING: LABELING

A special case of spatial clustering is the pairing of labels with the objects that they label, through spatial proximity. Most maps, and many other figures reproduced in this thesis contain labels. 'Label' is one of the possible specific syntactic roles that a graphic object may play within a syntactic structure (an inventory and discussion of syntactic roles is provided in 2.5.3). Label-objects are anchored to the object that they label by spatial clustering, sometimes also involving containment or superimposition. An alternative is the linking of labels to labeled objects by connectors, see for example figure 2-16. Containment, superimposition and linking are discussed below. Concerning semantics, a label-object specifies information that is related to the labeled object.

Many labels are textual, however, labels may also be pictorial objects or abstract shapes (see mode of expression, section 3.2), or composite graphic objects. In the London Underground diagram in figure 2-15 for example, the station markers are not only labeled with the stations' names, but some of them are also labeled with abstract shapes. The British Rail logo is used to label stations with connections with British Rail, and stars are used to label stations that are closed on Sundays. In figure 2-03, whole charts function as composite labels of the marked cities.

In need of a term for the syntactic role of all graphic objects that do not play one of the other specific syntactic roles discussed in this subsection (e.g. label, connector, separator), we will refer to these remaining graphic objects as 'nodes'. So we will for example say that a label is labeling a node, that a connector is linking two nodes, that a lineup is a string of nodes, and that a separator divides a group of nodes (see subsection 2.5.3).

SEPARATION BY A SEPARATOR

Spatial clustering separates graphic objects through the use of empty space. Another way to separate graphic objects is through the use of a separator. A separator is a line- or band-shaped graphic object that is anchored between the graphic objects that it separates. The separated objects (the nodes) are anchored to either one side or the other side of the separator(s). See the wheel clamp sign in figure 2-09 for an example of a separator.

Separators are free to run in all directions. For example, a set of graphic objects may be separated into subsets by curving separator-lines that 'wriggle' their way through the group in various changing directions. In other cases, separators may be straight, parallel lines. A separation may be ordered or unordered. An ordered separation is a separation in which the spatial order of the resulting subsets of graphic objects is subject to interpretation.
FIGURE 2-09: If you put money in the machine, you will get a parking permit ('ticket'). If you don't, you will get a wheel clamp. SOURCE: City of Amsterdam.

COMMENT: This figure serves to illustrate separation by a separator.

SYNTAX OF SPATIAL STRUCTURE (2.5): A multipanel display, involving vertical separation by a separator (the dashed line). Each panel contains two graphic objects (nodes) that are linked by a connector (an arrow).

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The vertical separation is metaphoric, expressing two different possibilities (and not some kind of physical partitions). The horizontal ordering expresses a temporal and/or causal sequence, also involving metaphoric correspondence. VISUAL ATTRIBUTES: The shapes of the little pictures involve literal correspondence, while the general shape of arrows involves metaphoric or arbitrary-conventional correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A multipanel display of link diagrams that involve pictures.
A table can be created by a simultaneous combination (subsection 2.5.4) of horizontal separations and vertical separations of graphic objects by separators (dividing lines). See the train timetable in figure 2-10 for an example. However, a table-structure can also be created without dividing lines, just by arranging graphic objects in horizontal lineups (rows), and simultaneously arranging them in vertical lineups (columns). See for example the table of the Los Angeles air pollution landscapes in figure 2-45. Lineups are discussed next.

LINEUP

A lineup is a basic type of object-to-object relation in which graphic objects are arranged in a 'string': Each graphic object is perceived as having two neighboring objects, except for the two objects at either end of the lineup. A
graphic object in a lineup is anchored either between its predecessor and its successor, or to the beginning or end of the lineup. A lineup may be ordered (a sorted sequence) or unordered (an unsorted enumeration). In an unordered lineup elements can switch positions without altering the intended meaning of the representation. Figure 2-11 shows an example of an ordered lineup.

![Figure 2-11: Detail of the Mexico City subway map. Pictograms representing the stations are lined up according to their physical order along the rails. SOURCE: By L. Wance (reproduced in Wurman 1989, p. 269).](image)

**COMMENT:** This figure serves to illustrate the lineup of graphic objects. It shows a nice way of making a subway map without the use of lines. The original also includes crossing routes, shown as intersecting horizontal and vertical lineups.

**SYNTAX OF SPATIAL STRUCTURE** (2.5): An ordered lineup of composite symbols. The composite symbols consist of a container object (black), a content object (white), and a label.

**TYPE OF CORRESPONDENCE** (3.1): SPATIAL STRUCTURE: The order of graphic objects involves literal correspondence (it represents the physical order of the stations along the rails). VISUAL ATTRIBUTES: The type of correspondence involved in the shapes of the content objects is probably mostly metonymic.

**TYPE OF GRAPHIC REPRESENTATION** (4): A lineup of composite symbols.

A table can be created by arranging graphic objects in horizontal lineups (rows), and simultaneously arranging them in vertical lineups (columns). For an example of a lineup-based table see the illustration of Los Angeles air pollution in figure 2-45. Here each table cell (each air pollution landscape) can be regarded as simultaneously participating in two orthogonal lineups.

A **segmented lineup** is a lineup that is broken up into several parallel shorter lineups, usually all running in the same direction. The lineup of words on this page, and the lineup of frames in a comic book are examples of segmented lineups. (See section 3.2 for a discussion of written text as a special case of graphic representation.) Being a lineup of lineups, a segmented lineup can be regarded as a recursive application of the lineup principle. Twyman’s distinction between ‘linear’ and ‘linear interrupted’ configurations concerns this phenomenon of lineups and segmented lineups (Twyman 1979).
FIGURE 2-12: The changing ratio of the number of produced motorcycles and the number of workers involved in their production.


COMMENT: Like the next figure, this figure serves as an illustration of proportional repetitions.

SYNTAX OF SPATIAL STRUCTURE (2.5): A simultaneous combination of spatial clustering (into three columns, representing workers, years, and production) and vertical lineups along a vertical metric axis (representing time, from top to bottom) of composite graphic objects (the proportional horizontal lineups) and labels. In both the left and the right column, the composite graphic objects consist of proportional repetitions of graphic (sub-)objects, and are aligned with regard to a common horizontal metric axis.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The vertical lineup involves metaphoric correspondence (order in space stands metaphorically for order in time).视觉属性: The proportional variation of the number of objects could be regarded as involving more or less literal correspondence (the changing number of the pictures stands for the changing number of the pictured objects). The shapes of the pictorial objects can also be regarded as involving literal correspondence (they basically stand for what we recognize in them).

TYPE OF GRAPHIC REPRESENTATION (4): A statistical time chart.

AN APPLICATION OF LINEUP: PROPORTIONAL REPETITION

Bar charts use the relative sizes of metric bars (subsection 2.5.3) to express quantitative proportions. An alternative to this method is the proportional repetition of graphic objects. See figures 2-12 and 2-13 for examples.
2.5.1 Object-to-object relations

FIGURE 2-13: Two ways of expressing numerical comparisons.


COMMENT: This figure shows the use of sizes (upper panel) versus the use of proportional repetitions (lower panel) to express quantitative comparisons.

SYNTAX OF SPATIAL STRUCTURE (2.5): A multipanel display. The upper panel contains two size-coded, labeled graphic objects. The lower panel contains two labeled proportional repetitions of graphic objects, arranged as lineups aligned with regard to a common metric axis.

TYPE OF CORRESPONDENCE (3.1): VISUAL ATTRIBUTES: Manipulating size (upper panel) involves metaphoric correspondence (changing graphic sizes does not stand for changing physical sizes), while manipulating number (lower panel) could be regarded as involving more or less literal correspondence (the changing number of the pictures stands for the changing number of the pictured objects). The shapes of the pictorial objects could also be regarded as involving literal correspondence (the pictures basically stand for what we recognize in them).

TYPE OF GRAPHIC REPRESENTATION (4): Two statistical time charts.
A **proportional repetition** is an evenly spaced collection of several identical copies of a graphic object, usually arranged in a *lineup*, in which the number of copies - and thus the *size* of the resulting *composite object* - expresses quantitative information. When the individual objects of a proportional repetition are arranged in a *lineup* (as opposed to in a cluster), then the relevant size of the resulting composite object concerns the *length* of the lineup. Usually several of such lineups are displayed next to each other, all starting from a common baseline, in order to facilitate comparisons. These lineups behave much like the *metric bars* in a bar chart (see subsection 2.5.3), involving an implicit *metric axis* in the direction of the lineups.

Proportional repetition is a core principle of the kind of pictorial statistics that were designed and promoted by Otto and Marie Neurath in the nineteen-thirties. The Neuraths referred to their system as ISOTYPE - 'International System Of TIypographic Picture Education'. ISOTYPE-like pictorial statistics are still a common type of newspaper graphic today. In terms of our framework, these representations are *lineups of proportional repetitions of pictorial graphic objects*, aligned with regard to a common *metric axis*. (For a discussion of *pictorial representation*, see section 3.2).

**LINKING BY A CONNECTOR**

**Linking** is a basic type of object-to-object relation that involves graphic objects with two *syntactic roles*: *nodes* and *connectors*. A *connector* is a graphic object in the shape of an arrow, band or line that is anchored to two other graphic objects (*nodes*), connecting them. (See subsection 2.5.3 for an inventory and discussion of the different syntactic roles that graphic objects may play within a syntactic structure.) For examples of *linking* by *connectors*, see figures 2-14 (conceptual connectors), 2-15 (physical connectors) and 2-16 (connectors between labels and labeled objects).

A configuration involving linking may be a *linear chain*, a *circular chain*, a *tree*, or a *network*. A **linear chain** is a configuration of linking that involves *no branching*. A **circular chain** is a linear chain that forms a closed loop. A *tree* is a configuration of linking that involves *branching from one root*, with *no closed loops*. A *network* is a configuration of linking that involves one or *more closed loops*. A closed loop entails that there is more than one possible route for moving from one node to another. The distinctions of these types of configurations also apply to some structures that are created through the *lineup* of graphic objects, using proximity instead of connectors. Independently of these types of configurations, *connectors* may be visually *directed* (arrows) or *undirected* (lines or bars).
COMMENT: This figure shows conceptual connectors: the arrows do not stand for physical connections.

SYNTAX OF SPATIAL STRUCTURE (2.5): Linking of labeled nodes. This configuration is not a pure circular chain, because it involves branching.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: Both the circular lineup and the linking involve metaphoric correspondence. VISUAL ATTRIBUTES: The shapes of the plant components involve literal correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A link diagram that involves pictures.
An arrow that serves as a connector leads from a source object to a target object. Not every arrow, however, serves as a connector between two graphic objects. For example, an arrow may represent the physical movement through space of an object, rather than a link between two different objects. See the vertical upwards-arrow on the right side of figure 2-17. Such a ‘movement arrow’ is not a connector (see our definition of a connector above). It traces a path of movement of a physical object in physical space. Usually the moved object is shown, either in its ‘start’ position or in its ‘end’ position, or somewhere in-between. Being a ‘path locator’, a movement arrow could be regarded as a line locator (subsection 2.5.3) in an integral metric space (subsection 2.5.2). Arrows may also occur as isolated signs in the environment, usually meaning “go this way”.

COMMENT: The connectors in this figure can be regarded either as physical connectors (standing for rails between the stations), or as conceptual connectors (standing for specific journeys of trains).
SYNTAX OF SPATIAL STRUCTURE (2.5): A distorted metric space with line locators which are also connectors between labeled nodes. An additional line locator (representing the river Thames) is displayed, which is not part of the connector-network.
TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The positioning of the stations involves distorted literal correspondence. The linking of the stations can be regarded as involving either literal or metaphorical correspondence, see the comment above about physical or conceptual connectors. VISUAL ATTRIBUTES: The colors of the lines involve arbitrary-conventional correspondence.
TYPE OF GRAPHIC REPRESENTATION (4): A path map (= both a map and a link diagram).

COMMENT: This figure shows a type of connector that serves to establish a pairwise linking between a label and a labeled object.

SYNTAX OF SPATIAL STRUCTURE (2.5): An integral metric space in which graphic objects and their labels are linked by connectors.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The spatial configuration of the various parts of the ear involves literal correspondence, while the linking of parts to their names involves metaphoric correspondence. (The connectors do not stand for physical connections, but they metaphorically stand for the conceptual connections of labels to their objects.)

TYPE OF GRAPHIC REPRESENTATION (4): A picture.
FIGURE 2-17: When it rings, pick up the phone!
COMMENT: This figure shows that not all arrows are connectors (a connector links two graphic objects): The object on the right contains an arrow that is not a connector but a 'movement arrow'.

SYNTAX OF SPATIAL STRUCTURE (2.5): Two graphic objects that are linked by a connector.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The linking of the two pictures involves metaphor correspondence. VISUAL ATTRIBUTES: The shapes of the pictorial objects involve literal correspondence, while the general shape of arrows involves metaphor or arbitrary-conventional correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A link diagram that involves pictures.

CONTAINMENT BY A CONTAINER

Containment is a basic type of object-to-object relation that involves nodes and containers. A container is a graphic object that contains other graphic objects (nodes) by visually surrounding them. The contained objects are anchored inside the container. For an example of a container see the liver in figure 3-05. In some cases a graphic object may be perceived as a potential container even though it may be 'empty'. Venn diagrams involve overlapping containers in order to express set memberships. See figure 2-18 for an example of a Venn diagram.
AN APPLICATION OF CONTAINMENT: COMPOSITE SYMBOLS

On the next pages we will briefly look at some ‘families’ of composite symbols and at the specific visual languages that these may involve. Think for example of certain traffic signs (such as shown in figure 2-20).

A composite symbol is a graphic object that is composed of a small number of elementary graphic objects (often two) which are arranged in a conventionally fixed arrangement, usually involving a containment or superimposition of the smaller object in or on the bigger object. Most composite symbols are members of a ‘family’, which is characterized by a shared visual vocabulary and a shared compositional grammar.
Shown above: different **container** objects for Apple file icons.

Figure 2-19: Apple file icons. Source: Horton 1994, pp. 134-135.

Comment: Apple file icons are composite symbols that are constructed from **container** objects, **content** objects, and **modifier** objects.
Note that according to this definition, a composite symbol is a special case of a composite graphic object, in other words, only certain composite graphic objects qualify as composite symbols.

There are specific syntactic roles that constituent objects may play within the fixed compositional grammar of a family of composite symbols. The most common ones of these syntactic roles can be referred to as container object (discussed above), content object (indicating the ‘specific subject’ of the composite symbol), label (discussed above) and modifier (discussed below). The terms ‘container’, ‘contents’ and ‘modifier’ are also used by Horton (1994, p. 134-135) in a case study of file icons in Apple’s system 7, see figure 2-19.

Consider the simple ‘traffic sign grammar’ shown in figure 2-20. This specific visual language involves a choice of content objects (bicycle, car, airplane, etc.) positioned inside a choice of container objects (permission, prohibition, attention). Another example is the specific visual language of word balloons in comics, which involves textual content objects and a choice of differently shaped container objects, see figure 2-21.

**FIGURE 2-20**: Certain traffic signs are composite symbols with a systematic composition grammar.

**SOURCE**: Adapted from Dreyfuss 1972, p. 28. Recreated by C.M. Semmler.

**COMMENT**: This figure shows how a traffic sign of this type (right column) is composed of a container object (left column) and a content object (middle column).
In Egyptian hieroglyphs, a Royal name is represented inside an oval shape, which is usually referred to as a ‘cartouche’, see figure 2-22. These graphic representations of Royal names are composite symbols, in which the cartouche serves as a container object.

A currently very common type of composite symbol is the 'pictogram-with-text-label'. As an example, see the labeled pictorial station markers in the subway map of Mexico city, part of which is reproduced in figure 2-11. The pictogram-with-text-label can also be found on most computer screens, in the form of icons with textual labels. The icons on computer screens may be composite symbols themselves, involving for example container objects, content objects and modifiers, as shown in figure 2-19.

A modifier can be regarded as a special case of a label: it is a label that has a fixed role within the grammar of a composite symbol. The bottom panel of figure 2-19 shows examples of modifiers of desktop icons. Another example of a modifier is the superimposed diagonal line or cross (X) as a sign of negation, often in red. This modifier is involved in the common non-smoking sign, and in many pictorial instructions. It can also be found in the lower panel of the ‘wheel clamp’ figure 2-09, in the form of a small diagonal line crossing out the coin.

Concerning their semantics, both modifier objects and container objects usually function to transform or further specify the meaning that is derived from a content object. In any given specific visual language the number of available content objects is usually larger than the number of available container objects and the number of available modifiers. For example, in the discussed visual language of traffic signs, there are only a very limited number of different container objects, while there are a large number of pictograms that can serve as content objects. While a container object contains its content object, a modifier is usually smaller than its content object, and is appended to it or superimposed on it.
2.5.1 Object-to-object relations

COMMENT: This is an ancient example of the use of container objects in graphic representations.

SYNTAX OF SPATIAL STRUCTURE (2.5): A container object filled with other objects.

TYPE OF CORRESPONDENCE (3.1): Some of the contained objects probably involve rebus-based correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A composite symbol.

We have mentioned in section 2.3 that the linguistic distinction between free morphemes and bound morphemes could possibly be applied to composite symbols. Free morphemes are morphemes that can occur by themselves, while bound morphemes are morphemes that are always attached to other morphemes. In composite graphic symbols, content objects could be regarded as corresponding to free morphemes, while modifier objects could be regarded as corresponding to bound morphemes. Some container objects could be regarded as free (e.g. the red-edged traffic signs in figure 2-20, the ‘Directory’ icon in figure 2-19), and others as bound (e.g. the blue circular traffic sign in figure 2-20, the ‘Programs’ icon in figure 2-19).
SUPERIMPOSITION

Superimposition is a basic type of object-to-object relation that involves a foreground object and a background object. The foreground object is perceived as being 'in front of' the background object, visually occluding part of it. For an example of superimpositions see figure 2-03. Superimposition is based on the phenomenon of visual layers in graphic space, discussed in section 2.2. Background-inset displays (see subsection 2.5.4) are superimpositions of composite objects on each other.

Due to the 'flatness' of graphic representations, containment (discussed above) and superimposition can appear to be similar. In both cases, a graphic object occupies a visual area that falls within the visual area occupied by another graphic object. It is, however, usually possible to distinguish between containment and superimposition. If the involved graphic objects are perceived as occupying the same visual layer (see section 2.2), then the configuration is regarded as a containment. If the involved graphic objects are perceived as occupying different visual layers (one 'in front of' or 'behind' the other), then the configuration is regarded as a superimposition. For certain configurations both interpretations may be possible. For example, a certain traffic sign involving a red circle and a pictogram (see figure 2-20) may be regarded as:

• a pictogram contained in a red circle (pictogram and red circle are regarded as sharing the same visual layer), or as
• a pictogram superimposed on a red-bordered background (pictogram and red circle are regarded as occupying different visual layers).

An overlap that involves partial occlusion will usually be regarded as a superimposition of objects that are on different visual layers. An additional difference between superimposition and containment is that a superimposed object may extend beyond its background object ('stick out'), while a contained object will usually not extend beyond its container object.

Having explored various types of possible object-to-object relations, let us conclude this subsection by briefly examining the existing literature in search of related concepts.

A LOOK AT THE LITERATURE CONCERNING OBJECT-TO-OBJECT RELATIONS

The proposed basic types of object-to-object relations can be regarded as owing their existence to Gestalt principles of visual perception, such as proximity and good continuation. However, a discussion of Gestalt principles and the related literature falls outside the scope of this thesis. What we will examine below is some of the most relevant literature regarding object-to-object relations in the context of graphic representation.
In his “schema for the study of graphic language”, Twyman divides “methods of configuration” into seven categories, arranged in a spectrum from linear to non-linear (Twyman 1979). These seven categories are “pure linear”, “linear interrupted”, “list”, “linear branching”, “matrix”, “non-linear directed” and “non-linear open”. Twyman’s notions can be partly matched to our basic types of object-to-object relations. His category of “pure linear” - as examples he gives the lineup of words in spiraling text, and the lineup of pictures and words in the Bayeux Tapestry - falls under our notion of lineups. His category of “list” - as examples he gives the vertical lineup of meals on a menu, and the vertical lineup of pictograms on some roadside signs - also falls under our notion of lineups. His notion of “linear interrupted” corresponds to our segmented lineups. His notion of “linear branching” concerns tree structures, which we have discussed above as a special case of linking. His notion of “matrix” includes tables as well as “line graphs” and “bar charts”, which require “the user to make searches about two axes” (Twyman 1979, p. 135). In our terminology a table involves a simultaneous combination (subsection 2.5.4) of horizontal and vertical separations and/or of horizontal and vertical lineups (subsection 2.5.1), while a two-axis line chart involves a simultaneous combination of a horizontal and a vertical metric axis (subsection 2.5.2). Most of the remaining possible configurations, such as the integral metric spaces (subsection 2.5.2) of pictures and maps (Chapter 4), fall under Twyman’s category of “non-linear”. The approaches of several other authors, more specifically geared towards object-to-object relations, can be summarized and compared in a table, see figure 2-23.

Making an inventory of “graphical means”, Richards (1984, pp. 8/5-8/6) briefly notes that the graphical means as derived from Bertin (the visual attributes, discussed here in section 2.4), can be extended with the possibilities of “proximity”, “alignment”, “connectivity”, and “enclosure”. These seem to match with four of our basic types of object-to-object relations: spatial clustering (‘proximity’), lineup (‘alignment’), linking (‘connectivity’), and containment (‘enclosure’). However, Richards does not discuss these any further in his work. Instead, he bases his framework on the distinction between “grouping”, “linking”, and “variation” (Richards 1984, pp. 8/1-8/46), which does not match with our basic types of object-to-object relations. While Richards’ “linking” matches with our linking, his “grouping” includes containment as well as for example the color-coding of graphic objects, regardless of their spatial arrangement. His “variation” includes positioning along a metric axis as well as the variation of the brightness of graphic objects (see the analysis of Richards’ distinctions in section 5.2 of this thesis).
There is an interesting parallel between the notion of basic types of object-to-object relations in graphics and certain ideas about cognition that were proposed by *Lakoff*, in a context seemingly unrelated to graphic representation. Drawing partly on Johnson (1987), Lakoff (1987) elaborates on the notion of ‘kinesthetic image schemas’ and claims that these play a central role in human cognition. Lakoff’s examples of such ‘image schemas’ include the ‘linear order schema’, the ‘link schema’, the ‘container schema’, the ‘front-back schema’, and the ‘up-down schema’ (Lakoff 1987, p. 283). According to Lakoff, metaphorical mappings of these image schemas form the basis of all

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* Richards’ other ‘graphical means’ are the visual attributes as derived from Bertin.

**FIGURE 2.23:** Comparison of the literature concerning notions related to object-to-object relations.

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* Richards’ other ‘graphical means’ are the visual attributes as derived from Bertin.

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**FIGURE 2.23:** Comparison of the literature concerning notions related to object-to-object relations.

There is an interesting parallel between the notion of basic types of object-to-object relations in graphics and certain ideas about cognition that were proposed by *Lakoff*, in a context seemingly unrelated to graphic representation. Drawing partly on Johnson (1987), Lakoff (1987) elaborates on the notion of ‘kinesthetic image schemas’ and claims that these play a central role in human cognition. Lakoff’s examples of such ‘image schemas’ include the ‘linear order schema’, the ‘link schema’, the ‘container schema’, the ‘front-back schema’, and the ‘up-down schema’ (Lakoff 1987, p. 283). According to Lakoff, metaphorical mappings of these image schemas form the basis of all
our abstract conceptual structures. Lakoff does not mention anything about graphic representations, but several of his image schemas match nicely with the basic types of object-to-object relations that we propose for graphics: lineup (‘linear order schema’), linking (‘link schema’), containment (‘container schema’), and superimposition (‘front-back schema’). Furthermore, Lakoff’s ‘up-down schema’ seems to be related to our notion of meaningful space in graphics (subsection 2.5.2). If Lakoff is correct about the central role of these image schemas in all human thought, then one could conclude that graphic representations are based on exactly those structuring principles that form the very basis of human cognition. This is an entertaining thought, although it may not have any practical consequences for the study of graphic representations.

The list that the table above provides for Horton is actually not given by Horton in this form. Rather, this list is the result of our selection and regrouping of concepts that appear in different places in Horton’s chapter on ‘Showing relationships’ (Horton 1994, pp. 75-109).

Card et al. briefly mention ‘connection’ and ‘enclosure’ as possible representations of ‘topological structure’ (Card et al. 1999, pp. 28-29), without discussing these in detail.

Horn lists six types of ‘visual topologies’, each with an example diagram, but without any further definition or explanation (Horn 1998, pp. 81-82). From his example diagrams it seems justified to match his topologies to ours as follows. Horn’s ‘proximity grouping’ seems to correspond to our spatial clustering, his ‘network’ seems to correspond to our linking, and his ‘boundary’ seems to correspond to our separation by a separator. His ‘concentric’ may correspond to the notion of a meaningful space with a radial axis (subsection 2.5.2). Finally, his ‘level’ seems to correspond to what we would call vertical separation, and his ‘matrix’ to the simultaneous combination (subsection 2.5.4) of horizontal and vertical separation.

Object-to-object relations are one of two ways of creating spatial structure. In the next subsection we will discuss the other way of creating spatial structure: object-to-space relations, which involve meaningful space.
2.5.2 Structures involving *meaningful spaces* and object-to-space relations

Imagine sitting in a bar and using the arrangement of empty beer glasses on the bar table to explain, say, the location of Amsterdam with respect to London and Paris. The positioning of two beer glasses, standing for London and Paris, creates a *meaningful space* (see Engelhardt 1998, 1999) - every position on the bar table has been assigned a geographical meaning. The meaningful space can even be regarded as extending beyond the bar table - a person on the other side of the bar may now happen to be 'sitting in Africa'. Similarly, when starting to draw a financial chart, by drawing two labeled axes (e.g. one for the months of the year, and the other for expenses in dollars), a *meaningful space* has been created: every position in the yet-empty chart has been assigned a meaning, even before we have any data. The face of a clock also constitutes a meaningful space - it assigns meaning (time of day) to the spatial positions along a circle. By the way, even though they are not made of ink on paper or pixels on a screen, both the beer glasses on the bar table and the clock face could be regarded as *graphic representations* according to our definition (Chapter 1): Arguably, the configuration of beer glasses constitutes 'a visible artifact on a more or less flat surface, that was created in order to express information'. So does the clock face.

The graphic space of a composite graphic object is a *meaningful space* if spatial positions in it are subject to interpretation regardless of whether or not there are graphic sub-objects present at those positions. To say it differently, a meaningful space is a graphic space that involves an interpretation function from positions in space to information.

In the context of this thesis, we will restrict our notion of meaningful space to *metric spaces*, such as those involved in topographic maps and in two-axis charts, and to *distorted metric spaces*, such as those involved in subway maps and in the vertical time lines of 'evolution trees'. In my earlier publications on the concept of meaningful space (Engelhardt 1998, 1999), I have also included ‘partitioned graphic spaces’, such as those involved in tables, as a possible type of meaningful spaces. In this thesis however, I have supplemented the notion of meaningful space with the notion of various types of object-to-object relations, as discussed in subsection 2.5.1. This introduces a dilemma: if a system of syntactic analysis would include the possibility of parsing a graphic structure as a *spatial clustering*, as a *lineup* or as a *separation by separators* (subsection 2.5.1), as well as the possibility of parsing graphic structures as ‘partitioned graphic spaces’, then this system would offer two fundamentally different ways of parsing segmentations and tables (such as the wheel clamp sign in figure 2-09, and the Los Angeles air pollution illus-
2.5.2 Meaningful space and object-to-space relations

Segmentation and tables could then be parsed as consisting either of spatial clustering, lineups and separations by separators, or as consisting of arrangements into 'partitioned graphic spaces'. This situation would therefore not offer a system of unambiguous syntactic parsing. The notion of a spatial clustering of graphic objects, the notion of a lineup of graphic objects, and the notion of a separation of graphic objects by a separator, are broad basic notions which also apply to scattered, curved and 'winding' graphic structures. They appear to be indispensable notions in any minimal set of basic syntactic structures. 'Partitioned graphic spaces' on the other hand, can be analyzed as being created through spatial clustering, lineups and separations by separators, and do therefore not appear to be indispensable ingredients of a minimal set of basic syntactic structures.

In summary, in the context of this thesis we are making the choice to strive for a system of unambiguous parsing, involving a minimal set of basic syntactic structures. We therefore choose to analyze 'partitioned graphic spaces' as object-to-object structures which are created through spatial clustering, lineups and separations by separators, and we restrict our notion of meaningful spaces to metric spaces and distorted metric spaces. Metric spaces and distorted metric spaces will be discussed in detail, further on in this subsection.

Let me now add a few general remarks about the difference between object-to-space relations and object-to-object relations. See the table on the next page (figure 2-24). In object-to-object relations (spatial clustering, separation by separators, lineup, linking by connectors, containment, superimposition), an object is anchored to one or more other objects. For example, a connector is anchored to the nodes that it connects, and a label is anchored to the node that it labels. In object-to-space relations on the other hand, an object is anchored to one or more spatial positions in the involved (distorted) metric space. We will see, for example, that a point locator (e.g. a 'city-dot' on a map) is anchored to a single point, while a surface locator (e.g. a lake on a map) is anchored to a set of points. Objects in object-to-object relations usually have a certain degree of freedom in their spatial positioning (e.g. on a map, a city-name may appear above or below its 'city-dot'). This could be referred to as 'loose' anchoring. Objects in object-to-space relations however are fixed in their spatial positioning in the involved (distorted) metric space (e.g. a 'city-dot' is fixed in its exact position on a map). This could be referred to as 'tight' anchoring. Object-to-object relations can express information regarding association, dissociation, and order. Object-to-space relations can express information regarding order, proportion, and direction.
<table>
<thead>
<tr>
<th>object-to-space relations</th>
<th>object-to-object relations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>example:</strong></td>
<td><strong>example:</strong></td>
</tr>
<tr>
<td>a line on a map that</td>
<td>a textual label consisting</td>
</tr>
<tr>
<td>stands for a river</td>
<td>of the river's name</td>
</tr>
<tr>
<td>an object is</td>
<td>one or more points</td>
</tr>
<tr>
<td>anchored to:</td>
<td>in a meaningful space</td>
</tr>
<tr>
<td></td>
<td>one or more other objects</td>
</tr>
<tr>
<td>exactness of</td>
<td>'tight' anchoring</td>
</tr>
<tr>
<td>spatial positioning:</td>
<td>(fixed positioning)</td>
</tr>
<tr>
<td></td>
<td>'loose' anchoring</td>
</tr>
<tr>
<td></td>
<td>(degree of freedom)</td>
</tr>
<tr>
<td>can express</td>
<td>order, proportion,</td>
</tr>
<tr>
<td>relationships of:</td>
<td>direction</td>
</tr>
<tr>
<td></td>
<td>association, dissociation,</td>
</tr>
<tr>
<td></td>
<td>order</td>
</tr>
</tbody>
</table>

**FIGURE 2-24:** Comparison of object-to-space relations and object-to-object relations.

Let us briefly consider a few examples. Graphic objects on a topographic map are involved in object-to-space relations. Graphic objects in a flow chart, connected by arrows, are involved in object-to-object relations. Graphic objects on a map that are also connected by arrows are simultaneously involved in object-to-space relations and in object-to-object relations - they are anchored in space through their positions and anchored to each other through arrows. Graphic objects that are randomly arranged on the presentation surface are involved in an arbitrary spatial structure.

Concerning types of basic meaningful spaces, we will distinguish *metric spaces* and *distorted metric spaces*. We will first discuss *metric spaces*. This will include metric *axes*, integral *metric spaces*, and *composite* metric spaces. After that we will discuss *distorted* metric spaces. Further down we will discuss the degree to which various spatial structures make use of the intrinsic *properties of space*. Finally, at the end of this subsection, we will examine the existing *literature* in search of notions concerning meaningful space.
METRIC SPACES

A **metric space** is a graphic space in which *metric* aspects of spatial positioning are subject to interpretation, such as the ratios of distances between objects (e.g. 'the distance between A and B is twice the distance between B and C'). We will distinguish *basic* metric spaces from *composite* metric spaces.

A **basic metric space** may either be a graphic space with a single *metric axis* (such as a time line) or it may be an *integral metric space* (such as a map):

- A **metric axis** creates a graphic space in which ratios of spatial distances, measured along the spatial dimension of the axis, are perceived as meaningful. Example: a time line.
- An **integral metric space** is a *two- or three-dimensional* graphic space in which all geometric properties of Euclidian space are subject to interpretation. Examples: a topographic map, a drawing of a three-dimensional physical object (e.g. the ear in figure 2-16).

A **composite metric space** is a metric space that is constructed from two or more **basic metric spaces**. See the discussion of composite spatial structures in subsection 2.5.4. The simplest type of composite metric space involves the simultaneous combination of two orthogonal metric axes into a two-axis chart. See for example the rectilinear two-axis charts in figures 2-25 and 2-26, and the polar two-axis chart in figure 2-27.

How does an **integral** metric space differ from a **composite** metric space? Of course, an **integral** metric space can be artificially decomposed into orthogonal **metric axes**. This is nicely illustrated by the coordinate system that is shown in the old map in figure 2-28. However, the involved choices - orientations of the axes, rectilinear or polar coordinates - will be arbitrarily imposed. For example, either a rectilinear or a polar coordinate system can be used to span the same integral metric space. The difference between integral and composite metric space can be specified in the following way. In an **integral** metric space, the ratio between any two spatial distances is perceived as meaningful, regardless of the directions in which these two distances are measured (e.g. horizontally, vertically, diagonally, or in any direction in-between). On a map for example, one might compare how far various people live from their respective jobs, regardless of the directions in which these people commute. In a **composite** metric space on the other hand (e.g. a two-axis chart), the ratio between two spatial distances is only perceived as meaningful if these two distances are measured in certain directions (due to the way the space is **constructed**).

A spatial dimension that is neither structured by **separators** (2.5.1) nor by a **metric space**, is referred to as an **unstructured dimension**.

COMMENT: This figure shows an early example of a graphic representation that involves a composite metric space.

SYNTAX OF SPATIAL STRUCTURE (2.5): A composite metric space (e.g. diagonal distances are not meaningful), constructed through simultaneous combination of a horizontal and a vertical metric axis. The space contains line locators, surface locators, labels, and labeled grid lines.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: Both axes involve metaphoric correspondence (spatial distance metaphorically stands for time and money).

TYPE OF GRAPHIC REPRESENTATION (4): A statistical time chart.
COMMENT: This is an unconventional bar chart, regarding the downward orientation of the vertical axis.
SYNTAX OF SPATIAL STRUCTURE (2.5): A composite metric space, constructed through simultaneous combination of a horizontal and a vertical metric axis. The left side of the horizontal metric axis is distorted (two-year jumps instead of one-year jumps). The third spatial dimension does not serve informational but decorative purposes. The same could be said of the displayed ship (see section 3.3).
Continued caption for figure 2-26:
The space contains metric bars (the columns), labels, labeled grid lines, and an inset (the legend). The metric bars are 'stacked bars': they are divided into sub-objects of proportional sizes, which is referred to as proportional division.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: Both axes involve metaphoric correspondence. VISUAL ATTRIBUTES: The length of the columns involves metaphoric correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A statistical time chart.

Figure 2-27 (showing accidents per hour) can be regarded as a bar chart forced into polar coordinates - the time axis is not horizontal but circular. Bar charts involve a metric axis along which the lengths of the bars are measured, and a lineup of the bars in the orthogonal direction. The lineup of bars in a bar chart may be an unordered lineup, an ordered lineup, or a lineup along a (second) metric axis. The latter case, a lineup of bars along a metric axis involves not only an ordering of the bars, but also proportional distances. Note that while the bars in figures 2-26 and 2-27 (the vertical columns and the black pie slices respectively) are chosen to cover only fixed segments or chunks of the time axis (one per year and one per hour respectively), the involved time axis is in both cases still a metric axis, in the sense that the distance between any two randomly chosen bars is proportional to the time that has passed between them. (Upon careful reading however, the time axis in figure 2-26 turns out to be a distorted metric axis: the two leftmost bars involve two-year jumps, while all other bars involve one-year jumps.)
2.5.2 Meaningful space and object-to-space relations

FIGURE 2-27: Percentages of occupational accidents per hour of the working day.
SOURCE: Ratté 1924.

COMMENT: This figure serves as an example of polar coordinates. It can be regarded as a bar chart that is forced into polar coordinates. Note that surfaces of the black pie slices (the 'bars') distort the represented proportions, because their radius has been used as a metric axis here, while the surface of a slice is proportional to the square of its radius.

SYNTAX OF SPATIAL STRUCTURE (2.5): A composite metric space, constructed through simultaneous combination of a circular and a radial metric axis. The space contains metric 'bars' (the black pie slices), labels, and a labeled circular grid line (the clock face).

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: Both axes involve metaphoric correspondence. VISUAL ATTRIBUTES: The length of the black pie slices involves metaphoric correspondence (their surface distorts the represented proportions, see comment above).

TYPE OF GRAPHIC REPRESENTATION (4): A statistical time chart.
Ecce formulam, vulum, atque

struaturam Tabularum Ptolomai, cum quibusdam locis, in
quibus studiis Geographiae fatis exerceret poeta.

SEPTENTRIO.

pars superior.

pars inferior.

MERIDIES.

FIGURE 2-28: A map showing, among other cities, Prague, Vienna and Venice.


COMMENT: The map shown in this figure serves to illustrate an integral metric space. Any decomposition into two metric axes is artificial, and one could use for example a polar coordinate system to yield the same meaningful space.

SYNTAX OF SPATIAL STRUCTURE (2.5): An integral metric space containing labeled point locators, a surface locator (representing a mountain area) and labeled grid lines along its four edges. This (map-)space is nested into a higher-level integral metric space (which displays the map, two threads that function as grid lines, four hands, and additional labels).

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The positioning of cities in the metric space of the map involves literal correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A map.
2.5.2 Meaningful space and object-to-space relations

FIGURE 2-29: Section of a graphic timetable, with the route running vertically and time running from left to right. The diagonal lines represent trains traveling from Paris to Lyon (3) and from Lyon to Paris (7). The density of the diagonal lines corresponds to the frequency of trains. The slope of the lines corresponds to the speed of the trains.

SOURCE: By E.J. Marey 1885 (reproduced in Tufte 1983, p. 31.)

COMMENT: Note that both this and the next figure show spaces that are hybrids of physical space and conceptual space. In this case we have a combination of vertical physical space with horizontal conceptual space. In the next figure this is the other way around.

SYNTAX OF SPATIAL STRUCTURE (2.5): Line locators and labeled grid lines in a composite metric space. The composite space is constructed through simultaneous combination of two orthogonal metric axes.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The vertical metric axis involves literal correspondence (spatial distance in the chart stands for spatial distance along the rails), while the horizontal metric axis involves metaphoric correspondence (spatial distance in the chart stands for the passing of time).

TYPE OF GRAPHIC REPRESENTATION (4): A time chart.

COMMENT: Note that both this and the previous figure show spaces that are hybrids of physical space and conceptual space. In this case we have a combination of horizontal physical space with vertical conceptual space. In the previous figure this is the other way around.

SYNTAX OF SPATIAL STRUCTURE (2.5): A surface locator (the whole landscape) in a three-dimensional composite metric space, with labels (the textual comments) that are attached by connectors. Embedded in the surface locator are line locators (marking State borders) and very tiny point locators with labels (marking cities). The composite space is constructed through simultaneous combination of a two-dimensional horizontal integral metric space and a vertical metric axis.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The horizontal integral metric space involves literal correspondence (physical arrangement on the map stands for physical arrangement in the world), while the vertical metric axis involves metaphoric correspondence (height metaphorically stands for population density).

TYPE OF GRAPHIC REPRESENTATION (4): A statistical map (= both a map and a statistical chart).
There are a few common orientations for spatial dimensions:

- **rectilinear** coordinates: **horizontal** and **vertical**, plus - in 3-D graphics - **distal** (variation of the ‘distance’ from the viewer), or
- **polar** coordinates: **circular** (angular rotation around a center) and **radial** (away from the center).

See also Bertin’s overview of coordinate systems in figure 2-36. For examples of **rectilinear** coordinates see figures 2-25 and 2-29. For an example of **polar** coordinates see figure 2-27. Additional possibilities concerning combinations of orientations are cylindrical, spherical and trilinear coordinates. **Trilinear** coordinates are used in triangular charts, which plot the proportional composition of a total with three ingredients (areas of application include election results, and the composition of sediments). Note that such trilinear charts are not **integral** metric spaces, but that their dimensions are also not ‘independent’, as they are in most **composite** metric spaces. Concerning this aspect, trilinear charts may form a separate category.

In the chapter on the **interpretation** of graphic representations we will make the distinction between representing **physical** structures and representing **conceptual** structures (subsection 3.1.1). It may seem that integral metric spaces always represent **physical** spaces while metric axes and composite metric spaces always represent **conceptual** spaces. This is, however, not the case. While our impression is that integral metric spaces indeed always represent **physical** spaces, metric axes may represent either **physical** or **conceptual** spaces, and composite metric spaces may represent either **conceptual** or **hybrid** spaces. A **hybrid** space is a space that represents both physical and conceptual space. Figure 2-29 for example traces the paths of trains through space and time. Its vertical dimension represents spatial distances along the route, and is an example of a metric axis that represents **physical** space. In combination with the **conceptual** space of the horizontal time axis, a **hybrid** space is created. Figure 2-30 is another example of a **hybrid** space - here the horizontal integral metric space represent **physical** space, while the vertical metric axis represent **conceptual** space.

**DISTORTED METRIC SPACES**

Some graphic representations involve **distorted metric spaces** such as ‘exploded’ views and ‘fisheye’ views. Most subway maps involve a distorted metric space. A **distorted metric space** is a graphic space that can be thought of as a metric space that was printed on a ‘rubber sheet’ and then stretched non-homogeneously, preserving both order and approximate directions, but not preserving the ratios of spatial distances. The vertical time axis in figure 2-31 is an example of a **distorted metric axis**.
**FIGURE 2-31:** Evolution. SOURCE: L. Gonick 1990, part of drawing on p. 20.

**COMMENT:** The vertical time axis in this figure serves to illustrate positioning along a *distorted metric axis*. (This is part of a larger drawing which is, in its original context, aligned with a distorted vertical time axis that is labeled in millions of years).

**SYNTAX OF SPATIAL STRUCTURE** (2.5): *Labeled nodes, linked by connectors, in a distorted metric space* that is created by a vertical *distorted metric axis*.

**TYPE OF CORRESPONDENCE** (3.1): SPATIAL STRUCTURE: Both the vertical positioning and the *linking* of creatures involves *metaphoric correspondence* - positions higher on the page metaphorically stand for developments later in time, and the connectors metaphorically stand for evolutionary descent.

**VISUAL ATTRIBUTES:** The *shapes* of the creatures involve *literal correspondence*.

**TYPE OF GRAPHIC REPRESENTATION** (4): A *chronological link diagram* (= both a *link diagram* and a *time chart*).
2.5.2 Meaningful space and object-to-space relations

The subway map in figure 2-32 is an example of a distorted integral metric space. Strictly speaking, all maps could be regarded as distorted integral metric spaces. As MacEachren has pointed out, “map space is always a transformation and manipulation of world space” (MacEachren 1995, p. 313). The major inevitable distortion factor in a map arises from the projection of the curved surface of the earth onto the flat surface of the map, see the world map in figure 2-33.
The Turgot map of Paris in figure 2-34 involves slight distortions, but for another reason: many of the streets are widened in order to minimize the degree to which buildings visually occlude each other. The thunderstorm simulation in figure 2-42 also involves a distorted metric space: the vertical dimension is exaggerated by stretching it with almost a factor 2.
2.5.2 Meaningful space and object-to-space relations


COMMENT: Note that in order to minimize the degree to which buildings visually occlude each other, the width of the streets is greatly exaggerated, especially of those that run horizontally. In this sense, this is a locally distorted metric space.

SYNTAX OF SPATIAL STRUCTURE (2.5): Graphic objects in a locally distorted integral metric space.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The distorted metric space involves a distorted, though basically literal correspondence. VISUAL ATTRIBUTES: The shapes of the displayed objects involve literal correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A picture.
DEGREE TO WHICH ASPECTS OF SPACE CAN BE MEANINGFUL

Space has different intrinsic properties or 'aspects', such as spatial proximity and distance, spatial order, and spatial direction. Different types of spatial structures in graphic representations differ in the degree to which they assign meaning to such aspects of space. Recall the basic types of object-to-object relations discussed in subsection 2.5.1. A spatial clustering makes use of spatial proximity. A lineup makes use of spatial order. An unordered separation makes use of the separateness of sub-spaces. An ordered separation makes use of the separateness and the spatial order of subspaces. A metric axis makes use of proportional spatial distances.

Through these different degrees to which spatial structures assign meaning to spatial aspects, they also represent different types of information. See also the brief discussion of the difference between object-to-object relations and meaningful spaces in the beginning of this subsection (2.5.2). The table below (figure 2-35) provides an overview of types of spatial structures and the types of information that they represent.

<table>
<thead>
<tr>
<th>Spatial structure</th>
<th>Expressed information</th>
</tr>
</thead>
<tbody>
<tr>
<td>arbitrary spatial structure</td>
<td><em>no information</em></td>
</tr>
<tr>
<td>(random scattering of elements)</td>
<td></td>
</tr>
<tr>
<td>unordered separation</td>
<td><em>nominal</em> relations between elements (categories of elements)*</td>
</tr>
<tr>
<td>(e.g. unordered table columns)</td>
<td></td>
</tr>
<tr>
<td>ordered separation</td>
<td><em>ordinal</em> relations between categories of elements (ordered categories of elements)</td>
</tr>
<tr>
<td>(e.g. ordered table columns)</td>
<td></td>
</tr>
<tr>
<td>distorted metric axis</td>
<td><em>ordinal</em> and <em>distorted numerical</em> relations between individual elements (ordered elements)</td>
</tr>
<tr>
<td>(e.g. vertical axis in evolution tree)</td>
<td></td>
</tr>
<tr>
<td>metric axis</td>
<td><em>quantitative</em> relations between elements, concerning a single attribute</td>
</tr>
<tr>
<td>(e.g. proportional timeline)</td>
<td></td>
</tr>
<tr>
<td>composite metric space</td>
<td><em>quantitative</em> relations between elements, concerning two (or three) attributes</td>
</tr>
<tr>
<td>(e.g. two-axis chart)</td>
<td></td>
</tr>
<tr>
<td>distorted integral metric space</td>
<td>relations of <em>physical order</em>, and <em>distorted physical distance and direction</em> between elements</td>
</tr>
<tr>
<td>(e.g. subway map)</td>
<td></td>
</tr>
<tr>
<td>integral metric space</td>
<td>relations of <em>physical distance</em> and <em>physical direction</em> between elements</td>
</tr>
<tr>
<td>(e.g. topographic map)</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 2-35**: Type of information that is expressed by different spatial structures. See section 3.4 for a very brief discussion of types of information.
Bertin offers a classification of spatial structures ('impositions'), see figure 2-36 (Bertin 1967/1983, p. 52). He distinguishes four ‘groups of imposition’: ‘diagrams’, ‘networks’, ‘maps’ and ‘symbols’. These four categories will be discussed in our chapter on classification of graphic representations (4). Bertin also distinguishes five ‘types of impositions’: ‘arrangement’, ‘rectilinear’, ‘circular’, ‘orthogonal’ and ‘polar’. While the last four of these basically match with the common coordinate systems that we have discussed above, Bertin’s category of ‘arrangement’ is somewhat peculiar. With an ‘arrangement’-imposition of the ‘network’-type, marked by him with an ‘S’-shaped arrow, Bertin seems to refer to link diagrams in which the nodes are not positioned in a meaningful space. With the ‘arrangement’-imposition of the ‘map’-type however, marked by him with an arrow that runs in two or-
thogonal dimensions (note the difference with his two arrows for 'orthogonal'), Bertin may have something in mind that corresponds to our notion of integral metric spaces. With the 'arrangement'-imposition of the 'symbol'-type, which is the only imposition not marked by any kind of arrow, Bertin seems to mean what we call object-to-object relations involved in composite symbols. Finally note that an 'arrangement'-imposition and the 'diagram'-type seem to exclude each other - in his table Bertin leaves that cell empty.

Various classifications of spatial structures can be found in the literature that have to do with the degree to which meaning is assigned to the properties of space. Some of these are included in the table (figure 2-37) and in the discussion below. Richards' (1984) three modes of organization - 'grouping', 'linking', and 'variation' - are discussed separately in section 5.2.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic dimensions:</td>
<td>Spatial pictorial devices:</td>
<td>Representational uses of space:</td>
<td>Types of axes:</td>
<td>Spatial structures:</td>
</tr>
<tr>
<td>nominal dimension</td>
<td>conveying categorical relations</td>
<td>nominal: random arrangement</td>
<td>unstructured axis</td>
<td>arbitrary spatial structure</td>
</tr>
<tr>
<td>ordinal dimension</td>
<td>conveying ordinal relations</td>
<td>categorical: unordered slotting</td>
<td>nominal axis</td>
<td>unordered separation</td>
</tr>
<tr>
<td>linear dimension</td>
<td>conveying interval relations</td>
<td>ordinal: ordered slotting</td>
<td>ordinal axis</td>
<td>ordered separation</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>quantitative: sliding</td>
<td>quantitative axis</td>
<td>metric axis</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>spatial: spatial mapping</td>
<td>-</td>
<td>integral metric space</td>
</tr>
</tbody>
</table>

FIGURE 2-37: Comparison of the literature concerning notions related to structure along a spatial dimension.
Wexelblat (1991, pp. 259-262) and Tversky (1995, pp. 46-49) both note that spatial arrangement can express relations of different 'scale types', such as nominal/categorical relations, ordinal relations, and quantitative/interval relations (see also section 3.4).

In a paper titled “The visual grammar of information graphics”, Engelhardt et al. propose a list of “basic representational uses of space” (Engelhardt et al. 1996, pp. 5-8). The paper uses somewhat clumsy terminology, but in addition to discussing the spatial representation of relations of the different scale types, it includes the notion of arbitrary spatial structures (“random arrangement”), and it implicitly includes the notion of integral metric spaces (“spatial mapping”).

Referring to Engelhardt et al.’s 1996 paper, Card, Mackinlay and Shneiderman (1999, p. 26) list four different types of spatial dimensions: unstructured dimensions, and dimensions representing relations of the three scale types.

It seems that nowhere in the literature an explicit distinction has been made between integral metric spaces and composite metric spaces, and their different properties, as discussed in this thesis (e.g. at the beginning of this subsection, 2.5.2).

Having examined object-to-object relations and object-to-space relations as the two types of basic spatial structures, we will now first make an inventory of syntactic roles that graphic objects may play within these structures (subsection 2.5.3), and then turn our attention to composite spatial structures (subsection 2.5.4) and the ways in which these are constructed from basic spatial structures.
2.5.3 An overview of syntactic roles of graphic objects

At several points in this thesis we have made remarks about the ‘anchoring’ of graphic objects, and about the various syntactic roles that a graphic object may play within a syntactic structure (e.g. a node-role versus a connector-role, in a syntactic structure based on linking). In this subsection we will examine ‘anchoring’ and syntactic roles of graphic objects in a little more detail.

In the context of traditional linguistics, issues of grammar and syntax include the study of different ‘syntactic roles’ of language constituents such as nouns, adjectives, transitive verbs, intransitive verbs, adverbs, etc. In this thesis we are trying to apply related concepts to graphic representations, taking a look at the different ‘syntactic roles’ that graphic objects may play within the graphic syntactic structure that they are part of. Little can be found in the literature concerning any notions of different syntactic roles of graphic objects. Two exceptions are Horton’s distinction into ‘containers, contents, and modifiers’ in Apple file icons, shown in figure 2-19, and Richards’ notion of ‘noun spaces and verb spaces’. Richards suggests that “elements occupying noun spaces function like nouns and elements occupying verb spaces function like verbs”. As an example, he shows a line connecting the letters ‘A’ and ‘B’, where he regards the line (a connector in our terminology) as occupying a ‘verb space’, and the letters (nodes in our terminology) as occupying ‘noun spaces’ (see Richards 1984, pp. 3/20-3/29, 9/2-9/4, and 2000, p. 89). Engelhardt et al. (1996, pp. 1, 4) make a somewhat similar proposal regarding the distinction of ‘syntactic categories of visual components’, such as ‘nodes, connectors and borders’.

The different syntactic roles of language constituents in verbal expressions could be regarded as involving different types of ‘anchoring’ of these language constituents within a syntactic structure: an adverb is ‘anchored’ to a verb (e.g. “aging rapidly”), an intransitive verb is ‘anchored’ to a noun phrase (e.g. “she sleeps”), a transitive verb is ‘anchored’ to two noun phrases (e.g. “she loves me”), etc. In a related way, we can approach the syntactic role of a graphic object as concerning its type of graphic ‘anchoring’ within a syntactic structure: a label is anchored to a node (e.g. the name of a subway station is anchored to a station marker), a connector is ‘anchored’ to two nodes (e.g. an arrow in a flow chart is anchored to the two boxes that it connects), a point locator is ‘anchored’ to a point in meaningful space (e.g. a ‘city-dot’ is anchored to a position on a map), etc.
At the most general level of distinction we divide the different types of graphic anchoring into three main categories:

- **Object-to-object anchoring**: An object-anchored object (e.g. a label, a connector) is a graphic object that is anchored to one or more other objects as part of a structure that involves object-to-object relations (discussed in subsection 2.5.1).

- **Object-to-space anchoring**: A space-anchored object (e.g. a point locator, a surface locator) is a graphic object that is anchored to one or more spatial positions in a meaningful space (discussed in subsection 2.5.2, and below).

- **No anchoring**: A non-anchored graphic object is a graphic object that is anchored neither to a position in a meaningful space nor to another object. Graphic objects that are arranged in an arbitrary spatial structure (mentioned at the beginning of section 2.5) are non-anchored graphic objects.

The possible syntactic roles of object-anchored objects were discussed in the subsection on object-to-object relations (2.5.1). There we have made distinctions between the syntactic roles referred to as **node**, **label**, **separator**, **connector**, **container**, and **modifier**. Recall that in linguistic structures, a composite expression consists of constituents with specific syntactic roles. For example, a sentence consists of a **noun phrase** and a **verb phrase**, etc. Continuing the comparison with linguistics, we could note that in the composition of graphic structures, a 'basic labeling structure' consists of a **node** and a **label**, a 'basic containment structure' consists of a **node** and a **container**, a 'basic linking structure' consists of two **nodes** and a **connector**, etc. Before we elaborate further on syntactic roles in graphic representations, let us look at the possible syntactic roles of space-anchored objects.

A **space**-anchored object is a graphic object that is anchored to one or more points in a meaningful space. Different syntactic roles of space-anchored objects consist of different ways in which an object can be anchored in meaningful space. Let us consider a few examples. If a graphic object functions as a **point locator** (e.g. a 'city-dot' on a map), the object is anchored only to a single point in meaningful space, leaving the graphic object free in its size and shape. If a graphic object functions as a **surface locator** (e.g. a 'lake' on a map), the complete set of points (the surface) that it encompasses is anchored in meaningful space, fixing both the object's size and the object's shape.

We will now make a brief inventory of the possible syntactic roles of objects in object-to-space anchoring: **point locators**, **line locators**, **surface locators**, **volume locators**, **metric bars**, and **grid lines**:

A **point locator** is anchored to a specific point in a meaningful space. Examples: a church symbol on a map, a dot in a scatter plot, the city-markers in the map in figure 2-28. Usually the area occupied by a point locator is centered on the specified point in meaningful space. Another possibility is that the point locator has a kind of 'vertex' or 'tip' that is positioned on the speci-
fied point in meaningful space, see for example the pin-shaped city-locators in figure 2-28. A point locator is basically free in its shape and size.

A **line locator** is anchored to a specific line in a meaningful space. Examples: a political border on a map, the 'train-lines' in the graphical train schedule in figure 2-29. The area occupied by a line locator is usually centered on the specified line in meaningful space. A line locator is fixed in its shape and length, but is free in its width.

A **surface locator** is anchored to a specific surface in a meaningful space. Example: a lake on a map. A surface locator may locate a surface in a two-dimensional meaningful space (e.g. in the continents in the world map in figure 2-33) or in a three-dimensional meaningful space (e.g. the mountainous surface representing U.S. population density in figure 2-30). The area occupied by a surface locator covers exactly the specified surface in meaningful space. A surface locator is fixed in both its shape and size.

A **volume locator** is anchored to a specific volume in a meaningful space. Example: a marked three-dimensional area in a 3-D chart or a drawing of physical objects. See for example the cloud in the thunderstorm-animation in figure 2-42. The area occupied by a volume locator covers exactly the specified volume in meaningful space. A volume locator is fixed in both its shape and size.

A **metric bar** is a graphic object in a bar chart that is anchored to two points, extending between them: One end of a metric bar is anchored to the bar chart's base line (or base point in polar coordinates), and the other end is anchored to a point at a distance from the base line that is measured along a metric axis (thereby determining the bar's length/height). See figures 2-26 and 2-27. A metric bar is fixed in its length/height, but depending on the type of bar chart that it is part of, it may be free in its width and shape (such as in pictorial bars). A special case of a metric bar is the **stacked bar** (figure 2-26), which is a metric bar that is divided into sub-objects by **proportional division** (discussed in section 2.4).

A **grid line** is a line that serves to mark a meaningful space. Many meaningful spaces involve grid lines. Some two-axis charts for example use a dense pattern of grid lines in both directions (see figures 2-25 and 2-26). A simple time axis on the other hand can be regarded as a single grid line. A grid line in itself is not subject to interpretation, but it serves to enable or facilitate the interpretation of the object-to-space relations of graphic objects that are positioned in a meaningful space. Often a grid line has one or more labels attached to it. See section 3.3 on **informational roles** of graphic objects, where we discuss the difference between **information objects** and **reference objects**.

After this inventory of possible syntactic roles of graphic objects, let us briefly return to the comparison with verbal expressions. In order to analyze the syntactic structure of a sentence in a foreign language, we will have to
2.5.3 Syntactic roles

know or guess for each word what its syntactic role is - that is whether it is a noun, a verb, an adjective, or another type of word. Likewise, in order to analyze the syntactic structure of a graphic representation, we will have to know or guess for each graphic object what its syntactic role is.

As an example, imagine a simple map of a country that shows the locations of main cities and their names, and that also includes several arrows to represent the course of a certain journey from city to city. In order to interpret the map correctly, we need to know or guess that the dots marking the cities (the 'city-dots') are point locators in a metric space and not, for example, unanchored objects in an arbitrary spatial structure. We also need to know or guess that the names of the cities are not point locators, but that they are labels, attached to point locator objects (to the city-dots). We need to know or guess that an arrow on the map is not a point locator either (marking for example the location of the local School of Archery - the art of shooting with bow and arrow), but that it is a connector, attached to a pair of point locators (the city-dots), stretching between them.

Objects with different syntactic roles are interpreted differently. Whether a point locator (a city-dot) is located above or below another point locator, is definitely subject to interpretation. We might want to know, for example, whether a certain city is north or south of another city. In contrast, whether a label (a city-name) is located above or below the point locator that it labels, is not subject to interpretation, as long as the label is visually grouped with that point locator. We only need to know which city-name belongs to which city-dot.

Imagine that in our map a picture of a little blue airplane is used to show the location of an airport. In this case, we need to know or guess that this is another point locator, and not for example a surface locator representing a lake (which happens to have the shape of an airplane).

Let us finally try to classify the syntactic role of an ambiguous example: a line on a map that represents the border between two countries. One may feel tempted to classify the syntactic role of such a border as that of a separator, which we have discussed in the subsection on object-to-object relations (2.5.1). However, by its location in a metric space and by its shape, a border on a map expresses more information than the mere separation of other objects (which may or may not be present): it locates every point on the concerned border. It is anchored tightly to these points - even minor changes of the border's shape and position correspond to changes in the information that is represented. In addition, a border on a map may enclose an 'empty' area, in which case there are no objects that could be regarded as having been separated from other objects. For all the above reasons, the syntactic role of a border on a map should not be classified as a mere separator, but as a line locator in a metric space. For similar reasons, the winding road between two mountain villages on a map should not be classified as a mere connector, but also as a line locator in a metric space.
At the beginning of this section, we mentioned Richards' proposed distinction between graphic objects that function as 'verbs' (e.g. a connecting line) and graphic objects that function as 'nouns' (e.g. the objects that are connected by the line). After the inventory and discussion above, we can now conclude that these roles of connector (the connecting line) and node (the objects that are connected) are only two possibilities from a wide range of different possible syntactic roles that graphic objects can play within syntactic structures.

Let us recapitulate the contents of this chapter (2) so far. We have discussed two types of basic syntactic structures: those based on object-to-object relations, and those based on object-to-space relations. Above we have provided an overview of the different syntactic roles that graphic objects may play within such syntactic structures. In the following section we will examine how these basic syntactic structures can be combined into composite syntactic structures.
2.5.4 Composite syntactic structures

So far we have discussed basic syntactic structures in graphic representations - basic syntactic structures involving object-to-object relations were discussed in subsection 2.5.1, and basic syntactic structures involving object-to-space relations were discussed in subsection 2.5.2. We did already mention composite metric space, such as the meaningful space in a two-axis chart. (The reason we mentioned composite metric space was to contrast it with the integral metric space of pictures and maps, which is not composite). This subsection is devoted to exploring the various ways in which composite syntactic structures can be constructed from basic syntactic structures.

A **composite syntactic structure** is a syntactic structure that is constructed from two or more basic syntactic structures, through simultaneous combination and/or nesting.

We will successively discuss simultaneous combination, nesting, and different types of nested structures.

**SIMULTANEOUS COMBINATION**

*Simultaneous combination* is one of the two ways in which composite syntactic structures can be constructed from basic syntactic structures.

In a **simultaneous combination** of basic syntactic structures, a set of graphic objects simultaneously participates in two or more basic syntactic structures, at the same syntactic level of object decomposition.

Examples: A two-axis chart involves the simultaneous combination of arrangement along a horizontal metric axis and arrangement along a vertical metric axis. A table involves the simultaneous combination of horizontal separations and vertical separations. Station markers on a subway map are simultaneously involved in linking and in arrangement in a distorted integral metric space. See figure 2-38 (illustrating document flow procedure) for an example of the simultaneous combination of linking, separation, and positioning along a metric axis. In this respect, syntactic structures in graphic representations differ from syntactic structures in linguistics. Syntactic structures in linguistics concern a single dimension and aspect - linear sequence, and do therefore not allow for its constituents to simultaneously participate in several syntactic structures. (This applies within a set of constituents at some given level of decomposition. Of course, any constituent in a nested structure could be regarded as 'participating in different structures' at the different levels of nesting, but this is not what we mean here.)
Noted that, through the simultaneous participation in more than one syntactic structure, a graphic object can simultaneously function in more than one syntactic role. For example, ‘city-dots’ on a map that are connected by arrows, function as point locators in the integral metric space of the map, and also as nodes in the linking by arrows. The lines in a subway map function as line locators in a distorted integral metric space, and also as connectors in the linking of the stations.
NESTING

In a nesting of syntactic structures, a composite graphic object serves as a single (composite) graphic object in a syntactic structure at a ‘higher level’.

Nesting can also be referred to as ‘embedding’. If the same structuring principles can be applied at different levels of a nested structure, then this is referred to as recursion. Since Noam Chomsky’s work in the 1950’s, recursive nesting is the dominant aspect of most linguistic approaches to syntactic structure. Because syntactic structures in linguistics do not allow for the simultaneous combination of basic syntactic structures at the same level of constituent decomposition, the nesting of basic syntactic structures is the only way of constructing composite syntactic structures in linguistics.

For a recursive application of polar coordinates see the representation of wind data in figure 2-39. For a recursive application of proportional division see the representation of baseball data in figure 2-40. Both of these figures are special cases of nesting because they recursively apply the same type of syntactic structure at different levels.
FIGURE 2-39: Representation of a year of wind data.


COMMENT: This figure shows a recursive application of polar coordinates.

SYNTAX OF SPATIAL STRUCTURE (2.5): A graphic multiple of a (small) metric space with polar coordinates (a circular metric axis and a radial metric axis), which is nested into a (large) metric space with polar coordinates (a circular metric axis). The constituent objects of the repeated small representation are a label (the name of the month), a circular grid line (the compass circle), and a set of metric bars (the pie segments).

TYPE OF CORRESPONDENCE (3.1): The circular axis of the small metric space involves literal correspondence (standing for wind directions in physical space), while the circular axis of the large metric space involves metaphoric correspondence (standing for the course of a year). The sizes of the pie segments involve metaphoric correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A statistical time chart.
FIGURE 2-40: Representation of baseball data (a ‘tree map’).
COMMENT: This figure shows a recursive application of proportional division.
SYNTAX OF SPATIAL STRUCTURE (2.5): Nested proportional divisions, involving three levels of division (first horizontally, then vertically, and finally horizontally again).
TYPE OF CORRESPONDENCE (3.1): The proportional sizes of the segments involve metaphoric correspondence (the sizes of the segments do not stand for any kind of physical sizes, but they metaphorically stand for baseball-related information).
TYPE OF GRAPHIC REPRESENTATION (4): A statistical chart.

A presentation of several maps next to each other (e.g. figure 2-43) is a quite simple example of nesting: the integral metric space of a map (‘lower’ level of such a syntactic structure) is nested into a lineup (‘higher’ level of such a syntactic structure). Regarding nested spatial structures of meaningful spaces, we can distinguish several general types of arrangement. Meaningful spaces may be part of a background-inset display or part of a multipanel display. Two special cases of a multipanel display are the graphic multiple and the shared-axis multipanel. All of these will be discussed below.
BACKGROUND-INSET DISPLAYS AND MULTIPANEL DISPLAYS

Some nested spatial structures are background-inset displays. A background-inset display is a nested syntactic structure that consists of the superimposition of one or more composite graphic objects on a background object (see visual layers, discussed in section 2.2). Figure 2-41 (illustrating the characteristics of weeds) shows an example in which both the background and the insets are pictures. Legends are often superimposed as insets, see for example the ancient map of England in figure 3-12. An ‘inset’ that is anchored to a specific graphic object can be regarded as a label, see for example the embedded charts in the map shown in figure 2-03 (which are anchored to the point locators that mark the cities). Insets that are not labels are more or less free in their placement, and the main criterion for determining their position is usually that they should not visually occlude any important objects in the background.

Other nested spatial structures are multipanel displays. A multipanel display is a nested syntactic structure in which two or more composite graphic objects are arranged as separate panels, next to each other. See the thunderstorm-animation in figure 2-42 and Napoleon’s march in figure 2-47 as examples.
FIGURE 2-41: Characteristics of the ultimate weed.


COMMENT: This figure serves as an example of a background-inset display.

SYNTAX OF SPATIAL STRUCTURE (2.5): An integral metric space in the background, with several superimposed insets, which also contain integral metric spaces. A number of the graphic objects have labels attached to them.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The integral metric spaces, in the background and in the insets, involve more or less literal correspondence.

VISUAL ATTRIBUTES: The shapes of displayed graphic objects involve either metonymic or literal correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A picture with insets of pictures.
FIGURE 2-42: From an animation of a numerical model simulating a thunderstorm. The lower part displays 'stills' from the animation along a timeline.
COMMENT: This figure serves as an example of a multipanel display.
SYNTAX OF SPATIAL STRUCTURE (2.5): A multipanel display involving a vertical lineup of two panels. The upper panel involves a volume locator (the cloud) and grid lines in a distorted integral metric space (the vertical dimension is exaggerated by stretching it with almost a factor 2). The lower panel is itself a multipanel display, more specifically it is a graphic multiple of the upper panel (without the grid lines), arranged in a lineup along a horizontal metric axis (a time axis).
TYPE OF CORRESPONDENCE (3.1): The spatial dimensions of the cloud involve distorted literal correspondence, while the arrangement of clouds on a timeline involves metaphoric correspondence.
TYPE OF GRAPHIC REPRESENTATION (4): A multipanel display consisting of a picture and a time chart that involves pictures.
GRAPHIC MULTIPLES

A graphic multiple is a special case of a multipanel display:

A **graphic multiple** is a multipanel display in which the panels can be regarded as variations of a single representation. These variations have the same design and the same general syntactic structure (usually based on a meaningful space), but they display different data. Often the individual panels are nested into a lineup or a table.

In the panels of a graphic multiple neither the syntactic structure nor the reference objects (if present, see section 3.3) change, while (some of) the information objects (also see 3.3) usually do change. This distinguishes graphic multiples from *proportional repetitions* (discussed in 2.5.1), in which a proportional number of identical copies of an *elementary* graphic object are repeated.

The most common type of graphic multiple is the *chronological multiple*, which uses its panels to show changes over time. Examples of chronological multiples are shown in figure 2-39 (wind directions), in the lower panel of figure 2-42 (thunderstorm), in figures 2-43 (growing railway system) and 2-44 (how to tie a tie), and in the horizontal rows of figure 2-45 (L.A. air pollution).

The concept of graphic multiples has been described by various authors. **Bertin** promotes graphic multiples, referring to them with the confusingly unspecific term “collections of images” (Bertin 1967/1983, pp. 397-407; and 1977/1981, pp. 161-167). **Tufte** also advocates the use of graphic multiples, referring to them as “small multiples”:

> “Small multiples resemble the frames of a movie: a series of graphics, showing the same combination of variables, indexed by changes in another variable.” (p. 170)
> “Small multiples are economical: once viewers understand the design of one slice, they have immediate access to the data in all the other slices. Thus, as the eye moves from one slice to the next, the constancy of the design allows the viewer to focus on changes in the data rather than on changes in graphical design.” (p. 42)

*Tufte* (1983)

**Kosslyn** refers to what we call *graphic multiples* as *‘pure* multipanel displays’, while he refers to other multipanel displays, in which the individual panels have different formats, as *‘mixed* multipanel displays’ (Kosslyn 1994, p. 54). **Wilkinson** refers to graphic multiples as ‘facets’, and describes them as “many little graphics that are variations of a single graphic” (Wilkinson 1999, p. 301).
COMMENT: This figure is a graphic multiple of a map.
SYNTAX OF SPATIAL STRUCTURE (2.5): A labeled graphic multiple of an integral metric space (the map), arranged into a horizontal lineup of two panels.
TYPE OF CORRESPONDENCE (3.1): The integral metric spaces of the maps involve literal correspondence.
FIGURE 2-44: How to tie a tie. SOURCE: Mijksenaar and Westendorp 1999, p. 49.

COMMENT: This figure is a graphic multiple of a picture.

SYNTAX OF SPATIAL STRUCTURE (2.5): A graphic multiple of an integral metric space, arranged in an ordered horizontal lineup.

TYPE OF CORRESPONDENCE (3.1): While the pictures themselves involve literal correspondence, their ordered horizontal lineup involves metaphorical correspondence (order in space stands metaphorically for order in time).

TYPE OF GRAPHIC REPRESENTATION (4): Pictures.
**FIGURE 2-45:** Varying intensity of air pollution in the Los Angeles area in the course of the day, concerning three different pollutants.


**COMMENT:** This figure is a graphic multiple that is arranged in a table.

**SYNTAX OF SPATIAL STRUCTURE (2.5):** A graphic multiple of a composite metric space (the 'pollution landscape'), nested into a table. The table is constructed through a simultaneous combination of an ordered horizontal lineup (representing time of day) and an unordered vertical lineup (representing pollutant). The repeated composite metric space (the 'pollution landscape') is constructed through simultaneous combination of a horizontal integral metric space (representing geographic location) and a vertical metric axis (representing intensity of pollution).

**TYPE OF CORRESPONDENCE (3.1):** SPATIAL STRUCTURE: At the level of the table, the order of the horizontal partitions (different times of day) involves metaphoric correspondence, while the order of the vertical partitions (different pollutants) is arbitrary. At the level of the individual 'pollution landscape', the horizontal integral metric space (representing geographic location) involves literal correspondence, while the vertical metric axis (representing intensity of pollution) involves metaphoric correspondence.

**TYPE OF GRAPHIC REPRESENTATION (4):** A table of statistical maps.

(Statistical map = both a map and a statistical chart.)
2.5.4 Composite syntactic structures

FIGURE 2-46: The relationship of female reproductive hormones and the events in the ovary and uterus during the menstrual cycle.


COMMENT: This figure is a shared-axis multipanel in which the (horizontal) shared axis is a time axis.

SYNTAX OF SPATIAL STRUCTURE (2.5): A shared-axis multipanel involving four panels with a shared horizontal metric axis (a time axis). In both of the two upper panels a composite metric space is constructed by combining the shared horizontal metric axis with two superimposed vertical metric axes (in the original the curves have different colors and are annotated in corresponding colors on either side of the panel - enabling the display of two different quantitative phenomena in the same chart). (Caption is continued on the next page.)
Continued caption for figure 2-46:

The upper panels both contain grid lines, line locators, and labels. The two lower panels involve horizontal lineups of (pictorial) graphic objects.

**TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE:** The horizontal time axis and the vertical axes of the line charts all involve *metaphoric* correspondence.

**VISUAL ATTRIBUTES:** The (possibly distorted) relative thickness (here the height) of the lining of the uterus, as well as the shapes of the pictured objects such as the individual follicles involve *literal* correspondence.

**TYPE OF GRAPHIC REPRESENTATION (4):** A *multipanel time chart* involving *statistical time charts* and lineups of pictures. (Statistical time chart = both a statistical chart and a time chart.)

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**SHARED-AXIS MULTIPANELS**

A *shared-axis multipanel* is another special case of a multipanel display.

A *shared-axis multipanel* is a *multipanel display* consisting of panels that share a *metric axis*, and that are arranged in a *lineup* - aligned with each other with regard to this shared metric axis.

In a shared-axis multipanel with a *horizontal* shared axis the panels are arranged one above the other, while in a shared axis multipanel with a *vertical* shared axis the panels are arranged one next to the other. In other words, the direction of the lineup of the panels is orthogonal to the direction of their shared axis. For examples of shared-axis multipanels see the illustration of the menstrual cycle in figure 2-46 and the illustration of the march of Napoleon's army to Moscow in figure 2-47.

With these two figures we are coming to the end of this chapter on graphic syntax. We have explored the constituents and the structure of graphic representations. This has led us to discussions of graphic space, graphic objects, and various aspects of basic and composite syntactic structures. In the next chapter we will turn to an investigation of the *interpretation* of graphic representations.
FIGURE 2-47: The dramatically diminishing number of Napoleon's surviving soldiers during their march to Moscow (lighter path) and their retreat (black path). The chart at the bottom shows the temperatures during the retreat.


COMMENT: This figure is a shared-axis multipanel in which the (horizontal) shared axis represents longitude.

SYNTAX OF SPATIAL STRUCTURE (2.5): A shared-axis multipanel, involving two panels with a shared horizontal metric axis. The upper panel (the map) involves an integral metric space in which positions are linked with width-coded connectors. This (map) panel also contains line locators (representing rivers) and labels. The lower panel (the temperature chart) involves a composite metric space, constructed from the shared horizontal metric axis and a vertical metric axis (the temperature axis). This panel contains grid lines, a line locator (the temperature curve) and labels.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The integral metric space of the map involves literal correspondence, while the composite metric space of the temperature chart involves metaphoric correspondence. VISUAL ATTRIBUTES: The width of the path segments involves metaphoric correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A multipanel display consisting of a statistical path map and a statistical chart.

(Statistical path map = both a map and a statistical link diagram. Statistical link diagram = a link diagram that displays quantitative information per link.)